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Stress, Healthy Ageing and Physical Exercise: How Physical Activity Relates to Cortisol, Dehydroepiandrosterone (Sulphate) (DHEA(S)), Sleep, Physical Function and Well-Being in Older Adults

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Acknowledgements

"A kent'annos!" *or "May you live to be 100 years old."*

This timeless blessing comes to you from one of the world's renowned Blue Zones—the island of Sardinia.

You should shout "Akentannos!" to your loved ones as you raise a glass at your next homey get-together. "To the very last breath of your life, I wish you the best of health; And may you live to 100."

Your loved ones may respond, "And may you be here to count the years."

Here's to raising a glass to some incredible people who've been with me on this PhD journey.

First up, Anna, Jenni, and Gemma - what an adventure we've had! Remember those early days of the pandemic, meeting up in that open-air bar because the uni was under lockdown? And those trips to Stirling, which left me wishing I could've spent my entire PhD there. The first year was a whirlwind, wasn't it? Three systematic reviews with Esther, who I'm proud to call not just a colleague but a friend. And then, diving into two intervention studies in care homes right after COVID - still can't believe we pulled that off. Your support has been phenomenal. I know thanking your team in a PhD acknowledgment is pretty standard, but I genuinely mean it: you guys provided the perfect mix of space, guidance, and constructive criticism that helped me grow as an academic and a science communicator.

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So, here's to all of you. I raise my glass and say: 'May you live to be 100 years old - in good health, both mentally and physically' - the ultimate aim of my PhD thesis and myself. Here's to you all, my guides, my supporters, my inspirations. Cheers!

Declaration and conflict of interest statement

I, Len De Nys, declare that this dissertation, titled Stress, Healthy Ageing and Physical Exercise, is my own work and has been written by me. It has not been submitted for any other degree or professional qualification. The sources used in the preparation of this dissertation have been adequately acknowledged and referenced in accordance with the guidelines of the University of Stirling.

Further, as the first author of this PhD thesis, I have no conflicts of interest to declare.

Abstract

This PhD thesis investigates the role of physical activity (PA) in enhancing the health and well-being of older adults in care homes. Focusing on the impact of PA on key health indicators such as cortisol and dehydroepiandrosterone (sulphate) (DHEA(S)) levels, sleep quality, and well-being, this research explored the potential of digital interventions in promoting healthy ageing. First, this research uncovered that regular PA improves cortisol and DHEA(S) levels and enhances sleep quality in adults through two systematic reviews and meta-analyses. The findings highlight the need for further research into the mechanisms underlying these effects and the interplay between cortisol, sleep, and PA, particularly in older adults. Second, a realist evaluation of a feasibility study (Intervention One) demonstrated that implementing a digital music and movement intervention in a care home setting is feasible, albeit with challenges such as participant engagement and resource allocation. Notably, the intervention led to improvements in anxiety, depression, and sleep satisfaction among participants. Third, the subsequent pilot RCT (Intervention Two) provided insights into the intervention's efficacy, revealing its positive impact on anxiety, loneliness, fear of falling and DHEA levels despite methodological challenges. It further provided specific progression criteria to proceed to a more extensive randomised controlled trial (RCT). Overall, this thesis represents a progression from a comprehensive systematic literature review to a feasibility study and a pilot RCT, setting a foundation for a future full-scale RCT of a digital music and movement intervention in care homes. It contributes to the understanding of PA's role in promoting healthy ageing, particularly in care home settings. The findings underscore the potential benefits of PA facilitated through digital interventions for older adults' health and highlight the necessity for further research to optimise intervention implementation strategies, including recruiting a broader spectrum of older adults, especially regarding sex, ethnicity and cognitive capabilities. This is needed to fully comprehend PA's impact on physical and mental well-being among older adults in care home settings.

List of key acronyms

AC: Activity Coordinator

AG: Advisory Group

CAR: Cortisol Awakening Response

DHEA(S): Dehydroepiandrosterone (Sulphate)

FITT-D: Frequency, Intensity, Time, Type, and Duration

HPA: Hypothalamic-Pituitary-Adrenal

PA: Physical Activity

PICO: Patient/Population, Intervention, Comparison, Outcome

RCT: Randomised Controlled Trial

SHAPE: Stress Healthy Ageing and Physical Exercise

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List of publications and conference presentations arising from this thesis

This thesis includes three peer-reviewed published manuscripts, and one manuscript currently under peer review:

De Nys, L., Ofosu, E., Ryde, G., Connelly, J. & Whittaker, A.C., PA influences stress and healthy ageing by improving cortisol and dehydroepiandrosterone (sulphate) levels in older adults: a systematic review and meta-analysis. *JAPA, Volume 31; Issue 2, p 330-351 (2022),* https://doi.org/10.1123/japa.2021-0501

De Nys, L., Anderson K., Ofosu, E., Ryde, G., Connelly, J. & Whittaker, A.C. The effects of PA on cortisol and sleep: a systematic review and meta-analysis, *Psychoneuroendocrinology, Volume 143, (2022), 105843* https://doi.org/10.1016/j.psyneuen.2022.105843

Ofosu, E., De Nys, L., Connelly, J. Ryde, G.C., & Whittaker, A.C. (online 2023). A realist evaluation of the feasibility of a digital music and movement intervention for older people living in care homes. *BMC Geriatrics 23, 125 (2023), https://doi.org/10.1186/s12877-023-03794-5*

De Nys, L., Ofosu, E., Connelly, J. Ryde, G.C., & Whittaker, A.C. Digital music and movement resources to improve health and wellbeing in older adults in care homes: a pilot randomised trial. Under peer review BMC Geriatrics, https://doi.org/10.21203/rs.3.rs-3658587/v1

The work within this thesis has also been presented as other publications as part of this thesis, lay-friendly research articles, Conference talks, Conference posters and other research activities:

Other publications conducted as part of this thesis

Peer-reviewed publications

Ofosu, E., De Nys, L., Connelly, J. Ryde, G.C., & Whittaker, A.C. (2022 in press). Dimensions of PA are important in managing anxiety in older adults: a systematic review and meta-analysis. *JAPA, Volume 32, issue 4 (2023),* https://doi.org/10.1123/japa.2022-0098

Lay-friendly research articles

De Nys, L., Ofosu, E., Ryde, G., Connelly, J., & Whittaker, A.C. (2022). PA impacts the Cocktail of Healthy Ageing. *British Journal of Sports Medicine Blog*, Oct 17. https://blogs.bmj.com/bjsm/2022/10/17/physical-activity-impacts-the-cocktail-of-healthy-ageing/

De Nys, L., & Whittaker, A.C. (2022). Exercise can reduce stress and improve sleep – particularly for women with breast cancer. *The Conversation, July 7.* https://theconversation.com/exercise-can-reduce-stress-and-improve-sleep-particularly-for-women-with-breast-cancer-186144 *and* https://1000elders.stir.ac.uk/2022/09/30/91/

De Nys L., (2022) Minder stress en betere nachtrust dankzij lichaamsbeweging, Eos Blogs, July 5, https://www.eoswetenschap.eu/psyche-brein/minder-stress-en-betere-nachtrust-dankzij-lichaamsbeweging

De Nys, L., Ofosu, E., Ryde, G. & Whittaker, A.C. (2022). danceSing Care evaluation – summary of the feasibility study. *Stirling 1000 Elders blog post.* https://1000elders.stir.ac.uk/2022/09/30/dancesing-care-evaluation-summary-of-the-feasibility-study%ef%bf%bc/

De Nys L., (2023) Hoe lichaamsbeweging en slaap ons immuunsysteem kunnen versterken, Eos Blogs, July 10, https://www.eoswetenschap.eu/gezondheid/hoe-lichaamsbeweging-en-slaap-ons-immuunsysteem-kunnen-versterken

Conference talks

De Nys, L., Ofosu, E., Connelly, J., Ryde, G. & Whittaker, A.C. PA influences cortisol and dehydroepiandrosterone (sulphate) levels in older adults a systematic review and meta-analysis, *Talk presented at NTU, Nottingham, UK, July 5*

De Nys, L., Anderson, K., Ofosu, E., Connelly, J., Ryde, G. & Whittaker, A.C. A systematic review and meta-analysis on the effects of physical exercise on both cortisol and sleep in adults. *Talk presented at European Lifestyle Medicine congress, Athens, October 2022.*

Whittaker, A.C., De Nys, L. & Drayson, M.T. (2023) PA and Sleep Relate to Antibody Maintenance Following Naturalistic Infection and/or Vaccination in Older Adults. *Talk presented at American Psychosomatic Society conference, Puerto Rico, March 2023.*

De Nys L., Whittaker, A.C. & Drayson, M.T. (2023) Promoting immunity in older adults: The interplay of physical activity and sleep in antibody maintenance. *Talk presented at ELMO conference, Budapest, November 2023.*

Conference posters

De Nys, L., Ofosu, E., Connelly, J., Ryde, G. & Whittaker, A.C. Realist evaluation of a feasibility study, *SPARC, November 2023*

Other Research Activities

During this thesis, the candidate has presented other research and knowledge transfer.

Journal articles

Whittaker, A.C., De Nys, L., Brindle R.C., Drayson, M.T., Physical Activity and Sleep Relate to Antibody Maintenance Following Naturalistic Infection and/or Vaccination in Older Adults, *Brain Behaviour, & Immunity – Health*, Volume 31, 100661 (2023) https://doi.org/10.1016/j.bbih.2023.100661

Published abstracts

Whittaker, A.C., De Nys, L. & Drayson, M.T. (2023) PA and Sleep Relate to Antibody Maintenance Following Naturalistic Infection and/or Vaccination in Older Adults. *Psychosomatic Medicine*, 85 (2023)

Oral Presentations

De Nys, L. The Resilient Physiotherapist in a high-demanding Society, *University of Leuven, Belgium, September, 2022*

De Nys, L. Interaction between stress and sleep: tackling mental health issues, *NVVK, Netherlands, November, 2022*

De Nys, L. Elk jaar jonger?, conference on Age reversal, *Vrije Universiteit Brussel, Belgium, November, 2022*

De Nys, L. Cortisol/DHEA(S) ratio in health and longevity & therapeutic perspectives, *Eurosymposium on healthy ageing, online, November, 2022*

De Nys, L. Cortisol/DHEA(S) in health and well-being, *KU Leuven, Belgium, December, 2022*

De Nys, L. Unlocking Resilience: The Surprising Benefits of Exercise for Managing Stress and Improving Sleep, *Guest lecture University of Southampton, online, March 2023*

Whittaker, A.C., De Nys, L. & Drayson, M.T. (2023) PA and Sleep Relate to Antibody Maintenance Following Naturalistic Infection and/or Vaccination in Older Adults. *Talk presented at American Psychosomatic Society conference, Puerto Rico, March 2023.*

De Nys, L. Training for longevity: An Hormonal Perspective, *University of Ghent, April, 2023*

De Nys, L. Cortisol and Melatonin, the yin and yang of stress and sleep, *KU Leuven, December 2023*

Books

De Nys L., How exercise turns back time, A guide to how PA impacts longevity and promotes healthy ageing, *Independently published (January. 2023),* ISBN-13: 979-8372407855

Other personal contributions

See Appendix 1.

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Thesis outline

This thesis consists of six chapters, including four studies. **Chapter One** serves as the introduction to the thesis, offering an overview of the PhD project, introducing relevant topics pertinent to this thesis, and outlining the aims and objectives of the PhD. **Chapters Two and Three** feature the peer-reviewed systematic review and meta-analysis papers. Further, **chapters Four and Five** report the peer-reviewed papers on the two intervention studies. **Chapter Six**, the Discussion chapter, offers critical considerations on the PhD project, integrating conclusions drawn from the preceding chapters. The findings correspond to the pre-defined research questions, yielding both academic and clinical guidance and perspectives for future research. This chapter also encompasses a discussion and critical evaluation of the strengths and limitations of the included studies, thereby enabling readers to assess the research's reliability and validity.

Foreword

The Stress, Healthy Ageing and Physical Exercise (SHAPE) project aimed to deepen our understanding of physical activity's (PA) effects on cortisol, DHEA(S), physical function, and well-being in older adults, thereby promoting healthier ageing.

This doctoral thesis presents the research undertaken as part of this project under the auspices of the Faculty of Health Sciences and Sport at Stirling University, particularly by the 'Stirling PA Research, Knowledge & Learning Exchange' (SPARKLE) research group. Owing to its considerable size and scope, this interdisciplinary project encompassed the involvement of two PhD students. The author of this thesis (LDN), an MSc in Rehabilitation Sciences and Physiotherapy, examined the impact of PA on cortisol and DHEA(S) levels and sleep quality and the relationship between PA and physical function. At the same time, the other PhD student (EO), an MSc in Psychology, focused on psychosocial health markers in older adults from a psychological perspective. Although both PhD students contributed equally to two published papers, they maintained distinct and clear research focuses throughout the project. Collectively, these dual PhD perspectives sought to unravel the interactions between physical and psychosocial factors affecting older adults' health and well-being, thereby offering a more holistic understanding of the determinants influencing this demographic's health.

An overview of the PhD project, specifically focusing on the contributions of LDN over a three year period is provided in Figure 1.1. The figure outlines the major tasks and milestones achieved.

First Year:

- Systematic Review 1: Examining the relationship between physical activity (PA), cortisol, and dehydroepiandrosterone sulphate (DHEA(S)).
- Systematic Review 2: Investigating the connection between PA, cortisol, and sleep.

Second Year:

- Study 1: Feasibility study of a digital music and movement intervention in care homes, together with a bespoke well-being company (danceSing Care (DSC)).

Third Year:

- Study 2: Pilot Randomised Controlled Trial (RCT) of the DSC intervention.
- Study 3: Exploring the relationship between PA, sleep, and antibodies.

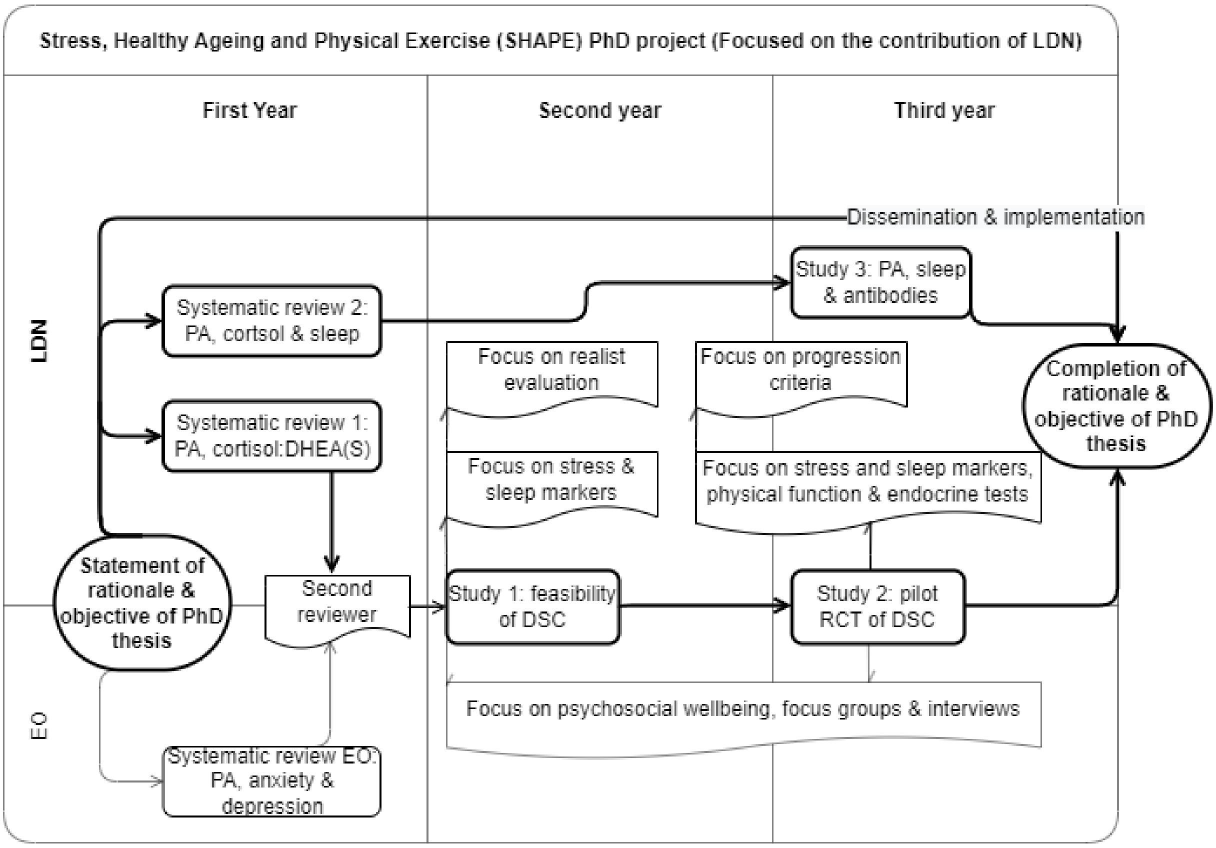

Figure 1.1 *Personal contributions to the PhD project.*

Note. LDN: Len De Nys, EO: Esther Ofosu, PA: Physical activity, DSC: DanceSing Care

CRediT authorship contribution statement

The CRediT authorship contribution statement is provided for each study below to delineate this PhD project's distinct focus and effort of the two PhD students. For all studies conducted during this PhD project, the supervisory team (GR, JC, and AW) was involved in conceptualisation, methodology, supervision, writing, review, during this PhD project, the supervisory team (GR, JC and AW) was involved in conceptualisation, methodology, supervision, writing – review and editing. Delineated below are the contributions of the PhD students working on this project.

Systematic review 1:

Len De Nys: Conceptualisation, Methodology, Investigation, Formal analysis, Visualisation, Writing – original draft. **Esther Ofosu:** Formal analysis.

Systematic review 2:

Len De Nys: Conceptualisation (lead), Methodology (lead), Investigation (lead), Formal analysis (lead), Visualisation (lead), Writing – original draft (lead). **Esther Ofosu:** Conceptualisation, Methodology.

Intervention 1:

Len De Nys: Conceptualisation (equal), Methodology (lead on realist evaluation and equal on quantitative methods), Investigation (equal), Formal analysis (equal), Visualisation, Writing – original draft preparation (equal). **Esther Ofosu:** Conceptualisation (equal), Methodology (lead on qualitative methods and equal on quantitative methods), Investigation (equal), Formal analysis (equal), Visualisation, Writing – original draft preparation (equal)**.**

Intervention 2

Len De Nys: Conceptualisation (equal), Methodology (equal), Investigation (lead on physical function tests and endocrinologic markers), Formal analysis (equal), Visualisation, Writing – original draft preparation (equal). **Esther Ofosu:** Conceptualisation (equal), Methodology (equal), Investigation (lead on well-being markers), Formal analysis (equal), Visualisation, Writing – original draft preparation (equal)**.**

Chapter 1: Thesis Introduction

1.1 Physical activity and healthy ageing

Over recent decades, there has been a notable increase in lifespan in the Western world (Roser et al., 2013), primarily due to advancements in medical science and improved living standards. However, this extension of life expectancy has not uniformly translated into additional years of good health (Crimmins & Beltrán-Sánchez, 2011; Crimmins, 2004). The rising prevalence of long-term multimorbidity is placing a tremendous strain on healthcare systems (Barnett et al., 2012) and deteriorating individuals' quality of life. As a result, understanding the factors that contribute to healthy ageing, defined as maintaining functional ability that ensures well-being in older age (Beard et al., 2016), becomes crucial.

Physical activity (PA), defined by Caspersen as any bodily movement produced by skeletal muscles resulting in energy expenditure (Caspersen, 1989), plays a role in promoting good health and particularly in facilitating healthy ageing across the lifespan (Macera et al., 2017; Peterson et al., 2009). Nevertheless, the specifics of how PA can enhance health span, or the period of maintaining wellness in old age (Aronson, 2020), require further exploration. Notably, a recent study found that consistent PA significantly lowers the risk of disability in older adults, underscoring the potential of PA as a key intervention in the realm of healthy ageing (Dos Santos & Gobbo, 2021).

The challenge of healthy ageing is accentuated in the UK, where there is a notable decrease in life expectancy free from disabling illness (see Figure 1.2). Moreover, as the ageing population grows, so does the number of individuals at risk for unhealthy ageing (ageing-better.org.uk). Addressing lifestyle factors, including diet, smoking, alcohol consumption, obesity, and, notably, PA, emerges as a critical strategy for promoting health in older adults (Khaw et al., 2008; Loef & Walach, 2012; Minkler et al., 2000; Morley & Flaherty, 2002; Peel et al., 2005).

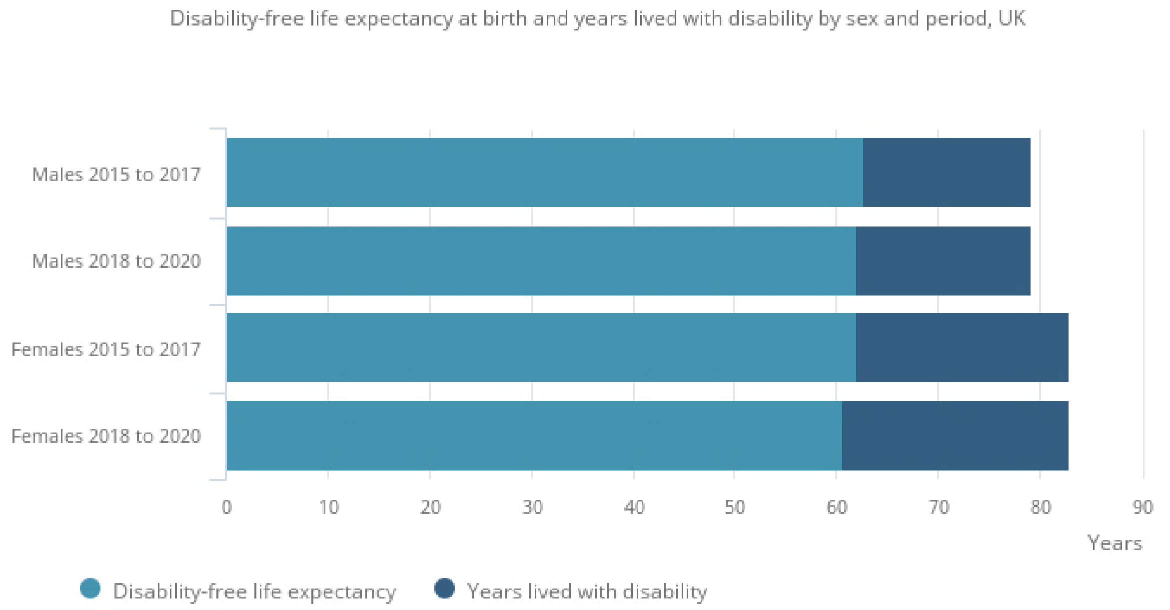

Figure 1.2 *Disability-free life expectancy at birth reduced by 0.7 years for males and 1.2 years for females in the UK between 2015 to 2017 and 2018 to 2020. Source: Office for National Statistics* (Office for National Statistics, 2021)

In an effort to promote regular PA, the World Health Organization (WHO) revised its 2020 guidelines on PA and sedentary behaviour (Bull et al., 2020). These guidelines advocate for older adults aged 65 and above to engage in 150 to 300 minutes of moderate-intensity aerobic PA weekly or its vigorous-intensity equivalent. Activities focusing on balance and coordination are also recommended three times per week, which is vital for enhancing functional capacity and reducing fall risks. Despite these guidelines, a worrying trend of global non-adherence has been noted, especially among older adults (Garcia-Hermoso et al., 2023; Gomes et al., 2017). This may be attributed to factors such as limited accessibility to safe exercising environments, physical limitations, or a lack of awareness about the importance of PA.

A landmark paper about PA's importance revealed that engaging regularly in PA can dramatically reduce the risk of premature death, a benefit that is even more pronounced in individuals who were previously sedentary (Warburton et al., 2006). Additional studies echo these findings, associating PA with numerous health benefits, including cognitive and physical function during older age (Erickson & Kramer, 2009; Peterson et al., 2009; Yates et al., 2008), well-being (Higueras-Fresnillo et al., 2018; Sjösten & Kivelä, 2006), mental health

(Singh et al., 2023), and healthy ageing (Chodzko-Zajko et al., 2009; Daskalopoulou et al., 2017).

In conclusion, addressing the challenge of declining healthy ageing in the UK, particularly as the population ages with increasing disabilities, is important. This thesis aims to contribute directly to this challenge by investigating the impact of PA on the well-being of older adults, thereby offering timely insights into healthcare strategies.

1.2 Population and setting

1.2.1 Contextualising older adult care

Recently, the focus on older adult care has increased, mirroring the global trend towards an ageing population. By 2050, almost 22% of the global population is estimated to be over 60 years old (WHO, 2022). This demographic shift intensifies the demands placed on older adult care systems globally. The spectrum of older adult care, ranging from care homes to community centres, has expanded to include diverse approaches such as personalised care plans, technological aids, and community engagement initiatives, all aimed at ensuring the well-being of older adults. The demographic shift brings with it several challenges, which can be categorised into five key areas:

1. Resource constraints: The increasing number of older adults puts financial pressure on care systems, leading to budgetary constraints and prioritisation issues. This affects the ability of these systems to offer comprehensive care, often leading to disparities in the quality of services provided.

2. Mental and emotional health: Emotional and psychological issues are prevalent among older adults. Conditions such as loneliness, depression, and anxiety are common and can be exacerbated by other health issues like dementia or Alzheimer's. This aspect of care is important, as it directly impacts the well-being of older adults.

3. Quality of life: Challenges such as limited mobility, chronic pain, and cognitive decline significantly impair the quality of life for older adults. For those in institutionalised settings like care homes, these issues are compounded by more restrictive environments, leading to reduced social interaction and engagement in activities.

4. Multimorbidity and frailty: With age comes an increased likelihood of multimorbidity - the coexistence of two or more chronic medical conditions. This, combined with frailty, a syndrome marked by a decline in physiological reserve and function, makes care more complex and demanding. It impacts the dynamics between healthcare providers, patients, and their families.

5. Individualised care: The diversity in backgrounds and personalities among older adults makes a generic approach to care suboptimal. Personalised care plans that acknowledge individual histories, preferences, and conditions are essential to effectively address the unique needs of each older adult.

Healthcare systems and societies need to adapt and evolve in response to these demographic changes to ensure the well-being of older adults.

1.2.2 Multimorbidity, frailty and PA

As the UK care home resident population ages, two critical health concerns have emerged: an increasing prevalence of multimorbidity and a high rate of frailty, which reduces the ability to perform daily activities and increases vulnerability to stressors (Xue, 2011).

The high prevalence of frailty among care home residents is particularly concerning. Specifically, while 7-16.3% of community-dwelling older adults experience frailty (Collard et al., 2012; Rodriguez-Mañas & Fried, 2015), this prevalence surges to 52.3% in care homes (Doody et al., 2023; Kojima, 2015). Given frailty's association with adverse health outcomes like hospitalisation and mortality (Clegg et al., 2013; Fried et al., 2001; Gill et al., 2006; Shamliyan et al., 2013; Sourial et al., 2013; Sternberg et al., 2011), understanding its roots and potential mitigating factors is essential.

In care homes, a concerning trend is the prevalent low levels of PA. This inactivity significantly contributes to the onset and exacerbation of frailty among residents. Such inactivity can lead to heightened feelings of depression (Sackley et al., 2006), loneliness (Rodriguez-Larrad et al., 2021), and overall physical deterioration, contributing to frailty (Feng et al., 2017; Fried et al., 2001; Gale et al., 2018). Recent research underscores the protective benefits of PA against frailty at all stages of life (Landi et al., 2010; Peterson et al., 2009), especially in older populations (Arrieta et al., 2019; Fiatarone et al., 1994). Specific exercise therapies have even shown the potential to reverse frailty symptoms (Ng et al., 2015;

Tarazona-Santabalbina et al., 2016). Chapters Four and Five explore further the relationship between frailty and PA.

There is mounting evidence supporting the positive impact of PA on both physical and mental well-being, even for those most dependent in care homes (for reviews, see (Cordes et al., 2021; Guzmán-García et al., 2013; Hwang & Braun, 2015)). However, it shows more beneficial effects on mental health and cognitive function in older adults without dementia compared to those with dementia or using wheelchairs (Da Silva et al., 2022). Specifically, moderate-intensity, tailored exercise programmes have shown promising results in reducing frailty in these residents (Arrieta et al., 2019). Despite these encouraging results, there is a need for research to evaluate the feasibility and adaptability of specific PA programmes across diverse care home settings (Fried, 2016), as these findings can significantly influence care strategies.

Physical function pertains to daily activity performance, such as personal care and mobility (Lawton & Brody, 1969). Studies have indicated that older adults with moderate to high PA levels often showcase superior physical function than their less active counterparts (Brach et al., 2004; Nusselder et al., 2008; Paterson & Warburton, 2010; Gabriel et al., 2017). This suggests that PA is paramount in promoting health and well-being in the ageing population.

1.3 PA interventions in older adults

1.3.1 PA interventions in older adults

PA, particularly structured exercise, is widely acknowledged as a key component of healthy ageing. Research studies have consistently demonstrated that PA can significantly reduce the risk of various age-related morbidities, such as cardiovascular diseases, osteoporosis, and diabetes, as well as all-cause mortality (Paterson et al., 2007). However, its impact on specific aspects, such as cognitive decline, may not be as strong or consistent as often assumed (Lautenschlager et al., 2008; Snowden et al., 2011). Beyond the general health benefits, regular PA and exercise play a role in promoting mental well-being, reducing the risk of depression, and mitigating the negative impact of age (Bherer et al., 2013; Strawbridge et al., 2002; Windle et al., 2010). Nevertheless, the relationship between PA and mental well-being can vary, with some studies indicating a weak relationship between quality of life and subjective well-being (Fox et al., 2007).

Several evidence-based strategies emerge when considering the most effective exercise interventions for older adults. The existing literature indicates that activities enhancing cardiorespiratory fitness, strength, power, and balance are particularly advantageous for older adults. These activities counteract the age-related declines in these physical components, ensuring the maintenance of functional capacities essential for daily living (Paterson et al., 2007). Further, resistance training, meditative movement interventions, and exercise-based active video games have been identified as particularly effective, with significant effect sizes noted for improving various health outcomes (Di Lorito et al., 2021). Moreover, aerobic exercises such as brisk walking, strength or resistance, flexibility, and balance training have been recommended for older adults to maintain muscle mass, specific muscle-group performance, and functional capacity (Lee et al., 2017; Mora & Valencia, 2018). Importantly, these interventions show promise for enhancing the physical function, daily living activities, and quality of life of frail older adults (Chou et al., 2012). However, one study found that neither strength training nor all-round, functional training of moderate intensity is effective in improving quality of life, vitality, or depression in older people living in long-term care facilities (Chin et al., 2004), which suggests that while PA can be beneficial, its impact on well-being and health outcomes may vary depending on individual health status, the presence of multimorbidities, and the specific care setting.

Building upon these findings, this thesis explores how PA enhances healthspan, a concept referring to the maintenance of wellness into old age (Aronson 2020). A crucial aspect of understanding PA's impact on healthspan involves examining the underlying biological mechanisms that drive these benefits (Rebelo-Marques et al., 2018). One such mechanism involves significant changes in endocrine pathways during ageing (van den Beld et al., 2018), particularly affecting the hypothalamic-pituitary-adrenal (HPA) axis. These changes result in imbalances in adrenal hormones like cortisol and dehydroepiandrosterone sulphate (DHEAS) (Ferrari et al., 2001), whose roles in healthy ageing, especially in relation to PA, remain largely unexplored. Despite the known benefits of PA, its uptake is low among older adults (McPhee et al., 2016), with those in care homes facing additional challenges such as limited mobility, restricted access to outdoor activities, and reduced social interaction (Sackley et al., 2006). These barriers not only diminish PA levels but also contribute to adverse mental health outcomes, including increased depression (Sackley et al., 2006) and loneliness (Rodriguez-Larrad et al., 2021). Further, technological advances have increased the development of digital PA interventions (Davies et al., 2012; Muellmann et al., 2018).

However, their effectiveness for older adults in care homes remains under-researched (Muellmann et al., 2018). There is currently insufficient evidence to assess whether face-to-face or remote approaches are more effective at promoting PA (Richards et al., 2013). This thesis aims to address these gaps, examining the potential of digital interventions in enhancing PA and improving the health and well-being of older adults in care settings.

1.3.2 Digital interventions for PA

The COVID-19 pandemic, with in-person exercise opportunities drastically reduced or disbanded due to group size limitations and stay-at-home orders, increased the need for alternative exercise or social opportunities for maintaining health in older adults (Son et al., 2020). Frail older adults, many residing in care homes, were particularly affected as they faced the double burden of social and digital exclusion (Seifert et al., 2021). This situation emphasised the importance of digital platforms for maintaining PA, leading to an increased use of these platforms (Bennell et al., 2021; Parker et al., 2021). Therefore, with some of the COVID-19 restrictions still in place during the PhD project, this thesis examined a digital PA intervention in collaboration with danceSing Care company (https://dancesingcare.uk/), who have made customised, on-demand digital music and movement sessions for older adults in care homes.

With an increasing number of older adults becoming proficient in using electronic devices like computers and smartphones (Smith, 2014), digital interventions – defined as the use of information and communications technologies in medicine and other health professions to manage illnesses and health risks and to promote wellness - emerge as a promising avenue (Ronquillo et al., 2023; Solis-Navarro et al., 2022). These interventions, delivered through smartphones, tablets, or computers, have features like online counselling, tailored instructional websites, personalised messaging, coaching, peer support, and planned activities. Such interventions offer more straightforward and quicker access to information, reaching populations otherwise inaccessible through traditional PA interventions (Norman et al., 2007).

Reviews have shown these digital resources to be feasible and well-received (Diener et al., 2022; Valenzuela et al., 2018). They effectively promote PA across various age groups (Davies et al., 2012; Norman et al., 2007), including older adults (Foster et al., 2013; Muellmann et al., 2018). Further, a recent systematic review showed that such interventions provide small-to-moderate benefits on a range of physical function outcomes, such as improved mobility, strength, and balance, and are well-received by older adults in care homes (Dawson et al., 2023). This is in line with a preliminary rapid review that showed the potential of digital approaches to support the engagement of older adults in strength and balance exercises (McGarrigle et al., 2020). Other studies also considered older adults' mental health through digital interventions (Deady et al., 2017; Riadi et al., 2022). For example, a computer-based telecommunication exercise intervention improved strength, balance and depressive symptoms in older adults (Sparrow et al., 2011). However, the effectiveness of these interventions in promoting PA among older adults presents mixed evidence and is often of low-to-moderate quality. In addition, there are still gaps in understanding their efficacy, especially in areas such as sustained engagement, user experience, and their impact on the health and well-being of residents in care homes. Although digital interventions can promote positive health outcomes in older adults, especially those with cognitively frail or vulnerable conditions, overcoming implementation and evaluation barriers can be challenging (Gutman & Shade, 2020).

1.3.3 Benefits of music and dance programmes

The integration of music and dance into PA programmes yields various benefits. Dance interventions, classified by styles from cultural to classical (Rodrigues-Krause et al., 2019), have shown efficacy in improving physical functions like muscular strength, balance, and endurance (Hwang & Braun, 2015; Liu et al., 2021; Sooktho et al., 2022; Vordos et al., 2017). Further, dance protects against falls (Britten et al., 2017) and promotes social engagement, which is key to healthy ageing (Brustio et al., 2018).

Beyond the physical benefits, integrating music into PA programmes helps mental well-being (Dingle et al., 2021). Music has the capacity to evoke memories and stimulate dopamine release, promoting motivation and mental health (Bromberg-Martin et al., 2010; Jakubowski & Eerola, 2022; Menon & Levitin, 2005). Music therapy increasingly reduces stress in medical and mental health care settings. It has been shown to have a medium-to-large beneficial effect on stress-related outcomes (de Witte et al., 2022). Importantly, evidence suggests that PA initiatives with music elements register higher attendance and motivation (Clair, 1996; Priest et al., 2004). However, research has shown that music interventions did not show within-session PA improvements for older adults compared to no-music interventions, although cumulative benefits may be seen over several weeks (Clark et al., 2012). While music interventions show promise in older adults, a study on people with dementia and their caregivers showed that efficacy can vary, and the effects over time need to be studied in high-quality trials (Cheung et al., 2022). Integrating music in movement-based therapies, such as dance sessions in care homes, is an interesting area for research into physical health and social outcomes.

1.3.4 Adherence to PA programmes

An issue in both digital and traditional PA programmes is the low adherence among older adults in care homes (Nyman & Victor, 2011). To improve the impact of PA interventions, it is essential to investigate factors influencing adherence (Collado-Mateo et al., 2021), especially in technology-based PA initiatives in older adults (Valenzuela et al., 2018). Recognising important factors, like personal preferences, physical abilities, and social context will enable a more tailored approach to PA programmes. This tailoring can help both the appeal and effectiveness of these programmes, aligning them with the specific needs of care home settings (Westhorp, 2014). However, tailoring programmes presents several challenges (Bull et al., 1999). Firstly, the heterogeneity of preferences and capabilities in a care home population at risk of cognitive decline makes it difficult to develop a one-size-fits-all solution (Cox et al., 2017). Conversely, overly customised programmes may also lead to logistical complexities and increased costs, limiting the scalability and sustainability of such interventions (Chapie & Arena, 2020). Secondly, there is a risk that personalised programmes may inadvertently isolate individuals, reducing opportunities for social interaction that are important in group-based activities. This could counteract one of the benefits of PA programmes in care homes: fostering a sense of community and social cohesion (Fakoya et al., 2020). Therefore, while tailoring PA programmes to individual needs is a valuable strategy, it must be balanced with considerations of practicality, cost-effectiveness, and the impact on social dynamics in care home settings.

1.4 PA and health outcomes

1.4.1 The HPA axis, cortisol and DHEA(S) in ageing.

The HPA axis, involving the hypothalamus, pituitary gland, and adrenal glands, regulates cardiovascular, cerebral, and immune system functions (McEwen & Seeman, 1999) and serves as the principal stress response system (Chrousos, 2009; Herman et al., 2016; Tsigos & Chrousos, 2002). Further, the glucocorticoid hormone cortisol is regulated by the HPA axis (Gjerstad et al., 2018) and plays a central role in the stress response and has various physiological functions (Cherrington, 1999; Chrousos, 1995; de Kloet, 2000; Macfarlane et al., 2008; McEwen, 2007; Munck et al., 1984). Its levels are influenced by stress, circadian rhythms, and other factors (Nicolaides et al., 2014; Ockenfels et al., 1995; Qin et al., 2016). Additionally, the adrenal cortex produces dehydroepiandrosterone (DHEA) and its sulphate ester, dehydroepiandrosterone suplhate (DHEAS), typically co-secreted with cortisol (Ceresini et al., 2000; Rosenfeld et al., 1971). They not only serve as precursors to other hormones but also exhibit anti-glucocorticoid, antioxidant, and immunomodulatory properties (Kroboth et al., 1999; Maninger et al., 2009). Their levels vary throughout the day (Montanini et al., 1988; Whetzel & Klein, 2010) and are important biomarkers of HPA axis function and health (Hinson & Raven, 1999; Legrain & Girard, 2003; Lennartsson et al., 2012; Marceau et al., 2014; Saczawa et al., 2013). Low DHEA(S) levels indicate poor physiological responses to stress and long-term health status and are associated with increased health risks like cardiovascular disease and cognitive decline (Barrett-Connor et al., 1986; Morales et al., 1994). For an exhaustive review of the variance in endogenous DHEA(S) levels related to specific disease states or influenced by particular activities, see, e.g., (Kroboth et al., 1999).

Ageing is often accompanied by hormonal imbalances (van den Beld et al., 2018), including alterations in the HPA axis, which in turn affect levels of cortisol and DHEA(S) (Ferrari et al., 2001). Age-related changes in cortisol production include increased variability and altered diurnal patterns (Heaney et al., 2012; Ice et al., 2004; Karlamangla et al., 2013; Van Cauter et al., 1996), while DHEA(S) levels decline progressively with age (Heaney et al., 2012; Orentreich et al., 1984). Particularly considering DHEA(S)'s ability to counterbalance cortisol's adverse effects (May et al., 1990; Wright et al., 1992), a lower cortisol:DHEA(S) ratio reflects a more balanced state between catabolic and anabolic hormonal influences, essential for maintaining health and combating age-related physiological decline (Butcher et al., 2005; Phillips et al., 2007). Imbalanced cortisol:DHEA ratios have been linked to various detrimental health outcomes, including immune dysfunction (Butcher et al., 2005), increased risk of dementia (Ferrari et al., 2001), metabolic syndrome (Phillips et al., 2010a), lower physical function (Heaney et al., 2012), and higher risks of depression, anxiety, chronic stress (Heaney et al., 2010), and mortality (Phillips et al., 2010b). These findings underscore the importance of hormonal balance in ageing.

1.4.2 The influence of PA on the HPA axis

PA is an intervention mechanism affecting the body's resistance to stress and modulating hormonal responses. Notably, the HPA axis has been the focus of many studies investigating the influence of PA (McEwen & Morrison, 2013). Repeated and prolonged exercise induces adaptive changes within the HPA axis, termed the cross-stressor adaptation hypothesis (Sothmann et al., 1996) or 'hormonal conditioning' (Cadegiani & Kater, 2019). These adaptations can decrease the hormonal stress response to physical exertion (Hackney, 2006b, 2006a; Silverman & Mazzeo, 1996) and may have beneficial implications in stress management and improving hormonal balance for older adults. Moreover, long-term exercise enhances tissue sensitivity to glucocorticoids, which might inhibit inflammatory responses and promote cytokine synthesis (Duclos et al., 2003; Luger et al., 1987; Sapolsky et al., 2000). Another avenue worth exploring is the impact of mind-body exercises, which incorporate mindfulness elements. Such exercises can reduce elevated cortisol levels in older adults (Lu et al., 2020; Prakhinkit et al., 2014; Tsang et al., 2013). The 'neuroendocrine hypothesis' suggests that mind-body exercises like qigong may effectively decrease stress signals to the brain, thereby modulating hormone release and reducing HPA axis hyperactivity (Ng & Tsang, 2009; Tsang & Fung, 2008).

To test the stress-buffering effects of PA, two randomised controlled trials (RCTs) measured physiological stress reactions relating to changes in fitness, showing an attenuated stress response for more fit individuals (Klaperski et al., 2014; von Haaren et al., 2016) while other research did not find improved HPA axis responses after six-month PA intervention, thus not confirming the hypothesis that PA could result in attenuated HPA axis reactivity or autonomic responses to stress (Arvidson et al., 2020). Possible reasons for contrasting results are the individual variance in the physiological response to acute stress, differences in training status, and the achieved physiological training effects of the intervention. Thus, although larger-scale RCTs are needed to further explain the stress-buffering effect of PA, most research implies that incorporating higher PA for older adults could improve stress reduction and cortisol regulation (Alghadir & Gabr, 2020; Gothe et al., 2016; Lucertini et al., 2015; Ponzio et al., 2015).

1.4.3 The influence of PA on cortisol, DHEA(S), and its ratio

First, while PA generally appears to impact cortisol levels in older adults, contributing to balanced endocrine profiles (Karlamangla et al., 2002; Kubzansky et al., 1999; Seeman et al., 1997), research findings are not entirely consistent (Banitalebi et al., 2018; Borst et al., 2002; Häkkinen et al., 2000; Hayes et al., 2013; Izquierdo et al., 2001; Kraemer et al., 1999; Sillanpää et al., 2010). This inconsistency highlights the need for standardised cortisol measurement protocols (Ryan et al., 2016; Stalder et al., 2016) and further investigation into how different PA modalities influence cortisol dynamics in ageing populations (Corazza et al., 2013). Second, research indicates that older individuals maintaining an active lifestyle tend to have higher DHEA(S) levels compared to their less active counterparts (Abbasi et al., 1998; Bonnefoy et al., 1998; Heaney et al., 2012; Ravaglia et al., 2001; Tissandier et al., 2001). However, some studies found no significant changes in DHEA(S) in older adults after a PA intervention (Aldred et al., 2009), and the response may differ between males and females (Heaney et al., 2014) and across mental health conditions (Alghadir & Gabr, 2020). Therefore, a research gap remains in understanding the full extent of PA's impact on these hormone levels, especially through high-quality RCTs. Third, research indicates that older adults who engage in regular aerobic exercise have a lower cortisol:DHEA ratio, suggesting a beneficial impact of PA on hormonal balance (Heaney et al., 2014). However, the influence of age and perceived stress on this balance remains an area for further exploration. The predominance of observational studies highlights a need for interventional research to assess the impact of PA programmes on this hormonal ratio in older adults.

In summary, while progress has been made in understanding endocrine changes with ageing, there are still unanswered questions, particularly regarding cortisol, DHEA(S), and their ratio and how they influence healthy ageing. The role of PA, in its various forms and its interaction with health conditions, remains a key area for investigation.

1.4.4 Sleep and the HPA Axis in ageing

Sleep hygiene, encompassing practices such as maintaining a consistent sleep schedule, creating a restful environment, and limiting exposure to screens before bedtime, is widely acknowledged as key for health maintenance (Irish et al., 2015; Irwin, 2015; Kripke et al., 2002; Mallon et al., 2002). Sleep disturbances are prevalent (Léger et al., 2008), and become more common as people age. The decline in sleep quality observed in normal ageing processes (Crowley, 2011; Espiritu, 2008; Mander et al., 2017) can have significant implications for health, including cognitive function and metabolic health.

The bi-directional relationship between sleep and the HPA axis, illustrated in Figure 1.3, reveals that sleep quality can inhibit the HPA axis and reduce cortisol secretion (Weitzman et al., 1983). This deep sleep phase is important for physical restoration and stress recovery, making it a key component of the sleep-health relationship. Conversely, disturbances in sleep can stimulate the HPA axis, leading to increased cortisol levels (Opp et al., 1989; Opp, 1995; Späth-Schwalbe et al., 1991). Cortisol plays a role in influencing sleep quality (Buckley & Schatzberg, 2005; Nollet et al., 2020; Steiger, 2002) and sleep-wake cycles (Buijs et al., 2003; Dickmeis, 2009; Kalsbeek et al., 2006). For instance, alterations in cortisol levels can affect sleep patterns, including changes in the time spent in different sleep stages and sleep quality (Born & Fehm, 1998).

The interaction between cortisol and sleep patterns is vital for healthy ageing. However, its balance remains to be fully explored (Born et al., 1999). Given that cortisol dysregulation and poor sleep can lead to downstream health effects, it is important to understand how these factors interact (Ono & Yamanaka, 2017).

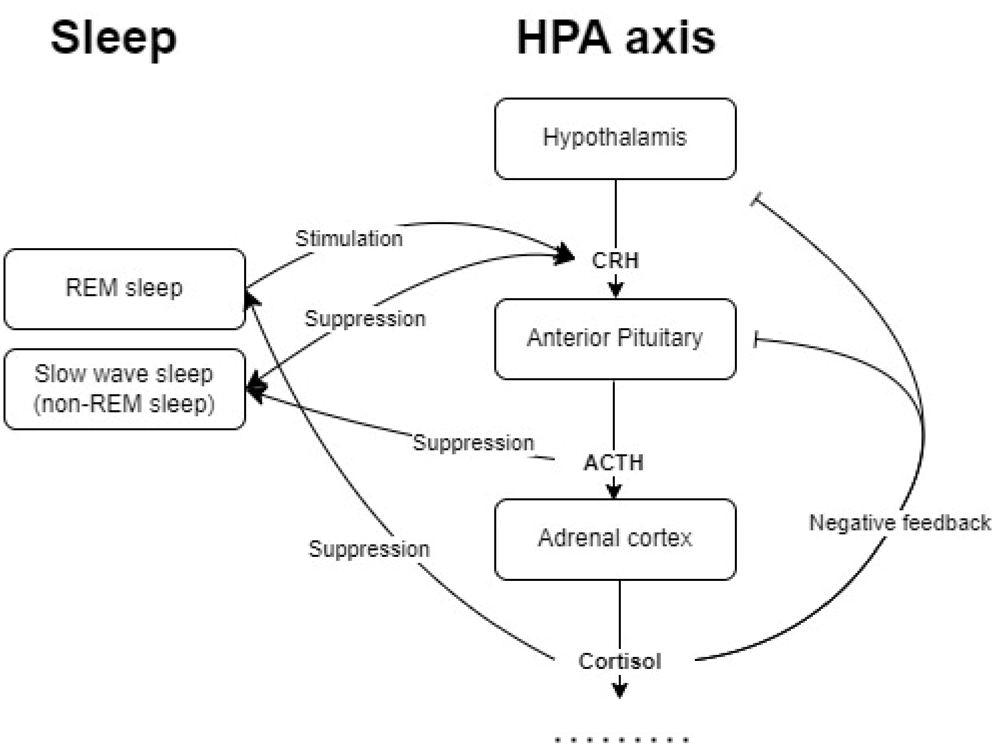

Figure 1.3 *Sleep and the HPA axis.*

Note. CRH: Corticotropin-Releasing Hormone, ACTH: Adrenocorticotropic Hormone, REM Sleep: Rapid Eye Movement Sleep, HPA Axis: Hypothalamic-Pituitary-Adrenal Axis

1.4.5 The influence of PA on cortisol and sleep

Given the close connection between stress and sleep, PA may mitigate stress effects, potentially enhancing sleep quality (Zschucke et al., 2015). Several studies have highlighted the beneficial effects of PA on sleep quality. Regular PA has been shown to enhance sleep efficiency, decrease sleep latency, and improve sleep architecture (Kredlow et al., 2015; Uchida et al., 2012; Vanderlinden et al., 2020; Wang & Boros, 2019). Given the interaction between the HPA axis and sleep during ageing, PA could be an important intervention for both. The systematic review in Chapter Three, focusing on PA's effects on stress and sleep, will offer insights into this relationship.

1.4.6 The influence of PA on physical function

Physical function, which includes cardiorespiratory performance, muscle strength, and balance, plays a role in executing daily living activities (Katz et al., 1963; Lawton & Brody, 1969; Liu et al., 2014; Wang et al., 2020). As individuals age, a decline in these physiological systems, cardiorespiratory performance, muscle strength, and balance often occurs, leading to reduced mobility and independence (McPhee et al., 2016; Nascimento et al., 2022). This gradual loss of function affects an individual’s capacity to perform daily activities and increases the risk of falls, injury, and dependence, significantly impacting their quality of life (O’Neill & Forman, 2020).

PA interventions promote physical function among older adults (de Vries et al., 2012). Both resistance and aerobic training have demonstrated significant mobility and muscle strength benefits in this demographic (de Vries et al., 2012; Jadczak et al., 2018). These exercises improve physical function and play a role in decreasing the incidence of falls, a common concern in this age group, particularly among those who are frail (Chin A Paw et al., 2008; Chou et al., 2012; de Labra et al., 2015; González-Rocha et al., 2022; Jadczak et al., 2018; Swales et al., 2022). Some studies show that although aerobic exercise could improve physical performance, such as gait speed and balance, resistance training is needed to improve muscle strength (Mangani et al., 2006; Marques et al., 2011).

Higher PA levels correlate with better physical function (Brach et al., 2004; Nusselder et al., 2008; Paterson & Warburton, 2010; Pettee Gabriel et al., 2017), and moderate-intensity exercises are effective in enhancing physical function in care home residents (Arrieta et al., 2018). Given the promising benefits outlined, there is a need to further research the implementation and efficacy of innovative interventions for older adults in care homes, such as e.g. digital music and movement programmes. These interventions could offer an engaging, accessible way to improve physical function and well-being in this population.

1.5 Main aim and objectives

The primary aim of this thesis is to investigate the impact of PA on the well-being of older adults. The research focuses on care home residents, exploring the interactions between PA and key healthy ageing indicators such as cortisol and DHEA(S) levels, sleep quality, physical function and well-being. Additionally, the thesis aims to explore the potential of digital PA interventions in care homes. To this end, the thesis is structured into four distinct yet interrelated studies, each addressing specific aspects of PA in the context of ageing.

The four objectives of the thesis are to (1) conduct a systematic review and meta-analysis examining PA's effects on cortisol and DHEA(S) levels (Chapter Two), (2) conduct a systematic review and meta-analysis on the relationship between PA, cortisol, and sleep quality (Chapter Three), (3) develop and assess the feasibility of a digital music and movement intervention tailored for care homes (Chapter Four), and (4) conduct a pilot randomised controlled trial (RCT) to evaluate the intervention’s efficacy and inform a future full-scale RCT (Chapter Five).

The methodology employed across these studies, detailed in Appendices 2 to 5, offers insights into the research design, data collection, and analysis methods. The concluding chapter (Chapter Six) synthesises the findings, reflecting on the initial research questions and presenting critical considerations for future research.

Chapter 2: Systematic review One: PA influences stress and healthy ageing by improving cortisol and dehydroepiandrosterone (sulphate) levels in older adults.

This Chapter is based on the peer-reviewed systematic review and meta-analysis published as “PA Influences Cortisol and Dehydroepiandrosterone (Sulfate) Levels in Older Adults: A Systematic Review and Meta-Analysis.” In the *Journal of Aging and Physical Activity*, Volume 31: Issue 2, p 330–351 (De Nys et al., 2022).

2.1 Background

Promoting healthy ageing is a growing concern among health professionals and researchers globally, particularly as populations age rapidly. In response to this challenge, the SHAPE project was initiated to develop an intervention protocol that could influence healthy ageing across psychosocial, neuroendocrine and physiological health outcomes.

The two systematic reviews presented in this thesis contribute to understanding PA and its role in promoting healthy ageing. These reviews analyse existing literature, focusing on important health markers in older adults. Methodological details, ensuring accuracy and replicability, are outlined in Appendix 2.1.

Systematic Review One studies PA's effects on cortisol and DHEA(S) levels. These biomarkers are key in assessing immune system health and well-being. Systematic Review Two expands this investigation to include sleep quality, another vital component of health and well-being. Both reviews uphold stringent methodological standards, aligning with the PRISMA statement and the Cochrane Handbook guidelines for systematic review of interventions.

These reviews informed the intervention trials described in Chapters Four and Five. These Chapters build on the established understanding of the relationship between PA, cortisol and/or DHEA(S) and sleep on health outcomes among older adults.

2.2 Introduction

In the past century, lifespan has increased significantly (Roser et al., 2013). Although humans live longer, data suggests these additional years are often not spent in good health (Crimmins & Beltrán-Sánchez, 2011; Crimmins, 2004). The population's increasing long-term multimorbidity poses an enormous capacity burden on the healthcare system (Barnett et al., 2012). Therefore, research is increasingly needed to conceptualise what governs healthy ageing. Much progress has been made in evidencing how PA contributes to good health (Macera et al., 2017; Peterson et al., 2009). For example, a recent study states that being sufficiently active at an older age dramatically decreases the odds of disability (Dos Santos & Gobbo, 2021). Despite this progress, research remains to be conducted to fully understand how PA can improve healthspan, essentially defined as maintaining wellness throughout old age (Aronson, 2020).

In ageing, hormonal balances and endocrine pathways become increasingly challenged (van den Beld et al., 2018). There is evidence for age-related alterations to the hypothalamic-pituitary-adrenal (HPA) axis, driving imbalances in the adrenal hormones, cortisol and dehydroepiandrosterone sulphate (DHEAS) (Ferrari et al., 2001). One of the main stress hormones, cortisol, is key for establishing an adequate stress response (Ockenfels et al., 1995); however, when cortisol levels are chronically elevated, its effects will negatively impact health (Juster et al., 2010). On the other hand, DHEA, a steroid hormone also produced in the adrenals, often measured in its active sulphated form DHEAS, appears to counterbalance many of the adverse effects of cortisol (Buoso et al., 2011; Pluchino et al., 2015), thereby implicating the importance of cortisol:DHEA(S) ratio in ageing (Butcher et al., 2005; Phillips et al., 2007). Several age-related changes can be noted in these two hormones: older adults display an increased daily cortisol output (Heaney et al., 2012a; Karlamangla et al., 2013; Nater et al., 2013; Van Cauter et al., 1996), a blunted cortisol awakening response (CAR) (Kudielka et al., 2004) and a flatter diurnal profile (Deuschle et al., 1997; Heaney et al., 2012b; Kumari et al., 2010). In contrast, studies reported a steady decline in levels of the hormone DHEA(S) with age (Heaney et al., 2012a; Orentreich et al., 1984) and a flatter diurnal profile in both older males and females compared to younger adults (Al-Turk & Al-Dujaili, 2016). Not surprisingly, the cortisol:DHEA ratio increases with age (Phillips et al., 2007). High cortisol:DHEA(S) ratios are associated with immune impairment (Butcher et al., 2005), dementia (Ferrari et al., 2001), metabolic syndrome (Phillips et al., 2010b), and mortality (Phillips et al., 2010a). As stated above, research has shown changes in endocrine pathways in ageing. However, important questions regarding the role of these hormones and the cortisol:DHEA(S) ratio in healthy ageing remain unanswered, such as how they relate to PA to maintain health.

Several previous studies suggest the cortisol:DHEA ratio is an important marker of healthy ageing, with increased cortisol:DHEA ratio relating to poorer physical function (Heaney et al., 2012a), low social support, and higher depression, anxiety and chronic stress (Heaney et al., 2010). Further, Heaney et al. noted that older adults reporting more severe recent stressful events but low PA show a higher cortisol:DHEA ratio than those reporting fewer stressful experiences (Heaney et al., 2014). Moreover, they found evidence that the observed association between stress severity and cortisol:DHEA was driven by lower DHEA levels in those experiencing more severe stress rather than high cortisol levels. They argued that regular PA may buffer against the negative influence of stressful life events on the cortisol:DHEA ratio. This agrees with the conclusions of a more recent study (Moraes et al., 2016) and adds to the consensus that PA may buffer the effects of chronic stress (Rimmele et al., 2009; Unger et al., 1997; Zschucke et al., 2015) and decrease stress reactivity (Rimmele et al., 2007). Similar results are found in experimental studies, where it was shown that exercise programmes can produce psychological and physiological changes (Klaperski et al., 2020; Kraemer & Ratamess, 2005). Despite increasing interest in how PA impacts the endocrinology of stress and healthy ageing over the last few decades (for most recent reviews on this topic, see (Anderson & Wideman, 2017; Daskalopoulou et al., 2017; Duclos & Tabarin, 2016; Fragala et al., 2011; Sellami et al., 2019)), the association between PA and cortisol and DHEA(S) levels have not yet been systematically reviewed in older adults.

This review focused on broader PA (incorporating exercise) on hormone responses rather than the impact of acute exercise bouts or exercise only for several reasons. First, PA goes beyond the regularly planned activities we know as exercise and incorporates unplanned movement that can contribute to physical health, such as active travel, moving about in the workplace and during chores as part of an active lifestyle. These types of bodily movement all contribute to health and have formed the significant evidence base behind global and national PA guidelines (Bull et al., 2020). For example, exercise and PA improve stress and prevent or improve several physical and mental health problems such as depression, cardiovascular, immunological and metabolic diseases (Hill et al., 2008; Penedo & Dahn, 2005; Ströhle et al., 2007). In older adults, an active lifestyle is associated with a higher quality of life (Koltyn, 2001), and there is consensus that PA yields salutary psychological and physical effects in older adults. This includes moderate-intensity aerobic activity, muscle-strengthening activity, reducing sedentary behaviour, and risk management (Nelson et al., 2007). More specifically, Heaney et al. (2014) found that habitual PA buffers the adverse effects of stress in older men and women by opposing the stress-associated increases in the ratio between cortisol and DHEA (Heaney et al., 2014). The evidence further shows that higher physical fitness is associated with lower daily cortisol output (Lucertini et al., 2015). In addition, a physically active life positively affects the brain structures, promoting better control of the HPA axis and greater resilience to stress (McEwen & Morrison, 2013). Second, while there is indeed a whole-body adaptation through acute exercise challenges (Hawley et al., 2014), which not all PA might be sufficient to induce, there is also an essential behavioural health perspective to active lifestyles that should not be overlooked. This systematic review was conducted to inform future research where implementing the research into clinical practice is considered necessary. Exercise programmes are proven to be feasible and effective for multiple health outcomes. However, many people do not continue exercising after the end of a programme. Therefore, investigating population associations between longer-term PA as part of an active lifestyle (as well as exercise interventions) and more favourable cortisol levels might yield engaging and pragmatic clinical guidance for long-term health.

Third, for healthy ageing, one needs to adapt and effectively respond to the dynamic challenges of daily life. Allostasis is a dynamic concept where the brain is considered to have a role in feedback regulation to adapt to these challenges and where health is conceived as a whole-body adaptation to contexts (Schulkin, 2003; Sterling, 2004). Allostatic load has been proposed as a cumulative measure of dysregulation across multiple systems, such as the neuroendocrine, autonomic nervous, and immune systems (McEwen & Stellar, 1993). The glucocorticoid cascade hypothesis of ageing is a prime example of allostatic load since it recognises a feed-forward mechanism that gradually wears down a fundamental brain structure, the hippocampus. At the same time, the gradually dysregulated HPA axis promotes pathophysiology in tissues and organs throughout the body (McEwen, 2003). This model identifies PA as an important allostatic load covariate in older adults (Karlamangla et al., 2002; Kubzansky et al., 1999; Seeman et al., 1997). As a result, in light of the health impact and practice applications of PA and the allostatic load model, it is vital to investigate further the associations between PA and exercise and more favourable endocrine profiles in older adults.

Therefore, the main aim of this systematic review was to explore the existing literature on how PA influences physiological markers of cortisol and/or DHEA(S) in older adults aged 65 years and above. The main objectives were to investigate: (1) whether there is observational evidence to suggest regular PA is associated with lower cortisol and/or higher DHEA(S) levels and which factors contribute most to these levels; (2) the average effect of physical exercise interventions of at least 12 weeks duration on reducing cortisol and/or increasing DHEA(S) levels in older adults. The sub-objectives were to determine different effects between males and females, different exercise types (e.g., aerobic, resistance, mixed-types or mind-body) or intensities (low-moderate, moderate-high), and in a healthy population versus those with a specific disease and the influence of differences between cortisol or DHEA(S) sample timing, and the number of samples throughout the day. These objectives and sub-objectives were set to reveal current knowledge gaps, provide future directions to better understand the intervention effects of PA programmes on endocrine health in older adults, and contribute to better clinical guidance.

2.3 Methods

2.3.1 Protocol

The conduct and analysis of this systematic review is mainly based on PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Page et al., 2021) complemented with guidance from the Cochrane Handbook (Higgins et al., 2021). The published protocol for the review is available at the International Prospective Register of Systematic Reviews (PROSPERO) https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42021236934, registration number CRD42021236934. For transparent reporting of the review, the PRISMA checklist 2020 was used (Appendix 2.2).

2.3.2 Study eligibility criteria

The selection process used to include studies in the review was as follows: (1) Original sources of peer-reviewed evidence to date with both experimental and observational designs in the English language, except for letters and conference abstracts. To this end, observational studies were considered to be used to report population-based data that would usefully supplement and extend the data drawn from RCTs. (2) Studies irrespective of publication status, unless exclusion is explicitly justified. (3) Articles addressing the pre-defined Population, Intervention, Comparison and Outcome (PICO) criteria (Richardson et al., 1995). The PICO criteria were:

- Population: community-dwelling free-living older adults, 65 years or older and older individuals in supporting housing or care homes. Eligible studies were also included if they involved only a subset of relevant participants but had separate analyses. Intervention: Experimental or observational studies looking at PA, daily living activities, or exercise programmes maintained long enough for possible habit formation (≥ 12 weeks).

- Interventions included PA and/or exercise protocols equal to or over 12 weeks.

- Comparison: Controls having an inactive/sedentary lifestyle or receiving no intervention or usual care.

- Outcome: Cortisol and/or DHEA(S), objectively measured in saliva, blood, hair or urine samples.

2.3.3 Search strategies

The searches were run on 01/03/2021 and re-run just before the final analyses on 02/09/2021. The following electronic bibliographic databases were searched: PubMed, PEDro, PsycINFO, OvidSP, the Cochrane Library (the Cochrane Central Register of Controlled Trials (CENTRAL)), CINAHL and Web of Science (no data limits were chosen). The search strategy included only terms relating to or describing the PICO criteria of interest and was adapted for each bibliographic database. Grey literature searches were conducted by searching online databases (ClinicalTrials.gov) and using the Google Scholar search engine according to the recommendations of Haddaway (Haddaway et al., 2015). The exact search strategy used with suitable search terms for each database is available in Appendix 2.3. Finally, the tool "connected papers" (https://www.connectedpapers.com/) was used to identify the most prominent papers in this field. Reference lists of key and already included papers were searched and cross-referenced by hand to supplement initial keyword searches.

2.3.4 Data collection and management

Search results were collected in Sciwheel (sciwheel.com), and the extracted titles and abstracts of papers were screened using Rayyan (rayyan.qcri.org) (Ouzzani et al., 2016). Two reviewers (LDN & EO) independently performed a first-stage screening of titles and abstracts to determine whether each study met the eligibility criteria. Any study identified by either reviewer was included for further screening. Two independent reviewers again performed a second-stage screening of the selected full-text articles. Further, a third-stage screening consisted of a pilot data extraction screening of the retrieved full-text articles. Disagreements in the screening process were resolved by consensus. Reasons for excluding studies from the pilot data extraction screening were documented. Finally, a flowchart showing the screening and selection process was made.

Study authors were contacted to obtain missing data if needed (n = 5). Data extraction was conducted in Excel, where two independent reviewers collected the following: study ID, design, PICO characteristics, general findings, and statistics relevant to the research question. Retrieved data from observational studies were extracted separately from intervention studies. Assembling and grouping data elements was done using RevMan 5 software (The Cochrane Collaboration, 2020). Any transformations of the reported data can be found in Appendix 2.4.

2.3.5 Assessment of risk of bias

Two reviewers (LDN and EO) independently assessed the risk of bias using the Joanna Briggs Institute (JBI) tool (https://joannabriggs.org/critical-appraisal-tools) (Vardell & Malloy, 2013) for observational studies and the Cochrane Risk of Bias (RoB) 2.0 Tool (Higgins et al., 2011; Ma et al., 2020) for intervention studies. The certainty of all evidence was assessed using the GRADE approach (Guyatt et al., 2008) for the cortisol and DHEA(S) outcomes. For randomised controlled trials, a starting rating of 'High quality' evidence was downgraded by one level if serious concerns (or by two levels for very serious concerns) became apparent regarding the risk of bias, inconsistency, indirectness, imprecision or publication bias. For studies with observational features, a starting rating of 'Low quality' was downgraded, as proposed by GRADE guidelines (Schünemann et al., 2013). A funnel plot (Egger’s test) (Egger et al., 1997) was performed for the included RCTs to visualise possible reporting bias. There were insufficient observational studies to allow construction of such a plot.

2.3.6 Data synthesis

When included, study data were found to be similar enough in terms of methodological and clinical characteristics to ensure meaningful conclusions from a statistically pooled result, and meta-analyses were performed.

Observational studies were considered not similar enough to combine data using meta-analysis, so narrative analyses were conducted. All studies were given equal weight. Effect directions for both outcomes were assessed, and p-values were reported for the sign test based on existing guidance (Boon & Thomson, 2021). The p-value from a sign test represents the probability of observing the given number of positive and negative results if the null hypothesis were true. To calculate the p-value of each outcome domain, GraphPad was used (https://www.graphpad.com/quickcalcs/binomial1/). Differences in the relative sizes of the studies were accounted for visually, not statistically (Borenstein et al., 2009).

Intervention studies were deemed similar enough to allow pooling of data using meta-analysis. The data were analysed based on mean, standard deviation (SD) and number of participants assessed for both the intervention and comparison groups and used to calculate the standardised mean differences (SMD) and 95% Confidence Intervals (CI) using the generic inverse variance method in RevMan5 (The Cochrane Collaboration, 2020). Assuming a true effect was not the same in all studies or that studies were performed in different populations, random-effect models were used to analyse data. Forest plots visualised these analyses. The degree of heterogeneity was thus assessed through Chi-squared (Chi^2) statistics. Heterogeneity was quantified and interpreted using the I-squared (I^2) statistic (Higgins et al., 2011). There were no deviations from the protocol in this final paper.

2.3.7 Subgroup analysis and investigation of heterogeneity

Where substantial heterogeneity was present, it was addressed by exploring possible reasons and conducting subgroup analyses as suggested by the Cochrane Handbook (Higgins et al., 2020). Studies were grouped based on the category that best explains heterogeneity and makes the most clinical and/or methodological sense to the reader, as *a priori* defined in the protocol. To be consistent across the review, forest plots of the low heterogeneity DHEA(S) outcomes were visualised with the same subgroups as the cortisol studies. Meta-analytic scores of subgroups are presented with the overall effects for both outcomes. However, there was still substantial statistical heterogeneity across the subgroups for cortisol.

2.3.8 Sensitivity analysis

Several analyses were performed to assess the robustness of the results. The effect of intervention duration was compared (12 weeks vs. >12 weeks), and aspects of trial size, quality assessment, patient characteristics and measurement of outcomes were considered.

Finally, analyses were performed with and without outliers studies, excluding these sequentially one by one to see if this changed the overall results.

2.4 Results

2.4.1 Results of the search

A total of 4834 records were identified through database searches, and an additional 18 through reference list searches (see PRISMA diagram Figure 2.1). After removing duplicates, 3069 titles and abstracts were screened for eligibility, 147 abstracts were obtained for further review, and 31 articles met the inclusion criteria. The reasons for exclusion are outlined in Figure 2.1. One ongoing trial was found, NCT03794050, but was paused due to the SARS-CoV-2 pandemic and excluded. A table with characteristics of excluded studies during the pilot data extraction can be found in Appendix 2.5.

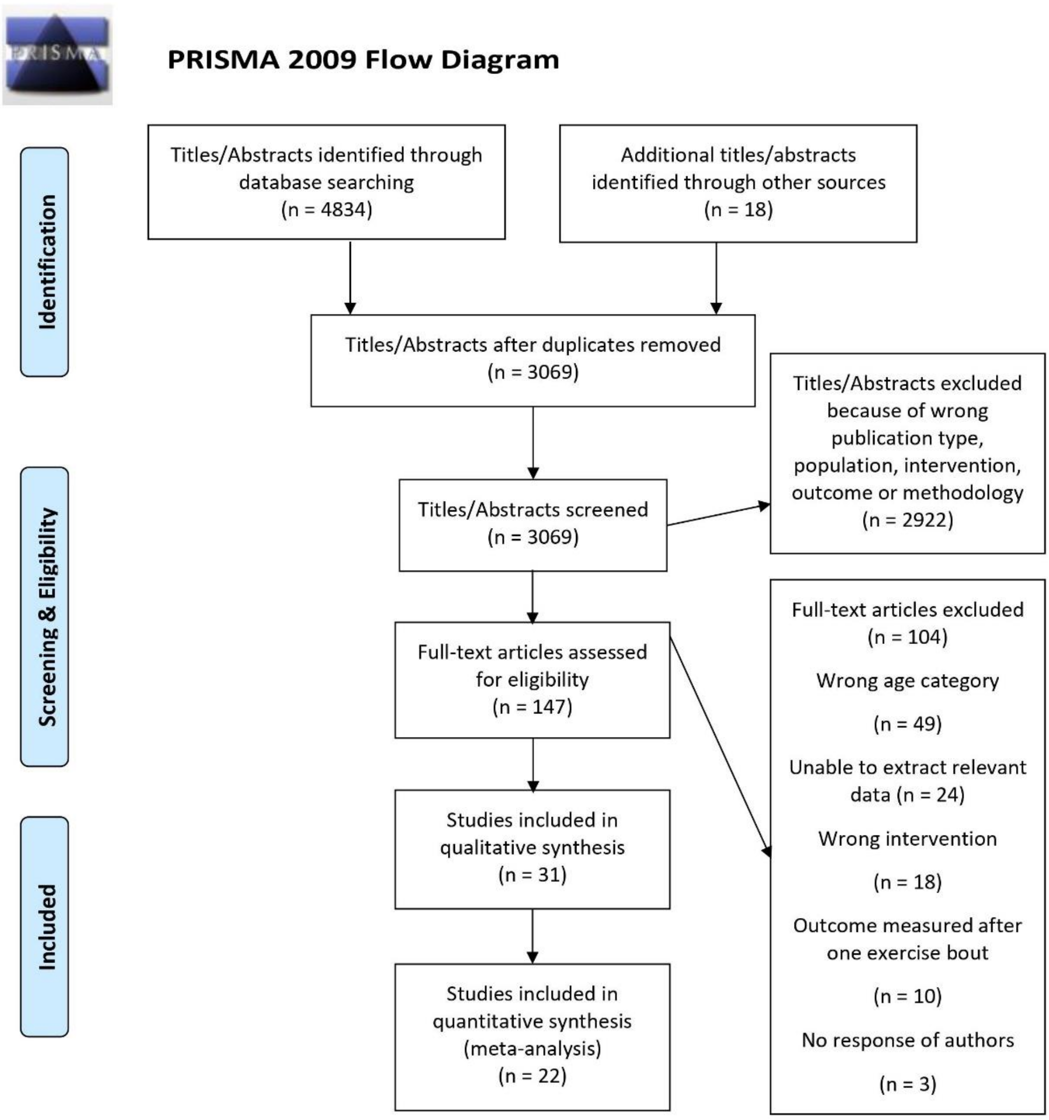

Figure 2.1 *PRISMA flow diagram of the systematic review. From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097*

2.4.2 Description of included studies

Observational studies were synthesised separately from obtained RCTs, and study characteristics were sorted by outcome (Tables 2.1 and 2.2).

Table 2.1 *Characteristics of included cross-sectional studies*

Study	Country	Population			PA measurement	Outcome		Relevant findings
		Sample size n (%male)	Mean age (SD) in years	Main group – subgroups		Cortisol (times - measure)	DHEA(S) (times - measure)	
Lucertini et al., 2015	Italy, Marche Region	22 (100%)	67.4 (1.5)	Generally healthy – high vs. low fitness	Time/week: categorical questionnaire	Saliva sample (6x – diurnal slope)	-	High fitness levels = lower cortisol*
Pauly et al., 2019	Canada	162 (50%)	71 (6)	Generally healthy, community-dwelling – high and low daily steps	Counts: accelerometry	Saliva sample (4x – diurnal slope)	-	High daily steps were correlated with lower cortisol*
Bonnefoy et al., 2002	France, Lyon	50 (50%)	71 (4)	Generally healthy – men vs. women	Energy expenditure: Questionnaire d'Activité Physique Saint-Etienne (QAPSE)	Blood sample (1x – morning)	Blood sample (1x – morning)	In women, higher PA = higher DHEAS*

Study	Country	Population			PA measurement	Outcome		Relevant findings
		Sample size n (%male)	Mean age (SD) in years	Main group – subgroups		Cortisol (times - measure)	DHEA(S) (times - measure)	
Heaney et al., 2014	UK, Birmingham	36 (50%)	72.6 (5.5)	Generally healthy, community-dwelling – high-stress vs. low-stress group	Time/week: categorical questionnaire	Saliva sample (6x – diurnal slope)	Saliva sample (6x – diurnal slope)	Higher PA = higher DHEA, and therefore lower cortisol:DHEA ratio*
Moraes et al., 2016	Brazil	63 (13%)	71.5 (12)	Mood disorders – depressed vs. healthy	Energy expenditure: International PA questionnaire (IPAQ)	Saliva sample (1x – afternoon)	Saliva sample (1x – afternoon)	Depressed patients = lower levels of cortisol than healthy controls
Abbasi et al., 1998	US, Wisconsin	262 (55%)	69.9 (4.5)	Generally healthy, community-dwelling – men vs. women and quartiles of serum DHEAS	Time/week: 7-day activity recall method	-	Blood sample (1x – morning)	Higher PA = higher DHEAS in men*

Study	Country	Population			PA measurement	Outcome		Relevant findings
		Sample size n (%male)	Mean age (SD) in years	Main group – subgroups		Cortisol (times - measure)	DHEA(S) (times - measure)	
Bonnefoy et al., 1998	France	60 (43%)	70 (4)	Generally healthy, community-dwelling – men vs. women and high vs. low active	Energy expenditure: QAPSE	-	Blood sample (1x – morning)	Lower habitual PA = lower levels of DHEAS*
de Gonzalo-Calvo et al., 2012	Spain, Oviedo	26 (100%)	75.5 (5)	Generally healthy, community-dwelling – long-term trained vs. sedentary	Time/week: checklist about regular PA	-	Blood sample (1x – morning)	Trained group = higher DHEA levels*
Ravaglia et al., 2001	Italy, Bologna	96 (100%)	67.8 (2.2)	Generally healthy – middle-aged vs. older adults	Energy expenditure: checklist about regular PA	-	Blood sample (1x – morning)	Physically active men = higher DHEAS levels*

Note. *: marks significance in the study

Table 2.2 *Characteristics of included intervention studies*

Study	Population				Intervention			Outcome		Relevant findings
	Sample size n (%male)	Mean age (range) (years)	Setting	Health status	Type	Duration	Control group	Cortisol (times - measure)	DHEA(S) (times - measure)	
Banitalebi et al., 2018	40 (0%)	M=67.35	Outpatient	Generally healthy	Resistance /endurance	12 weeks 3x per week (70 mins per session)	Aerobic vs. resistance vs. no exercise	Blood sample (1x morning)	-	Exercise = no change in cortisol levels
Borst et al., 2002	62 (45%)	60-85 (M= 68.1)	Centre for exercise and science, University of Florida, Gainesville	Generally healthy	Resistance	24 weeks 3x per week	No exercise program	Blood sample (1x time)	-	Resistance group = elevations in cortisol*

Study	Population				Intervention			Outcome		Relevant findings
	Sample size n (%male)	Mean age (range) (years)	Setting	Health status	Type	Duration	Control group	Cortisol (times - measure)	DHEA(S) (times - measure)	
Campo et al., 2013	63 (0%)	65.9 (55-84)	Free-living	Cancer survivors	Tai Chi - mind-body	12 weeks 3x per week (60mins/session)	Health education	Saliva sample (5x for diurnal slope)	-	Tai chi group = lower cortisol levels*
Furtado et al., 2016	35 (0%)	M= 83.81	Social and health care support centres	Generally healthy	Chair based yoga	14 weeks 2-3x per week	No exercise	Saliva sample (1x morning)	-	Yoga group = unchanged levels, control group = increased cortisol levels*

Study	Population				Intervention			Outcome		Relevant findings
	Sample size n (%male)	Mean age (range) (years)	Setting	Health status	Type	Duration	Control group	Cortisol (times - measure)	DHEA(S) (times - measure)	
Furtado et al., 2021	32 (0%)	82.4 (4.6)	Social and healthcare centres	Generally healthy/ pre-frail	Combined chair-based	14 weeks 2-3x per week (60mins/session)	No exercise	Saliva Sample (1x morning)	-	Exercise group = no changes, control group = increased cortisol*
Ho et al., 2020	204 (18%)	M=79	Outpatient psycho-geriatrics/ older adult community centre	Cognitive impairment	Dance movement therapy (DMT) /exercise	12 weeks 2x per week (1hr/session)	Regular care	Saliva sample (5x morning)	-	DMT group = Improved diurnal cortisol slope*

Study	Population				Intervention			Outcome		Relevant findings
	Sample size n (%male)	Mean age (range) (years)	Setting	Health status	Type	Duration	Control group	Cortisol (times - measure)	DHEA(S) (times - measure)	
Kim et al., 2018	20 (0%)	66.4	Free-living/ house wives	Metabolic - Obese	Aerobic/resistance	12 weeks 3x per week (90-120mins/session)	No exercise program	Saliva sample (1x morning)	-	Exercise groups = decrease in cortisol*
Lu et al., 2020	30 (52%)	60+	Nursing homes	Mood disorder	Qigong	12 weeks 2x per week (60mins/session)	Cognitive training	Saliva sample (5x for diurnal slope)	-	Qigong group = decrease in cortisol levels*
Mura et al., 2014	42 (62%)	65+	Community-dwelling	Generally healthy	Aerobic /anaerobic	12 weeks	Gymnastic group	Blood sample (1x morning)	-	Both groups = cortisol rise*

Study	Population				Intervention			Outcome		Relevant findings
	Sample size n (%male)	Mean age (range) (years)	Setting	Health status	Type	Duration	Control group	Cortisol (times - measure)	DHEA(S) (times - measure)	
Prakhinkit et al., 2014	45 (0%)	60-90 years	University hospital/ welfare centre	Mood disorder	Buddhism walking meditation/aerobic	12 weeks 3x per week (20-30mins/session)	No exercise program	Blood sample (1x morning)	-	Buddhism walking meditation group = cortisol decreased *
Rieping et al., 2019	47 (0%)	80	Care home	Generally healthy	Chair-based aerobic/ elastic band	14 weeks 3x per week (45 mins/ session)	No exercise program	Saliva sample (1x morning)	-	No cortisol level changes
Sin et al.,2015	70 (44%)	60-87	Korean community senior centre	Generally healthy	Walking	12 weeks	Walk on their own and no pedometer	Blood sample (1x morning)	-	No cortisol level changes

Study	Population				Intervention			Outcome		Relevant findings
	Sample size n (%male)	Mean age (range) (years)	Setting	Health status	Type	Duration	Control group	Cortisol (times - measure)	DHEA(S) (times - measure)	
Tada, 2018	61 (31%)	70.9 (60-87)	Community-dwelling	Generally healthy	Resistance	24 weeks 2x per week (20mins/session)	No exercise program	Saliva sample (1x morning)	-	Exercise group = decrease in cortisol levels*
Tsang et al., 2013	38 (31%)	65+	Psychogeriatric day clinics/ day care centres/ care homes	Generally healthy vs. Depression	qigong	12 weeks 3x per week (45mins/session)	No exercise program	Saliva sample (1x morning)	-	Exercise groups = decreasing trend in cortisol
Venturelli et al., 2016	80 (25%)	65-75	Nursing homes	Cognitive impairment – Alzheimer's disease	Aerobic exercise	12 weeks 5x per week (60mins/session)	No exercise program	Saliva sample (5x for diurnal slope)	-	Exercise group = cortisol levels reduced*

Study	Population				Intervention			Outcome		Relevant findings
	Sample size n (%male)	Mean age (range) (years)	Setting	Health status	Type	Duration	Control group	Cortisol (times - measure)	DHEA(S) (times - measure)	
Vrinceanu et al., 2019	40 (25%)	67.45 (60-86)	Geriatric institution/ gym	Generally healthy	Dance/aerobic	12 weeks 3x per week (60mins/session)	Waiting list	Saliva sample (3x morning)	-	Exercise group = decrease in cortisol level*
Furtado et al., 2020	60 (0%)	M= 81	Institutionalised older adults	Frail or pre-frail	Chair Based Exercise (CBE) /resistance	28 weeks 3x per week (45mins/session)	No exercise program	Saliva sample (1x morning)	Saliva sample (1x morning)	CBE group = DHEA increased, control group = DHEA decreased*

Study	Population				Intervention			Outcome		Relevant findings
	Sample size n (%male)	Mean age (range) (years)	Setting	Health status	Type	Duration	Control group	Cortisol (times - measure)	DHEA(S) (times - measure)	
Ha et al., 2018	20 (0%)	70-80	Living in Korea	Generally healthy	Aerobic /anaerobic /resistance	12 weeks 3x per week (60mins/session)	No exercise program	-	Blood sample (1x time)	Exercise group = increase in DHEAS*
Hersey et al., 1994	52 (45%)	M= 72 (70-79)	Living in Gainesville	Generally healthy	Endurance/ resistance exercise	24 weeks 3x per week (35-45 mins/ session)	No exercise program	-	Blood sample (1x morning)	No change in DHEA levels
Im et al., 2019	25 (0%)	M= 70	Fitness centre	Post-menopausal	Yoga and dance	12 weeks 3x per week (60mins/session)	No exercise program	-	Blood sample (1x morning)	Exercise group = decrease in DHEAS*

Study	Population				Intervention			Outcome		Relevant findings
	Sample size n (%male)	Mean age (range) (years)	Setting	Health status	Type	Duration	Control group	Cortisol (times - measure)	DHEA(S) (times - measure)	
Son et al., 2020	20 (0%)	M= 67.7	Multi-health community centre	Generally healthy	Resistance	12 weeks 3x per week (60mins/session)	Sedentary activities	-	Blood sample (1x morning)	Exercise group = increase in DHEAS*
Yamada et al., 2015	227 (37%)	65+	Community-dwelling	Generally healthy	Walking	24 weeks	Walking & nutrition & inactive control	-	Blood sample (1x morning)	walking/ nutrition group = DHEAS increased *

Note. *: marks significance in the study

2.4.3 Study and participant characteristics

Included observational studies were all cross-sectional designs (n= 9), involving a total of 729 participants (38% female) (Abbasi et al., 1998; Bonnefoy et al., 1998, 2002; de Gonzalo-Calvo et al., 2012; Heaney et al., 2014; Lucertini et al., 2015; Moraes et al., 2016; Pauly et al., 2019; Ravaglia et al., 2001). All studies, except one (Moraes et al., 2016), were conducted in high-income countries; all participants were Caucasians. The included RCT's (22) involved 1346 participants (79% female) (Banitalebi et al., 2018; Borst et al., 2002; Campo et al., 2013; Furtado et al., 2016, 2020; Furtado et al., 2021; Ha & Son, 2018; Hersey et al., 1994; Ho et al., 2020; Im et al., 2019; Kim et al., 2018; Lu et al., 2020; Mura et al., 2014; Prakhinkit et al., 2014; Rieping et al., 2019; Sin et al., 2015; Son et al., 2020; Tada, 2018; Tsang et al., 2013; Venturelli et al., 2016; Vrinceanu et al., 2019; Yamada et al., 2015), conducted in 10 countries. Studies were published between 1994 and 2021. However, most studies were published in the last five to 10 years (n= 25).

Observational studies included mostly generally healthy older adults (n= 8), and subgroup analyses in studies were performed by fitness level (n= 4), sex (n= 2), age (n= 1), stress exposure (n= 1) or DHEA level (n= 1). Intervention studies with a cortisol outcome investigated generally healthy older adults (n= 8) or individuals with mood disorders (n=3), cognitive impairment (n=3) or other (n= 3, cancer survivors, metabolic syndrome or frailty). Intervention studies with a DHEA(S) outcome investigated generally healthy older adults (n= 5) and frail or pre-frail older adults (n= 1).

2.4.4 Cortisol or DHEA(S) measurement

Cortisol and/or DHEA(S) samples of both cross-sectional studies and RCTs were taken either from saliva (n= 19) or blood serum (n= 15). None used urine or hair samples. Identified studies that focused on the diurnal cortisol slope took three to six samples during the day (Heaney et al., 2014; Ho et al., 2020; Lu et al., 2020; Lucertini et al., 2015; Pauly et al., 2019; Venturelli et al., 2016). In three studies, Cortisol Awakening Response (CAR) was analysed (Campo et al., 2015; Heaney et al., 2014; Vrinceanu et al., 2019). All other studies performed a one-time measurement in a fasted state, almost exclusively in the morning.

2.4.5 Risk of bias in studies

Across all studies, a low to moderate risk of bias was identified (Figures 2.2 and 2.3). In the cross-sectional studies, the fifth question in the JBI checklist asks if confounding factors are identified in each study. The review team recognised that many confounding factors are at play in a one-time point endocrinology measurement, certainly when trying to define life stressors. However, many studies did account for at least some confounders. Further, most studies measured PA with reliable and valid questionnaires. These are not robust activity measurements compared to, e.g., accelerometry. However, the review team judged that the exposure of all studies was measured validly and reliably in studies that reported transparent and standardised (*a priori*-defined) PA measurement tools. Traffic light plots summarising these decisions are shown in Appendix 2.6.

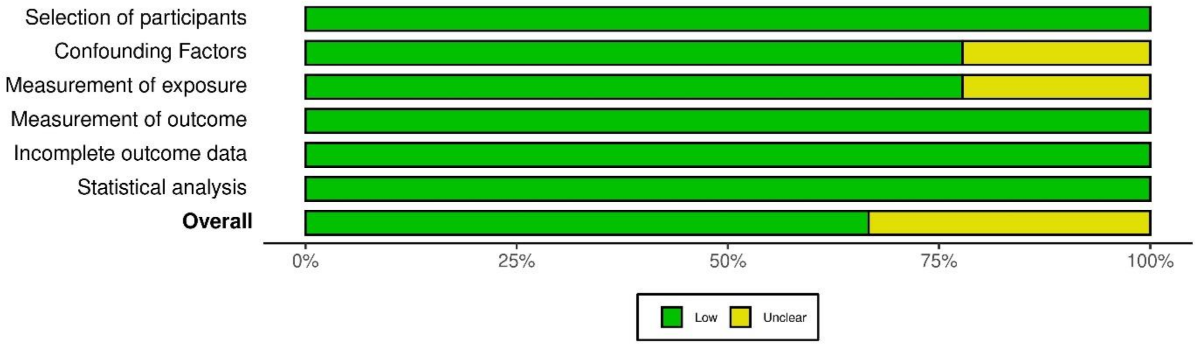

Figure 2.2 *Critical appraisal of cross-sectional studies, appraised by the JBI-tool. Green: low risk of bias, yellow: unclear information about given topics, yet included in further analysis. From: robvis tool, https://mcguinlu.shinyapps.io/robvis/.*

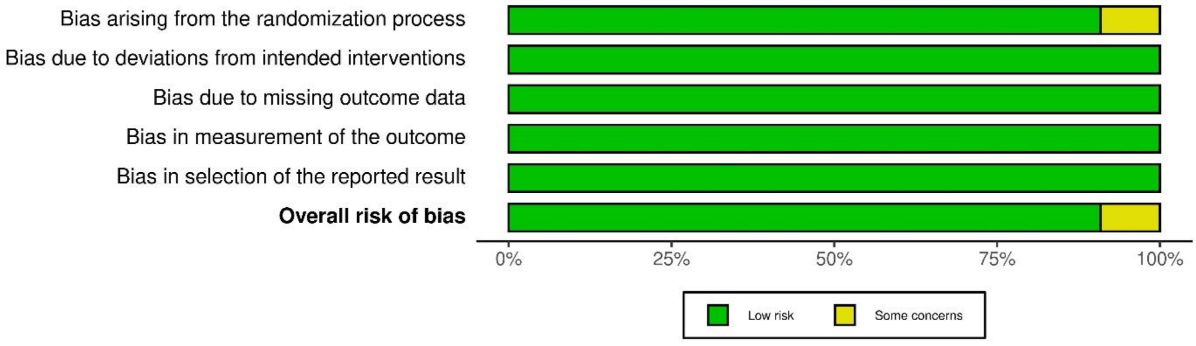

Figure 2.3 *Critical appraisal of RCTs, appraised by the Cochrane RoB tool. Green: low risk of bias, yellow: some concerns about given topics, yet included in further analysis. From: robvis tool, https://mcguinlu.shinyapps.io/robvis/*

2.4.6 Reporting biases

The funnel plot showed slight asymmetry due to missing studies on ‘no intervention effect’ (Figure 2.4). While reporting bias is thus considered, this asymmetry could be due to chance as the analysis contains few studies with a relatively small number of participants (Sterne et al., 2011). The funnel plot is grouped by intensity solely for consistency, and it should be acknowledged there are too few studies to interpret the findings by each subgroup. Other sources of bias, such as selection bias, performance and detection bias and attrition bias were considered (Appendix 2.7)

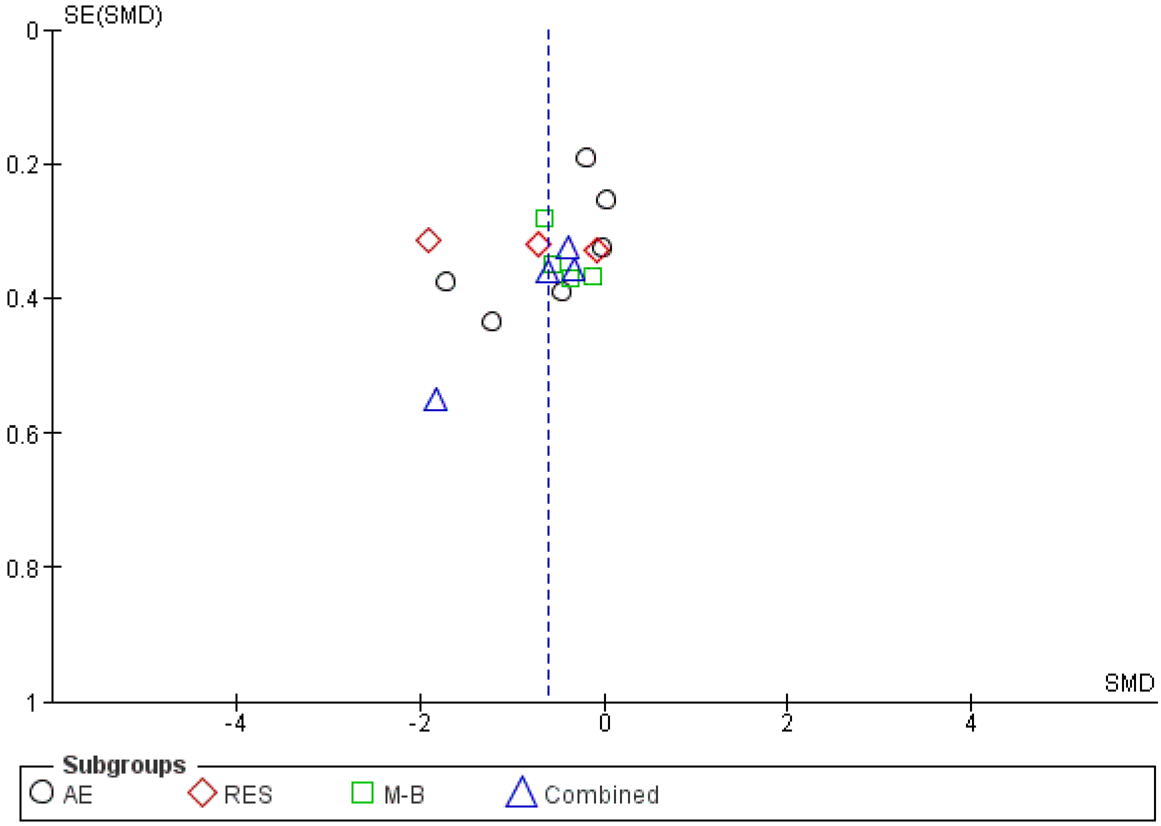

Figure 2.4 *Egger’s test by Funnel plot. AE = aerobic exercise, RES = resistance training, M-B = mind-body exercise, Combined = intervention including aerobic and resistance training elements.*

2.4.7 Results of syntheses and certainty of evidence

Observational studies

Cortisol. There was very low-quality evidence suggesting regular PA is associated with lower cortisol in both older males and females compared to being more sedentary (n = 333 with 53% males, p-value for sign test = .063 in males, all the studies reported a negative effect direction; and p-value for sign test = 0.38 in females, four studies reported a negative effect direction, with one unclear result) (Figure 2.5 and Table 2.3). GRADE guidelines state that grading non-RCTs' evidence starts at 'low quality'. It was deemed that inconsistency and/or indirectness did not appear to be an issue with this outcome, nor was there any publication bias detected. However, based on quality assessments, studies were downgraded (-1) because some imprecision exists, following the GRADE 'rule of thumb' that information is likely to be insufficient when rating continuous outcomes when the total number of participants is less than 400 (Schünemann et al., 2013)

DHEA(S). There was low-quality evidence to suggest that being physically active in daily life is associated with higher DHEA(S) levels compared to being more sedentary. (n = 545 with 59% males, p-value for sign test = 0.02 in males, with seven out of seven reporting a positive effect direction, and p-value for sign test = 0.45 in females, with five out of seven studies reporting a positive effect direction) (Figure 2.5 and Table 2.3). The same GRADE factors were considered, but none of these features appeared to be an issue for this outcome, so the overall quality of evidence was not downgraded.

Cortisol:DHEA(S) ratio. Only one study was found where higher PA levels were associated with lower cortisol:DHEA(S) ratio (p = .05), mainly driven by significantly higher average DHEA(S) levels in people who regularly engaged in PA (p = .009) compared to those who did not (Heaney et al., 2014).

Study	Cortisol male	Cortisol female	DHEA male	DHEA female
Lucertini F. et al., 2015	▼	◄►		
Pauly T. et al., 2019	▼	▼		
Bonnefoy M. et al., 2002	▼	▼	▲	▲
Heaney J. et al., 2014	▼	▼	▲	▲
Moraes H. et al., 2016	▼	▼	▲	▲
Abbasi A. et al., 1998			▲	▲
Bonnefoy M. et al., 1998			▲	▲
de Gonzalo-Calvo D. et al., 2012			▲	◄►
Ravaglia G. et al., 2001			▲	◄►

LEGEND

All included studies were of a cross-sectional study design

Effect direction: in cortisol colums: upward arrow ▲= increase in endocrine outcome, downward arrow ▼= decrease in endocrine outcome, sideways arrow ◄►= no change/mixed effects/conflicting findings

Sample size: Final sample size (individuals) in intervention group Large arrow ▲ >300; medium arrow ▲ 50-300; small arrow ▲ <50

Study quality: denoted by row colour: green = low risk of bias; amber = some concerns; red = high risk of bias

Figure 2.5 *Effect direction plot summarising direction of cortisol and DHEA(S) hormone level impacts from cross-sectional studies.*

RCTs

Cortisol. There was moderate quality evidence that exercise interventions in older adults for at least 12 weeks probably reduce cortisol levels compared to no intervention (SMD = -0.61, [-0.90, -0.33], 17 studies, 736 participants) (Figure 2.6 and Table 2.3). The overall quality was graded as moderate when pooling the studies because of substantial statistical heterogeneity (I2 = 69%). The heterogeneity was explained; thus, the overall evidence grade was downgraded by only one level due to inconsistency. After pre-specified sub-group comparisons and through sensitivity analyses, three studies with the highest effect sizes were found to explain all heterogeneity (Tada et al., 2018, Kim et al., 2018, Venturelli et al., 2016) (SMD = -1.83 [-2.26, -1.40], three studies, 121 participants). When including these studies, the overall finding favouring the interventions was relatively strong but with substantial variability. When these three studies were removed from the meta-analysis, the heterogeneity was substantially reduced. Excluding these three articles from the equation still resulted in high-quality evidence that exercise interventions of at least 12 weeks reduce cortisol levels slightly compared to controls in older adults (SMD = -0.35 [-0.51, -0.18], 15 studies, 615 participants).

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.3.1 AE								
Venturelli 2016	7.6	1.7	20	12.1	3.2	20	5.5%	-1.72 [-2.46, -0.99]
Vrinceanu 2019	16.969	6.107	12	24.6	6.02	14	4.9%	-1.22 [-2.07, -0.37]
Prakhinkit 2014	12.3	3.36	14	13.7	2.5	13	5.4%	-0.46 [-1.22, 0.31]
Ho 2020	4.9	2.7	56	5.5	3.4	55	7.7%	-0.19 [-0.57, 0.18]
Rieping 2019	0.295	0.2265	34	0.3	0.14	13	6.1%	-0.02 [-0.66, 0.62]
Sin 2015	3.94	2.91	44	3.86	2.99	24	6.9%	0.03 [-0.47, 0.52]
Subtotal (95% CI)			**180**			**139**	**36.5%**	**-0.54 [-1.05, -0.03]**
Heterogeneity: Tau² = 0.30; Chi² = 21.25, df = 5 (P = 0.0007); I² = 76%								
Test for overall effect: Z = 2.08 (P = 0.04)								
1.3.2 RES								
Tada 2018	0.14	0.01	32	0.17	0.02	29	6.2%	-1.90 [-2.51, -1.29]
Mura 2014	188.36	38.56	21	233.74	79.74	21	6.2%	-0.71 [-1.34, -0.09]
Borst 2002	120	46.9	22	125	60	16	6.1%	-0.09 [-0.74, 0.55]
Subtotal (95% CI)			**75**			**66**	**18.5%**	**-0.91 [-1.95, 0.14]**
Heterogeneity: Tau² = 0.75; Chi² = 16.66, df = 2 (P = 0.0002); I² = 88%								
Test for overall effect: Z = 1.70 (P = 0.09)								
1.3.3 M-B								
Campo 2015	24.65	8.18	29	29.95	7.8	25	6.6%	-0.65 [-1.20, -0.10]
Furtado 2016	0.62	0.16	20	0.73	0.22	15	5.8%	-0.57 [-1.26, 0.11]
Tsang 2013	-2.61	9.07	14	0.89	9.07	16	5.6%	-0.38 [-1.10, 0.35]
Lu 2020	107.24	19.63	14	109.65	19.58	16	5.6%	-0.12 [-0.84, 0.60]
Subtotal (95% CI)			**77**			**72**	**23.7%**	**-0.47 [-0.79, -0.14]**
Heterogeneity: Tau² = 0.00; Chi² = 1.49, df = 3 (P = 0.69); I² = 0%								
Test for overall effect: Z = 2.78 (P = 0.005)								
1.3.4 Combined								
Kim 2018	0.23	0.06	10	0.41	0.12	10	3.9%	-1.82 [-2.90, -0.74]
Banitalebi 2018	23.6	4.4724	24	25.94	1.33	12	5.7%	-0.61 [-1.32, 0.10]
Furtado 2020	0.21	0.12	20	0.27	0.17	19	6.1%	-0.40 [-1.04, 0.23]
Furtado 2021	0.26	0.09	17	0.31	0.2	15	5.7%	-0.32 [-1.02, 0.38]
Subtotal (95% CI)			**71**			**56**	**21.4%**	**-0.67 [-1.20, -0.14]**
Heterogeneity: Tau² = 0.14; Chi² = 5.88, df = 3 (P = 0.12); I² = 49%								
Test for overall effect: Z = 2.48 (P = 0.01)								
Total (95% CI)			**403**			**333**	**100.0%**	**-0.61 [-0.90, -0.33]**
Heterogeneity: Tau² = 0.24; Chi² = 52.03, df = 16 (P < 0.0001); I² = 69%								
Test for overall effect: Z = 4.25 (P < 0.0001)								
Test for subgroup differences: Chi² = 0.89, df = 3 (P = 0.83), I² = 0%								

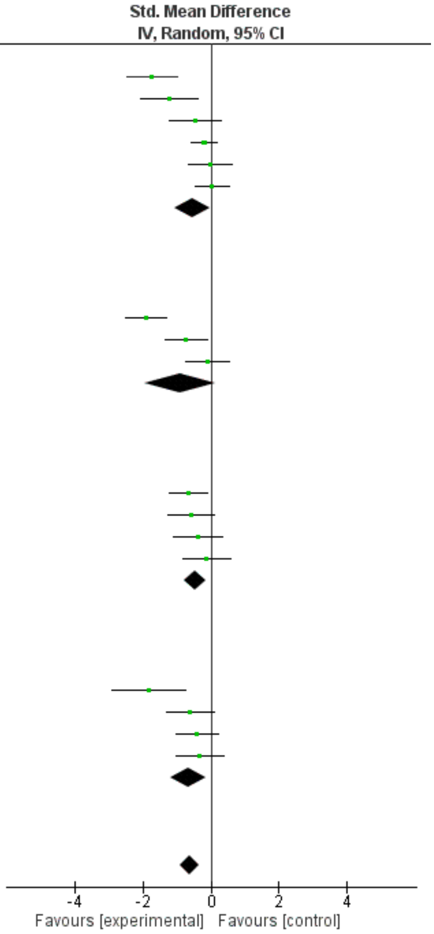

***Figure 2.6** Forest plot for cortisol , sub-grouped by intervention type. AE = aerobic exercise, RES = resistance training, M-B = mind-body exercise, Combined = intervention including aerobic and resistance training elements.*

DHEA(S). There was moderate quality evidence that exercise interventions in older adults for at least 12 weeks improved DHEA(S) levels slightly compared to no intervention (SMD = 0.39 [0.10, 0.68], six studies, 203 participants) (Figure 2.7 and Table 2.3). The studies were considered homogeneous (I^2=0). The quality of the evidence was rated as moderate due to some imprecision that may exist because the number of participants (n= 203) is lower than the general GRADE 'rule of thumb' of n ≥ 400 to be sufficient.

Cortisol:DHEA(S) ratio. No RCTs reported the impact of exercise interventions on the cortisol: DHEA(S) ratio.

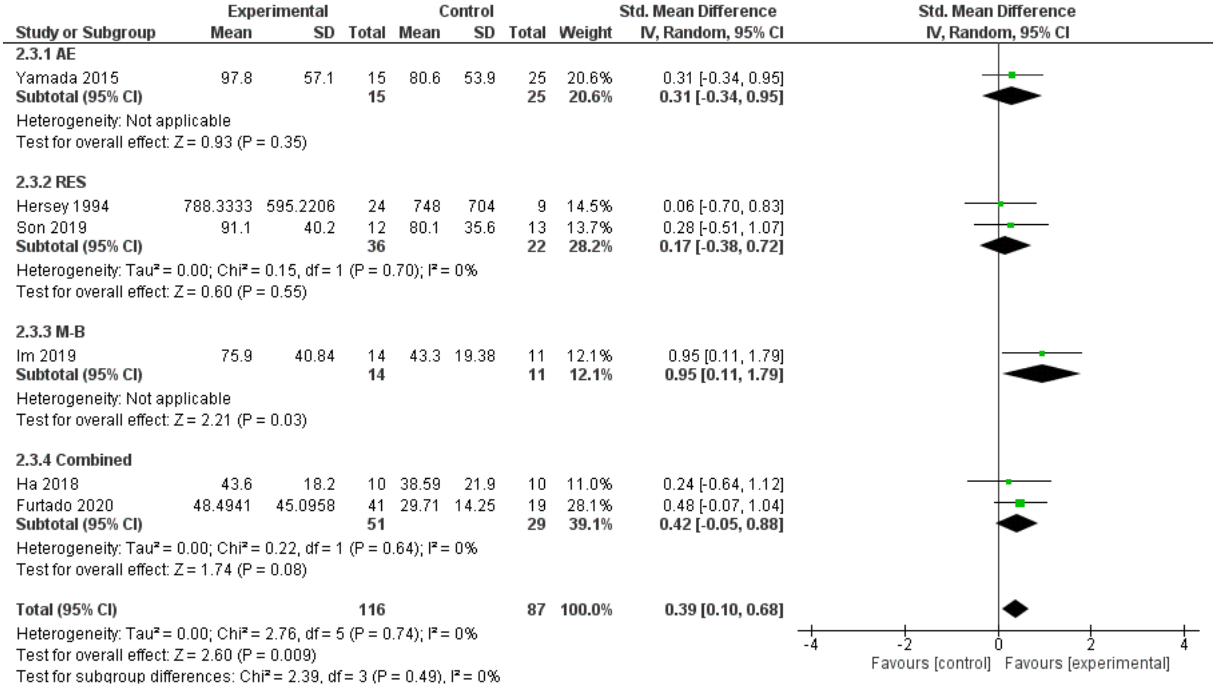

Figure 2.7 *Forest plot for DHEA(S), sub-grouped by intervention type.*

AE = aerobic exercise, RES = resistance training, M-B = mind-body exercise, Combined = intervention including aerobic and resistance training elements.

Table 2.3 *GRADE table.*

No of studies	Design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other	Certainty (overall score)[1]	Participants	Effect	
The average effect of PA intervention in older adults, compared to controls *Outcome: cortisol*								N (%male)	SMD [95% CI]	I^2
17	RCT	+	-	+	+	undetected	⊕⊕⊕◯	759 (23%)	-63 [-0.90, -0.36]	69%
Outcome: DHEA(S)										
6	RCT	+	+	+	-	undetected	⊕⊕⊕◯	203 (14%)	0.44 [0.20, 0.68]	0%

Evidence of the effect of regular PA compared to sedentary *Outcome: cortisol*									Effect direction	P-value (sign test)	
										M	F
5	Cross-sectional	+	+	+	-	undetected	⊕◯◯◯	333 (53%)	-	.0625	.3750
Outcome: DHEA(S)											
7	Cross-sectional	+	+	+	+	undetected	⊕⊕◯◯	545 (59%)	+	.0156	.4531

Note. SMD= Standardised Mean Difference, CI= Confidence Interval, I^2= I-square statistic, M= Male, F= Female

[1]4 ⊕⊕⊕⊕ High = This research provides a very good indication of the likely effect. The likelihood that the effect will be substantially different** is low.

3 ⊕⊕⊕◯ Moderate = This research provides a good indication of the likely effect. The likelihood that the effect will be substantially different** is moderate.

2⊕⊕◯◯ Low = This research provides some indication of the likely effect. However, the likelihood that it will be substantially different** is high.

1 ⊕○○○ Very low = This research does not provide a reliable indication of the likely effect. The likelihood that the effect will be substantially different** is very high.

** Substantially different = a large enough difference that it might affect a decision

Cross-sectional studies start out with ⊕⊕○○, conform to the GRADE guidelines.

Based on: Cochrane Consumers and Communication La Trobe University; Ryan, Rebecca; Hill, Sophie (2018): How to GRADE. La Trobe. Journal contribution.

2.4.8 Sub-grouping intervention studies

Cortisol. To further explore heterogeneity in the cortisol outcome, subgroup analyses were conducted by sex, intervention types, intensity, duration, and participants' health status showed no clinically important differences (Table 2.4). The table summarises the different PA interventions and their impacts on older adults across the included studies. It includes the type of intervention, intensity, duration, frequency, participants' health status, and the observed outcomes. It further details the PA intervention applied and the resulting health effects. An overview of the intervention specifics and adherence is shown for both outcomes combined in the TiDieR checklist (Appendix 2.8). Intervention intensity was rated as low-moderate intensity (20-75% VO_{2max}) or moderate-high intensity (>75% VO_{2max}) as stated by the American College of Sports Medicine (ASCM)) (American College of Sports Medicine, 2013). The forest plots of all relevant sub-groups can be found in Appendix 2.9.

Table 2.4 *Standardised Mean Differences (SMD) and 95% Confidence intervals (CI) of meta-analytic findings of the cortisol outcome subgroups*

	SMD [95% CI]	N studies	N participants
	Sex		
Males and females	-0.61, [-0.90, -0.33]	17	736
Females only	-0.52 [-0.79, -0.25]	8	290
	Intervention types		
Aerobic exercise	-0.54 [-1,05, -0.03]	6	319
Resistance training	-0.91 [-1.95, 0.14]	3	141
Combined protocol	-0.67 [-1.20, -0.14]	4	127
Mind-body exercise	-0.47 [-0.79, -0.14]	4	149
	Intervention intensity		
Low-moderate	-0.65 [-0.96, -0.33]	15	656
Moderate-high	-0.41 [-1.01, 0.20]	2	80
	Intervention duration		

12 weeks	-0.58 [-0.89, -0.27]	12	531
14-28 weeks	-0.67 [-1.32, -0.01]	5	205
	Health status		
Generally healthy participants	-0.59 [-1.02, -0.16]	9	385
Participants with mood disorders	-0.36 [-0.79, 0.06]	3	87
Participants with other health issues	-0.86 [-1.46, -0.26]	6	264

Note. SMD: Standardised Mean Difference, CI: Confidence interval.

Aerobic exercise: Activities that increase heart rate and improve cardiovascular health, such as walking, running, and cycling.

Resistance training: Exercises that improve muscle strength and endurance using weights, resistance bands, or body weight.

Combined protocol (aerobic and resistance): A regimen that includes both aerobic exercises to enhance cardiovascular health and resistance training to build muscle strength and endurance.

Mind-body exercise: Activities that combine physical movement with mental focus and breathing techniques, such as yoga, tai chi, and Pilates.

Low Intensity: Exercise that can be sustained for long periods without causing fatigue, such as slow walking or gentle yoga.

Moderate Intensity: Activities that cause a slight but noticeable increase in breathing and heart rate, allowing for conversation, such as brisk walking.

High intensity: Exercises that significantly elevate heart rate and breathing, making conversation difficult, such as running or vigorous cycling.

Generally healthy participants: Individuals without any significant health issues.

Participants with mood disorders: Individuals diagnosed with conditions such as depression, anxiety, or bipolar disorder.

Participants with other health issues: Individuals with chronic health conditions such as cardiovascular diseases, diabetes, osteoporosis, or other physical health challenges.

DHEA(S). Subgrouping of this outcome was explored narratively, as there was no heterogeneity in the pooled data. To sum up, there were no important differences detected between sub-groups. Of the six studies, interventions were as follows: aerobic training (n= 1), resistance training (n= 2), combined interventions (n= 2) and mind-body interventions (n= 1). Further, most studies were of low-moderate intensity (n= 4). Durations were 12 weeks (n= 3) or 24 and 28 weeks (n= 3). Four studies were conducted in generally healthy older adults, whereas one was in frail older adults.

2.5 Discussion

This review used a rigorous systematic approach to assess the impact of PA on cortisol and DHEA(S) levels in older adults. Findings from the narrative synthesis of observational studies suggested that there may be an association between regular PA in daily life and lower total cortisol output compared to being more sedentary. Further, DHEA(S) outcomes analyses showed that active older adults may have higher DHEA(S) levels than older adults who did not regularly engage in PA. As such, this cautiously confirms the hypothesis that there is low-quality evidence that regular PA in daily life is associated with a lower cortisol:DHEA(S) ratio. However, only one study directly looked at this ratio as an outcome. Results obtained by the meta-analysis of RCTs showed with moderate-quality evidence that PA interventions of 12 weeks or longer may reduce cortisol and increase DHEA(S) levels compared to control conditions in older adults (≥65 years).

2.5.1 Overall completeness and applicability of evidence

The aim of this review was twofold. First, to systematically review the existing literature on how PA influences physiological markers of cortisol and/or DHEA(S) in older adults, which is the first systematic review using rigorous methods. The second aim was to examine whether there was a difference in observational associations or experimental effects. These two aims were addressed by including nine cross-sectional studies to assess whether there is evidence to suggest that regular PA is associated with lower cortisol and/or higher DHEA(S) levels, and the 22 RCTs included in a meta-analysis to measure the average effect of physical exercise intervention on these outcomes. Using the GRADE approach, the overall certainty of evidence was deemed low to very low for observational studies (Schünemann et al., 2013). More studies with observational features and consistent methodologies could improve the precision and consistency across studies, which were the main concerns for both outcomes. In contrast, grading the intervention studies revealed moderate certainty of evidence.

There was substantial heterogeneity when combining the studies statistically for cortisol. However, after sensitivity analysis, three studies (Kim et al., 2018; Tada, 2018; Venturelli et al., 2016) were found to account for all heterogeneity. Removing these did not change the clinical importance of the prior intervention effects. Further, subgroups had too few participants to draw firm conclusions. Therefore, the findings regarding subgroup analyses should be considered tentative. More studies differentiating between intervention type, duration or intensity, or differentiating between health states, such as older adults with mood disorders or frail older adults, could possibly determine clinically important differences and increase the quality of evidence in the proposed subgroups.

It should also be noted that the included RCTs did not comment in detail on whether variation in response in the intervention groups might reflect a lack of physiological response to exercise among some participants instead of being attributable to intervention factors such as duration. Physiological exercise responses are driven by genetic differences, epigenetic changes, and gene transcription mechanisms (Hawley et al., 2014). Consequently, it would be essential to measure these factors alongside hormone levels in future exercise/PA interventions as they drive exercise effects on hormones via such mechanisms as changing receptor number or sensitivity (Hackney & Hackney, 2005).

Observational studies were all cross-sectional, primarily including generally healthy older adults in high-income countries, highlighting a clear research gap in population-based assessments, whether longitudinally or cross-sectionally, exploring associations between PA levels and cortisol and/or DHEA(S) levels in an older population with varying health status, in low to middle-income countries.

Included studies where cortisol was the outcome investigated generally healthy older adults (n = 8), those with mood disorders (n = 3), cognitive impairment (n = 3) or other (n = 3, cancer survivors, metabolic syndrome or frailty). This revealed that little research has been conducted on objective stress measures and their association with PA (≥12 weeks) in people with existing disease states. More specifically, no RCTs were identified for reducing cortisol through long-term resistance or aerobic training in older adults with mood disorders. This is important to note as chronic stress and inadequate cortisol regulation are key drivers of non-communicable diseases (Joseph & Golden, 2017; McEwen & Stellar, 1993) and is often seen in older populations experiencing depressive episodes (Murri et al., 2014). Included studies with DHEA(S) as the outcome also investigated generally healthy older adults (n = 5) or frail or pre-frail older adults (n = 1). Thus, quality research is lacking in measuring the effects of exercise interventions on DHEA(S) in people with specific disease states and/or frailty.

Contrary to expectations, the associations from observational studies between PA and decreased total cortisol output were small. This is in contrast with the present meta-analytic findings, which are in line with other reviews suggesting a regulatory role of PA on stress and cortisol levels (Anderson & Wideman, 2017; Corazza et al., 2013; Fragala et al., 2011; Sellami et al., 2019). Other PA intervention studies also report a cortisol-lowering response in generally healthy older adults (Chaturvedi et al., 2016; Ibáñez et al., 2008; Ponzio et al., 2015). However, other quality intervention studies found conflicting results, showing no effects or even higher cortisol levels after exercise interventions (Banitalebi et al., 2018; Borst et al., 2002; Häkkinen et al., 2000; Hayes et al., 2013; Izquierdo et al., 2001; Kraemer et al., 1999; Sillanpää et al., 2010). These studies generally used strength and resistance training protocols, which may acutely increase the activation of adrenal glands and stimulate cortisol production (Ahn & Kim, 2018). Nevertheless, no important differences in effect sizes were found in the present meta-analysis when exploring subgroup differences by intervention type (aerobic vs. resistance vs. combined vs. mind-body). Overall, more quality research is required to confidently understand the effect of different exercise types.

The findings of this review show low-quality evidence that regular PA at older age is associated with increased DHEA(S) levels. There is indeed consensus that DHEA(S) decreases with age for both active and sedentary people (Heaney et al., 2014; Orentreich et al., 1992) and that regular moderate PA is associated with higher levels of DHEA(S) in older adults (Abbasi et al., 1998; Aldred et al., 2009; Bonnefoy et al., 1998; Ravaglia et al., 2001; Tissandier et al., 2001). In addition, the present meta-analytic findings showed that exercise interventions of at least 12 weeks probably improve DHEA(S) levels slightly compared to no intervention in older adults. Similar results (Sato et al., 2014) and no changes (Häkkinen et al., 2000; Häkkinen et al., 2002) were found in non-controlled resistance training interventions of at least 12 weeks. Further, DHEA can be maintained at a high level by long-term training in older adults (de Gonzalo-Calvo et al., 2012).

2.5.2 Sex

Observational studies included 38% women (out of 729 participants), whereas interventional studies included 79% women (out of 1314 participants). As eight studies included females only, findings were meta-analysed, evidencing exercise interventions may reduce cortisol levels slightly in older females compared to controls. Laughlin & Barret-Connor (2000) found, however, that the cortisol:DHEA(S) ratio increased in ageing for both sexes, levels of DHEA(S) remained lower, and cortisol and the cortisol:DHEA(S) ratio was higher in women than in men throughout the 50-89 years of age range (Laughlin & Barrett-Connor, 2000). These results are in line with a cross-sectional study in a group of healthy older Tunisians investigating the sex-specific age-related alterations in cortisol and DHEAS, stating that the cortisol:DHEAS ratio increases with age, with larger increases in women (Chehab et al., 2007). This echoes the findings of studies on sex effects in ageing on cortisol (Zhao et al., 2003) and DHEA(S) (Berr et al., 1996; Mazat et al., 2001; Zumoff et al., 1995).

2.5.3 Exercise intensity, type, duration and adherence

Exercise can act as a stimulus to the HPA axis, increasing cortisol levels. This is due to the intensity and duration of exercise (McMurray & Hackney, 2000). Essentially, physical exercise programmes seek to produce favourable physiological adaptation effects, contributing to improved regulatory capacity, increased receptor number in the target tissue, and improved receptor sensitivity (Hackney & Hackney, 2005). More research is needed to elucidate how different exercises impact the endocrine regulatory axes. For this reason, an important research question of this systematic review was to differentiate between different exercise intensities, types and duration. PA (incorporating planned exercise) may contribute to influencing hormonal profiles in the longer term. Therefore, this review included PA interventions and observational data. To this end, no important subgroup differences were found between intensity types. However, there is an overarching consensus that the HPA axis is most impacted when training intensity exceeds 60% of VO2max (Caiozzo et al., 1982; Hill et al., 2008). This is evidenced by studies pointing out that this intensity increases the rate of glandular secretions, and cortisol elevations are not due to decreases in metabolic clearance rate (Hill et al., 2008; VanBruggen et al., 2011). Other factors that are also shown to influence hormonal release with exercise are aerobiosis, strength modalities, timing of the day, meal ingestion and participant characteristics (such as previous training and sex) (Hackney & Viru, 1999; Hackney, 2006; Leal-Cerro et al., 2003; Luger et al., 1987; Strüder et al., 1998; Traustadóttir et al., 2003). However, not all older adults can exercise at this intensity. However, they would still see some physical and mental health benefits from an active lifestyle (Bull et al., 2020) and possible longer-term benefits on endocrine function. Hence, this review also incorporated PA interventions and observational data.

The included RCTs overall reported good adherence rates, and there was no detected difference in adherence between exercise types or intensities (Appendix 2.9). It is important to note that in one study, although physical well-being was maintained after the completion of the programme, the therapeutic effects on depression were not sustained in the follow-up period (Tsang et al., 2013). This highlights the need for long-term adherence to an exercise programme. An exercise duration of 12 weeks could be long enough for participants to form a sustained habit change (Lally et al., 2010). This is important, as the largest body of evidence indicates that sustained regular exercise is needed to maintain any gained health benefits (Garber et al., 2011). In addition, literature suggests that the affective response to exercise is also essential (Wegner et al., 2020). This is clinically important if we want people to engage and maintain regular exercise for both their mental and physical health.

Further, most exercise adherence is seen near the ventilation threshold (65% VO2max) (Ekkekakis et al., 2011). However, studies highlight that pleasure and adherence are highest when the intensity (including during HIT) is self-selected rather than imposed (Ekkekakis et al., 2011; Parfitt et al., 2006). To sum up, it seems important for people to choose the exercise programme they enjoy most, in whichever modality or intensity they will adhere to, to optimise endocrinological responses and healthy ageing.

Subgrouping for duration revealed no important effectiveness differences, suggesting an exercise intervention of 12 weeks yields the same effects as longer interventions (14-28 weeks). This could help guide researchers when deciding on the duration of future exercise interventions (for time/cost efficacy). In clinical practice, however, it should be noted that it is uncertain whether the beneficial effects of interventions are maintained for extended periods (only one study measured this (Tsang et al., 2003)). This is similar to the consensus that PA of any kind needs to be maintained to sustain health benefits.

2.5.4 Health status

When subgrouping by health status for the cortisol outcome, the meta-analysis showed that exercise interventions may decrease cortisol levels slightly compared to controls in different disease states. This is consistent with findings of other intervention studies showing somewhat reduced cortisol in adults with different health conditions, such as breast cancer patients (Ho et al., 2016) or females with Multiple Sclerosis (Najafi & Moghadasi, 2017). However, other research groups found no change in cortisol after exercise in older adults with rheumatoid arthritis (Häkkinen et al., 2005) or fibromyalgia (Valkeinen et al., 2005).

For DHEA(S), only one study was conducted in frail older adults. This RCT found an increase in DHEA(S) levels after a multimodal chair-based programme (Furtado et al., 2020), agreeing with a prior intervention study in older adults (Heaney et al., 2013). Furtado et al. further highlight the importance of maintaining exercise to keep DHEA levels elevated into older age, as suggested by an earlier review about chronic exercise in older adults (Corazza et al., 2013).

2.5.5 Cortisol and DHEA(S) sampling

Most studies (n= 16) measured cortisol in saliva, while others (n= 6) measured serum cortisol. Cortisol salivary measures are accurate, non-invasive and rapidly sampled tests to measure the response to physical stress, making it increasingly used in research (Gatti & De Palo, 2011). Further, research seems to favour saliva measures over serum measures for the clinical assessment of adrenocortical function (Aardal-Eriksson et al., 1998; Gozansky et al., 2005; Vining et al., 1983). In contrast, more DHEA(S) samples were taken from blood (n= 10) vs. saliva (n= 3). However, salivary DHEA has the same feasibility advantages as salivary cortisol and DHEA(S) concentrations in saliva are highly correlated with serum concentrations (Ahn et al., 2007; Whetzel & Klein, 2010).

2.5.6 Number of samples for accurate measurement

Most of the studies included took cortisol and DHEA(S) samples at one point, mainly in the morning. Where samples were taken on multiple days (e.g., pre-and post-tests), measurements were taken at the same time on different days to decrease within the subject's diurnal variations. Indeed, the diurnal secretory activity is often reliably determined by a single sample in the morning to assess within-subject variations over a certain period in an older population (Kraemer et al., 2006). However, this has limited prognostic value due to intra-individual differences (Coste et al., 1994; Pruessner et al., 1997). This, together with the known diurnal rhythmicity of these hormones (Adam & Kumari, 2009; Stalder et al., 2016), the flattening of the diurnal profile with ageing (Deuschle et al., 1997; Van Cauter et al., 1996) and an increased day-to-day variation in older adults (Ice et al., 2004), means that there is a need for protocols with multiple measurements targeting the overall diurnal pattern (Segerstrom et al., 2014). This further highlights a need for measurement consistency in research to compare different study findings (Dickerson & Kemeny, 2004; Ryan et al., 2016). An accepted sampling design for cortisol involves, e.g. measurements immediately after awakening, 30 minutes post-awakening, noon, late afternoon, and immediately before bed (Hellhammer et al., 2007). This is similar to the measurement methods of the identified cross-sectional studies (Heaney et al., 2014; Lucertini et al., 2015; Pauly et al., 2019) and RCTs (Ho et al., 2020; Lu et al., 2020; Venturelli et al., 2016). Further guidance for conducting field research on cortisol is given in another article (Saxbe, 2008). For an overview of the definitions of different cortisol indices, read the review of Khoury et al. (Khoury et al., 2015).

2.5.7 Strengths and limitations

This systematic review used rigorous methods throughout the process to prevent possible bias by carefully following several established guidelines on systematic reviewing, both for narrative and meta-analyses (see Methods). Further, the selection of studies, critical appraisal and data extraction were conducted by two independent researchers (LDN and EO), while the data analysis and interpretation were carefully followed by the whole research team (AW, GR, JC). Further, relevant findings were compared with previous findings in an objective way by considering the “five C’s” (Cite, Compare, Contrast, Critique and Connect) (Kennedy, 2016) of the most prominent trials revealed during the review process.

Several limitations are considered in the conduct of this review process. First, although the sign test is a valuable tool for interpreting the overall pattern of effect direction, it raises several issues, as acknowledged by the authors who updated the effect direction plot for better research guidance (Boon & Thomson, 2021). Thus, the power of the sign test used in the narrative analysis of observational studies is limited due to the small number of included studies. Also, there are well-recognised caveats about the limitation of p-values and significance testing in judging associations (Sterne & Smith, 2001; Wasserstein et al., 2019) and with vote counting. Therefore, claims made regarding the effectiveness of regular PA in the cross-sectional studies were modest. Second, substantial heterogeneity in the cortisol outcome complicates a meaningful summary. However, combining studies was deemed appropriate, and the heterogeneity was properly explored by conducting *a priori*-defined subgroup analysis and explained after sensitivity analysis. Third, established pitfalls regarding claims of subgrouping were considered (Burke et al., 2015). Therefore, subgroupings were performed to allow for better interpretation rather than to let the conclusions of the discussed subgroup influence clinical guidance.

2.5.8 Implications for practice

The general picture emerging from the analysis is that regular PA in older adults is associated with improved cortisol and/or DHEA(S) levels. Physical exercise interventions of at least 12 weeks of any modality can beneficially improve these levels. The low to moderate certainty of this effect does not extend to different subgroups of health status or low-income countries. Considering the present findings in the light of previous literature about adherence to PA and habit formation, it is recommended that practitioners advise older adults to choose any activity they enjoy doing, will do regularly, and maintain over a long period.

2.5.9 Implications for research

Further research is required to assess the associations between regular PA and hormonal balances, including data from low-to-middle-income countries varying in socio-economic status and ethnicity, in line with a recent review (Daskalopoulou et al., 2017). As feasibility and safety are established in older adults for all discussed exercise modalities and health states, studies should continue to explore exercise intervention effects on cortisol and/or DHEA(S), and the ratio in older adults, differentiating between different health states (e.g., metabolic syndrome, different mood states, cognitive decline, frailty) or different exercise modalities (types or intensities) in well-controlled clinical trials. With this, a systematic review could be repeated to increase the precision of understanding of intervention effects in different health states for different exercise modalities.

Saliva samples are accurate, non-invasive and rapidly taken, so future studies could use this measurement approach. Further, multiple measurements to make assumptions about the diurnal slope of cortisol are best practice. However, the number of sampling times is clearly a cost/accuracy trade-off. These measures should be complemented with a more comprehensive assessment of the quality of life outcomes (e.g., questionnaires about well-being, anxiety, stress perception, and feelings of loneliness), as this will provide more in-depth insights on different variables contributing to how PA and hormonal parameters influence the general health of older adults. These recommendations are based on the literature base found through systematic review processes until September 2021.

2.6 Conclusion

This systematic review suggests that engagement in regular PA beneficially impacts cortisol and DHEA(S) levels. The evidence fell into two categories: First, a narrative synthesis of nine cross-sectional studies in older adults showed small associations between regular PA in daily life and lower total cortisol output. However, there was low-quality evidence that being physically active in daily life at older age is associated with increased DHEA(S) levels. Second, a meta-analysis of 17 RCTs showed that exercise interventions probably reduce cortisol levels compared to no intervention. In addition, meta-analytic findings of six RCTs showed that exercise training of at least 12 weeks probably improves DHEA(S) levels slightly compared to no intervention in older adults.

Chapter 3: Systematic review Two: PA influences cortisol and sleep in adults.

This chapter expands the investigation of PA's effects on healthy ageing to include sleep quality, another vital component of health and well-being. It presents a systematic review exploring the interactions among PA, cortisol levels, and sleep patterns in adults and older adults. This is based on the peer-reviewed systematic review and meta-analysis published as "The effects of PA on cortisol and sleep: A systematic review and meta-analysis" in *Psychoneuroendocrinology*, Volume 143, 105843 (De Nys et al., 2022).

3.1 Introduction

Regular PA, managing stress and having good quality sleep significantly contribute to healthy ageing (World Health Organization, 2015). Recent studies have shown that physical exercise can positively impact physical and mental health (Penedo & Dahn, 2005). Further, it moderates stress systems (Anderson & Wideman, 2017; Duclos & Tabarin, 2016; Fragala et al., 2011) and positively affects sleep quantity and quality (Kredlow et al., 2015; Uchida et al., 2012; Vanderlinden et al., 2020; Wang & Boros, 2019). Despite this, remarkably few studies have examined physical exercise's combined effect on stress and sleep.

Cortisol is an adrenal hormone released in response to stress (Ockenfels et al., 1995). It displays strong circadian rhythmicity, with high levels in the morning and a steady decline towards the evening (Adam & Kumari, 2009; Stalder et al., 2016). This diurnal fluctuation indicates hypothalamic-pituitary-adrenal (HPA) axis reactivity (Smyth et al., 1997). A favourable cortisol profile is characterised by a brief peek in the morning in the first 30-45 minutes after awakening (known as the CAR). A gradual decline follows this peak during the waking day to reach a low point around midnight (Kirschbaum & Hellhammer, 1989; Pruessner et al., 1997). Studies show that a daily cortisol curve with a typically sharp decline is associated with better physical and psychosocial health (Adam et al., 2006; Adam & Kumari, 2009). However, an accepted sampling design for cortisol involves, e.g. measurements immediately after awakening, 30 minutes post-awakening, at noon, in the late afternoon, and immediately before bed (Hellhammer et al., 2007). The known diurnal rhythmicity of cortisol (Adam & Kumari, 2009; Stalder et al., 2016), the significant intra-individual differences (Coste et al., 1994; Pruessner et al., 1997) and the significant variability between people in the shape of their diurnal cortisol rhythms (Adam et al., 2006; Smyth et al., 1997) highlight a need for measurement consistency in research in order to compare different study findings (Dickerson & Kemeny, 2004; Ryan et al., 2016). Cortisol is often used as a biomarker to indicate dysregulation of the HPA axis, triggering subsequent poor sleep and fatigue (Bower et al., 2005; Buckley & Schatzberg, 2005b), further promoting negative health states such as depression (Juster et al., 2010; Lupien et al., 2007), cancer recurrence (Sephton et al., 2013; Sephton et al., 2000), and is associated with all-cause and cardiovascular mortality (Kumari et al., 2011; Phillips et al., 2010).

Further, while sleep is necessary for human health (Grandner, 2017), sleep problems are prevalent globally (Léger et al., 2008). Sleep problems are associated with poorer quality of life and several comorbidities, such as cardiovascular problems, cancer, mental and physical health issues, and contribute to all-cause mortality (Irwin, 2015; Kripke et al., 2002; Mallon et al., 2002; Simon & VonKorff, 1997). This evidence highlights the importance of understanding how cortisol levels and sleep can be improved.

Numerous studies have investigated the reciprocal interactions between the HPA axis and sleep regulation (for a review, see e.g. (Nollet et al., 2020; Steiger, 2002)). First, the HPA axis is implicated in sleep regulation and sleep/wake cycles (Buckley & Schatzberg, 2005b; Ono & Yamanaka, 2017; Pawlyk et al., 2008). Second, sleep hygiene and circadian rhythmicity are proven to impact cortisol profiles through a decreased efficacy of the negative feedback regulation of the HPA axis (Spiegel et al., 1999). Sleep disruption increases stress by triggering the HPA axis and dysregulating the production of one of the main adrenal stress hormones, cortisol (Kim et al., 2015; Wright et al., 2015). In turn, stress increases sleep disruption. As both lead to downstream effects on health (Ono & Yamanaka, 2017), an integrative approach to understanding how these factors interact with each other deserves research attention.

In summary, there is established health importance of, and a bidirectional relationship between, cortisol and sleep. Both are moderated by physical exercise. However, few attempts have been made to summarise these data systematically. Consequently, this systematic review aimed to assess the effects of physical exercise on the physiological stress marker cortisol and sleep, either subjectively or by examining physiological sleep architecture. It further sought to examine whether there was a difference in participant characteristics (such as in different age groups, sex or health status) or intervention characteristics (type or duration of PA), and whether there was a relationship between cortisol markers and sleep outcome changes.

3.2 Methods

3.2.1 Protocol

This systematic review was conducted and analysed based on the PRISMA guidelines (Page et al., 2021). The systematic review protocol was registered in PROSPERO (https://www.crd.york.ac.uk/PROSPERO/display_record.php?RecordID=272251), registration number CRD42021272251.

3.2.2 Eligibility criteria

Original, peer-reviewed articles in the English language of intervention studies, such as randomised controlled trials (RCTs) and non-RCTs with relevant control groups, were eligible for inclusion. No date limits were chosen. The Population, Intervention, Comparison and Outcome (PICO) characteristics (Richardson et al., 1995) for eligibility were: (1) adults and older adults, regardless of their health condition (having a sleep complaint was not required); (2) physical exercise intervention programmes or movement-based mind-body approaches of any duration; (3) controls receiving no intervention (e.g., wait-list or usual care), or controls included in a different programme and; (4) physiological measure of stress (cortisol in saliva, blood, hair or urine samples) and measurements of sleep, either subjective (questionnaires such as Pittsburgh Sleep Quality Index) or objective (architecture of sleep such as polysomnography, actigraphy, and accelerometery). No filters in search databases were used. Studies were ineligible if outcomes of interest were not measured or because the results for the outcome of interest were not reported.

3.2.3 Information sources and search strategy

Searches were run in August 2021 and re-run before the final analyses in October 2021. The following electronic bibliographic databases were searched: PubMed, the Cochrane Library (the Cochrane Central Register of Controlled Trials (CENTRAL)), PsycINFO, OvidSP, CINAHL and Web of Science (no data limits were chosen). Grey literature searches were conducted by searching online databases (ClinicalTrials.gov) and using the Google Scholar search engine according to the recommendations of Haddaway (Haddaway et al., 2015). Reference lists of key papers were searched and cross-references manually to supplement initial keyword searches. Appendix 3.1 shows the exact search strategy used with suitable search terms for each database.

3.2.4 Selection process

Search results were collected using Sciwheel software (sciwheel.com). Two reviewers independently screened each title and abstract for eligibility using Rayyan software (rayyan.qcri.org) (Ouzzani et al., 2016). Any study identified by either reviewer was included for further screening. The same two reviewers performed full-text screening of selected records, and any disagreements were resolved by discussion and consensus. A third reviewer was available when no consensus was reached.

3.2.5 Data collection process

One reviewer (LDN) collected data from each selected record, carefully checked by the second reviewer (KA). Disagreements were resolved by discussion between the two reviewers, with a third reviewer overviewing the process. Study investigators were contacted to obtain missing information (n= 6). Data extraction from figures or graphs was conducted with WebPlotDigitizer (Rohatgi, 2021). When multiple records corresponded to a single study, the record most relevant to the review question was used to extract data of interest.

3.2.6 Data items

Data extraction was performed using Excel, collecting the following data items: (1) study ID, (2) design, (3) PICO characteristics, including different age groups (adults aged 26-47 years, middle-aged adults aged 48-64 years, and older adults aged 65 years or over), different exercise interventions using Frequency, Intensity, Time, Type and Duration (FITT-D) components, cortisol measurements (saliva/blood/other), and subjective (Pittsburgh Sleep Quality Index (PSQI)/other), or objective (polysomnography/other) sleep measurement, (4) general findings and (5) statistics relevant to the research question. Where multiple subjective sleep measurements were reported, we selected one outcome (PSQI) for inclusion in the meta-analysis and for reporting main outcomes, as this questionnaire was most frequently used.

3.2.7 Study risk of bias assessment

To ascertain the validity of eligible studies, the two reviewers independently assessed the risk of bias to determine the adequacy of randomisation, concealment of allocation, blinding of participants, personnel or data collectors, reliability and completeness of outcome data or selective reporting and an overall summary 'Risk of Bias' (RoB) judgement (low, some concerns, high), where the overall RoB for each study was determined by the highest

RoB level in any of the domains that were assessed for both outcomes. The Cochrane Risk of Bias (RoB) 2.0 tool (Higgins et al., 2011) was used to assess RCTs. There were no non-RCTs retrieved in the review process, so no bias assessment for non-RCTs was performed.

3.2.8 Effect measures

Continuous measures were displayed for each outcome using mean differences (MD) and 95% confidence intervals (CI) for studies using the same scale, and standardised mean differences (SMD) and 95% CI were used to compare the same outcomes measured in different ways.

3.2.9 Synthesis methods

No non-RCT studies with relevant control groups were retrieved, so only RCTs were synthesised. Study characteristics were tabulated and sorted by outcome for consistency. The risk of bias in included studies was visualised with the 'robvis' software (McGuinness & Higgins, 2021). Included study data were found to be similar enough in terms of methodological and clinical characteristics to ensure meaningful conclusions from a statistically pooled result, so meta-analyses were performed for both the cortisol and sleep outcomes. Assuming a true effect was not the same in all studies and that studies were performed in different populations, random-effects models to analyse data were performed. The data were based on mean, standard deviation (SD) and the number of participants assessed for both the intervention and comparison groups. They were used to calculate the SMDs and 95% in Review Manager 5 (The Cochrane Collaboration, 2020). Forest plots visualised these, and any data conversions or transformations of the reported data can be found in Appendix 3.2. The degree of heterogeneity was assessed through Chi-squared (Chi^2) statistics and was quantified and interpreted using the I-squared (I^2) statistic. To explore heterogeneity and in convergence with the research question, sub-group analyses were conducted to differentiate between age groups, sex and health status if there were enough studies identified to make relevant comparisons. RCTs not included in the meta-analysis were synthesised narratively. If sufficient studies showed a correlation between cortisol and sleep measures, effect sizes based on correlation were measured for these studies (as predefined in the protocol,
https://www.crd.york.ac.uk/PROSPERO/display_record.php?RecordID=272251).

A sensitivity analysis was conducted by making a chart with the characteristics of the retrieved trials that were relevant to the review question but did not have a control group in their design (non-RCTs) and by comparing them narratively with the results of the primary analysis. Second, an effect direction plot was performed with the retrieved RCTs and non-RCTs that reported the sleep outcomes in multiple ways based on existing guidance (Boon & Thomson, 2021). Third, intervention effects of RCTs in the meta-analysis were sub-grouped by relevant control groups (active control, usual care or waiting list) for both cortisol and sleep outcomes.

3.2.10 Reporting bias assessment

A funnel plot (Egger's test) (Egger et al., 1997) was assessed to evaluate small-study effects, together with visual inspection for asymmetry (Appendix 3.3). If asymmetry was detected, trial characteristics, protocols (if available), or methods and results sections of the trial publications would be reviewed to assess whether the asymmetry was due to publication bias or other factors, such as methodological or clinical heterogeneity of the trials. The potential impact of missing results was explored in the sensitivity analyses.

3.2.11 Certainty assessment

The certainty of all evidence was assessed as high, moderate, low, or very low, using the GRADE approach (Guyatt et al., 2008) for the cortisol and sleep outcomes. A starting rating of 'High quality' evidence was downgraded by one level if serious concerns (or by two levels for very serious concerns) became apparent regarding risk of bias, inconsistency, indirectness, imprecision, or publication bias. GRADE wording was used to incorporate certainty of evidence (Guyatt et al., 2011). The standardised statements to describe results are based on existing consensus (Glenton et al., 2010).

3.3 Results

3.3.1 Study selection

A total of 4143 records were retrieved through database searches. After duplicate removal, 3412 records remained, from which 103 were retrieved for full-text screening. Finally, 12 reports of 10 original studies were included (Figure 3.1) (Al-Sharman et al., 2019; Arikawa et al., 2013; Banasik et al., 2011; Bowden et al., 2012; Chandwani et al., 2010; Chen et al., 2013; Hilcove et al., 2021; Ho et al., 2016; Ho et al., 2018; Imboden et al., 2021; Payne et al., 2008; Ratcliff et al., 2016). Reports were mainly excluded due to wrong PICO characteristics, e.g., (1) participants were children, adolescents, or young adults (18-25 years old), (2) interventions were exercises which were not movement-based (mindfulness or meditation only) (3) outcome measures were stress and sleep, but the stress component was not measured through cortisol samples. A table with characteristics of studies that were excluded after full-text screening (de Bruin et al., 2017; Fouladbakhsh et al., 2014; Garrido et al., 2017; Grahn Kronhed et al., 2020; Leone et al., 2018; Passos et al., 2014; Reid et al., 2010; Vera et al., 2009; Zaccari et al., 2020), with reasons for exclusion, is in Appendix 3.4.

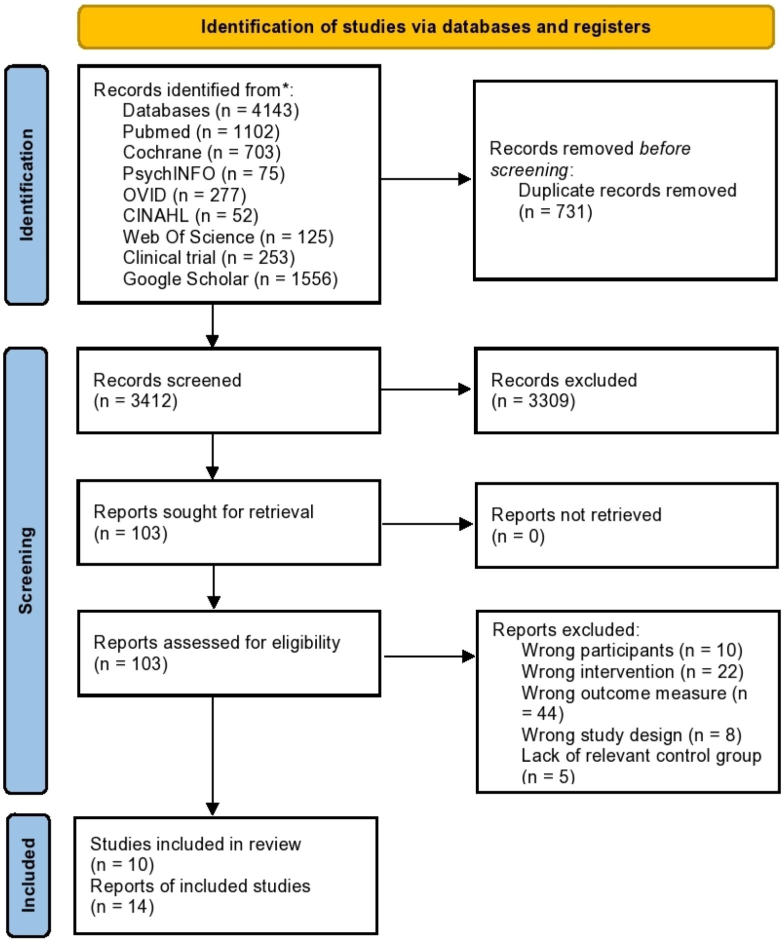

Figure 3.1 *PRISMA flow diagram of the systematic review.*

3.3.2 Study characteristics

All included studies were RCTs (n= 10), of which one was an RCT comparing three different interventions. Key characteristics of each study are presented in Table 3.1, and a chart summary was made to summarise all study characteristics (Figure 3.2).

Table 3.1 *Characteristics of included randomised controlled trials.*

Study	Country	Population			Intervention					Outcome		Relevant findings
		Sample size n (%male)	Age group[a]	Health status	Frequency	Intensity – type	Time	Duration	Comparison	Cortisol (times - measure)	Sleep measurement	
Payne et al., 2008	South-eastern United States	20 (0%)	Middle-aged adults	Breast cancer	4x/week	Moderate - Aerobic, walking activity	20 min	14 weeks	Usual care	Blood sample (1x)	PSQI, PRFS	Training group = improved PSQI scores*
Banasik et al., 2010	Washington, United States	18 (0%)	Middle-aged adults	Breast cancer	2x/week	Mind-body, yoga	90 min	Eight weeks	Waitlist control	Saliva sample (4x – diurnal slope)	Fatigue Likert scale	Yoga group = lower cortisol at 5 p.m. and less fatigue

Study	Country	Population			Intervention					Outcome		Relevant findings
		Sample size n (%male)	Age group[a]	Health status	Frequency	Intensity – type	Time	Duration	Comparison	Cortisol (times - measure)	Sleep measurement	
Bowden et al., 2012	London, United Kingdom	45 (27%)	Adults and middle-aged adults	Generally healthy	2x/week	Mind-body, yoga	75 min	Five weeks	Brain wave stimulation and mindfulness	Saliva sample (1x)	PSQI	All groups = improved sleep*
Arikawa et al., 2013	Boston, United States	141 (0%)	Adults	Breast cancer	Depends	Moderate to vigorous - Aerobic, weight-bearing exercise	150 minutes total each week	16 weeks	No exercise	Blood sample (1x – morning)	PSQI	No differences between groups in cortisol or sleep outcomes

Study	Country	Population			Intervention					Outcome		Relevant findings
		Sample size n (%male)	Age group[a]	Health status	Frequency	Intensity – type	Time	Duration	Comparison	Cortisol (times - measure)	Sleep measurement	
Chen et al., 2013	Shanghai, China	96 (0%)	Adults and middle-aged adults	Breast cancer	5x/week	Mind-body, Qigong	30-40 min	Six weeks	Waitlist control	Saliva sample (4x – diurnal slope)	PSQI, BFI	Yoga group = less fatigue*
Ratcliff et al., 2016	Texas, United States	163 (0%)	Middle-aged adults	Breast cancer	3x/week	Mind-body, yoga	60 min	Six weeks	Stretch and waitlist	Saliva sample (5x – diurnal slope)	PSQI	Yoga = reduced fatigue*, and steeper cortisol slope. No change in PSQI.

Study	Country	Population			Intervention					Outcome		Relevant findings
		Sample size n (%male)	Age group[a]	Health status	Frequency	Intensity – type	Time	Duration	Comparison	Cortisol (times - measure)	Sleep measurement	
Ho et al., 2016	Hong Kong	121 (0%)	Middle-aged adults	Breast cancer	2x/week	Dance movement therapy	90 min	Three weeks	Standard care	Saliva sample (5x – diurnal slope)	PSQI, BFI	Dance therapy = beneficial effect on cortisol slope
Al-Sharman et al., 2019	Jordan	30 (23%)	Adults	Multiple Sclerosis	3x/week	Moderate - Aerobic, recumbent stepping machine	40 min	Six weeks	Home-exercises	Blood sample (1x – morning)	PSQI, ISI, actigraphy	Exercise group = improvements in PSQI*
Hilcove et al., 2020	South-western United States	80 (5%)	Adults	Generally healthy	Depends	Mind-body, mindfulness-based yoga	120 min over one week period	Six weeks	No exercise	Saliva sample (3x - diurnal slope)	Item from PSQI	Exercise group = improved sleep*

Study	Country	Population			Intervention					Outcome		Relevant findings
		Sample size n (%male)	Age group[a]	Health status	Frequency	Intensity – type	Time	Duration	Comparison	Cortisol (times - measure)	Sleep measurement	
Imboden et al., 2021	Switzerland	42 (50%)	Adults	Mood disorders	3x/week	Aerobic, indoor bicycle	40-50 min	Six weeks	Active controls	Saliva sample (4x – morning CAR	PSQI, polysomnography	Both groups = lower cortisol and improved PSQI

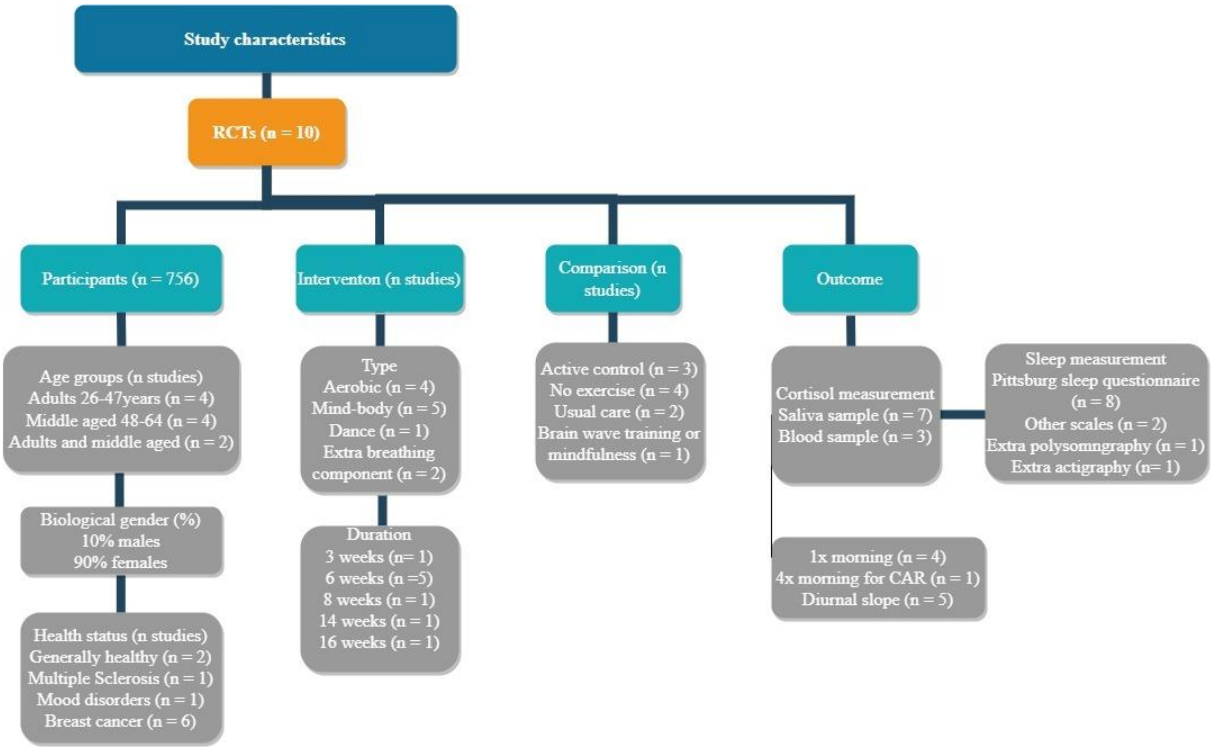

Figure 3.2 *Study characteristics of the included Randomised Controlled Trials (RCTs).*

3.3.3 Risk of bias in studies

Some concerns regarding the overall risk of bias arose in six of the ten studies due to domain four, ‘Bias due to outcome measurement’ (Figure 3.3). Subjective questionnaires may be subject to recall or performance bias. However, all included questionnaires were valid and reliable as standardised (*a priori*-defined) sleep measurement tools.

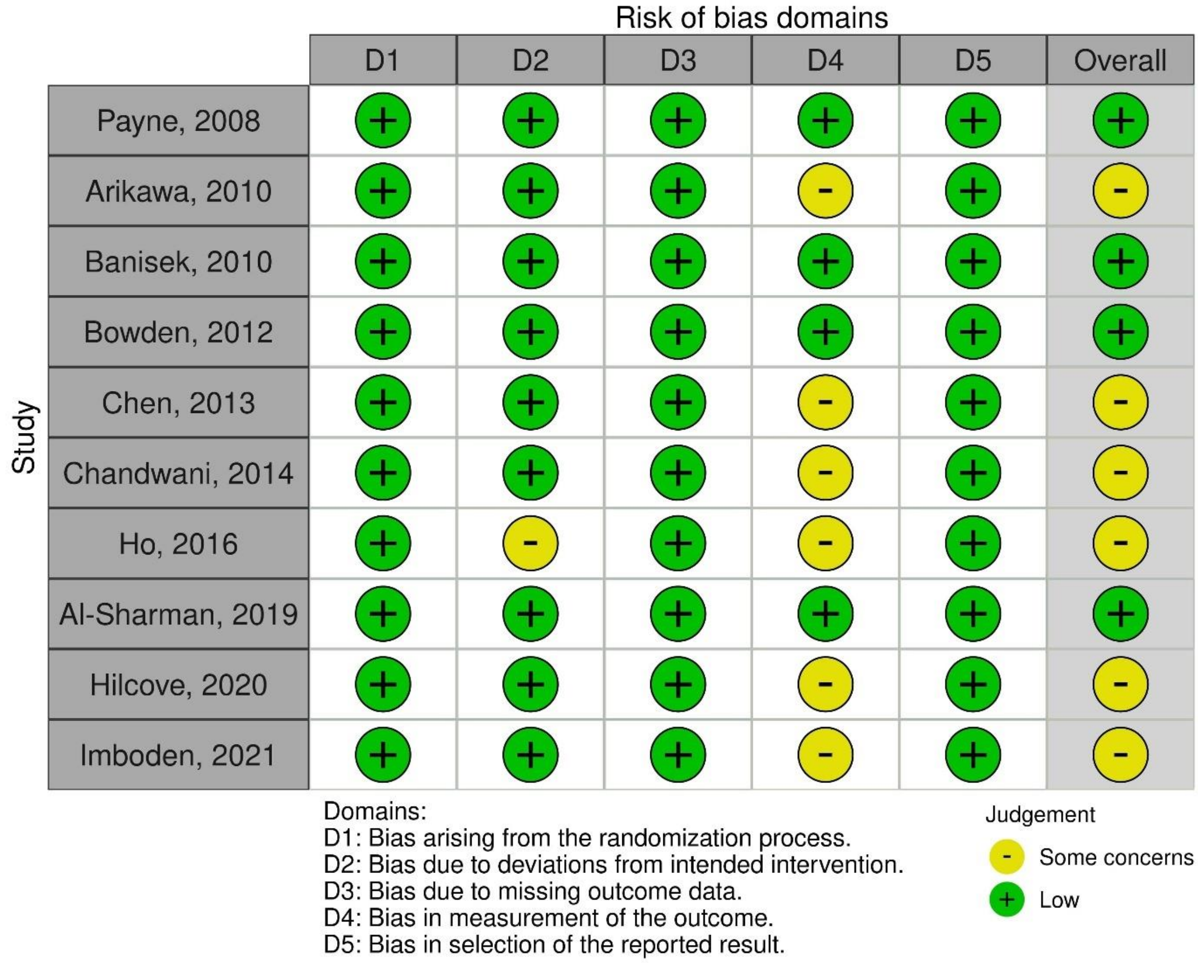

Figure 3.3 *Traffic light plot of the risk of bias assessment of the included studies.*

3.3.4 Results of individual studies

Each study's summary statistics, effect estimate, and precision are presented in a forest plot (Figures 3.4 and 3.5). For the articles by Payne and Arikawa (Arikawa et al., 2013; Payne et al., 2008), the mean SDs had to be computed or estimated from other information (Appendix 3.2)

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Arikawa 2013a	56	5	77	59	5	64	21.0%	-0.60 [-0.94, -0.26]
Banasik 2010	2.33	0.09	7	2.45	0.29	7	2.1%	-0.52 [-1.60, 0.55]
Ratcliff 2016	-0.1	0.04	53	-0.08	0.05	54	16.4%	-0.44 [-0.82, -0.05]
Hilcove 2020	-0.01	1.31	41	0.49	1.69	39	12.4%	-0.33 [-0.77, 0.11]
Ho 2018	-6.9	2	63	-6.33	1.89	58	18.8%	-0.29 [-0.65, 0.07]
Imboden 2021	264.4	195.2	22	314.2	168.9	20	6.5%	-0.27 [-0.88, 0.34]
Chen 2013	-0.12	0.04	49	-0.11	0.05	47	15.0%	-0.22 [-0.62, 0.18]
Payne 2008	8	6.02	10	9	6.02	10	3.1%	-0.16 [-1.04, 0.72]
Al-Sharman 2019	10.4	4.5	17	11.01	3.58	13	4.6%	-0.14 [-0.87, 0.58]
Total (95% CI)			**339**			**312**	**100.0%**	**-0.37 [-0.52, -0.21]**

Heterogeneity: Tau² = 0.00; Chi² = 3.38, df = 8 (P = 0.91); I² = 0%
Test for overall effect: Z = 4.61 (P < 0.00001)

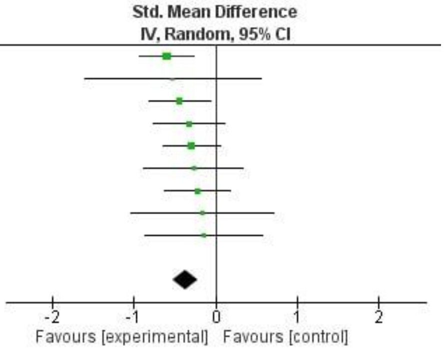

Figure 3.4 *Forest plot for the cortisol outcome*

Note. Experimental: physical exercise intervention programmes or movement-based mind-body approaches of any duration. Control: controls receiving no intervention (e.g., wait-list or usual care), or controls included in a different programme.

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Payne 2008	-3.5	3.62	10	2.2	3.62	10	4.9%	-1.51 [-2.53, -0.49]
Al-Sharman 2019	4.6	2.3	17	7.1	3.2	13	7.5%	-0.89 [-1.66, -0.13]
Hilcove 2020	0.85	0.59	41	1.24	0.64	39	13.0%	-0.63 [-1.08, -0.18]
Banasik 2010	1	0.89	7	1.57	0.98	7	4.5%	-0.57 [-1.65, 0.51]
Imboden 2021	7.2	2.9	22	8.5	4.4	20	9.7%	-0.35 [-0.96, 0.26]
Ratcliff 2016	6.7	3.1	53	7.3	3.7	54	14.7%	-0.17 [-0.55, 0.21]
Ho 2016	7.1	3.9	66	7.5	4.2	64	15.6%	-0.10 [-0.44, 0.25]
Arikawa 2013a	7.93	3.62	77	7.93	3.62	64	15.9%	0.00 [-0.33, 0.33]
Chen 2013	12	4.1	49	11.3	3.7	47	14.2%	0.18 [-0.22, 0.58]
Total (95% CI)			**342**			**318**	**100.0%**	**-0.30 [-0.56, -0.04]**

Heterogeneity: Tau² = 0.08; Chi² = 18.82, df = 8 (P = 0.02); I² = 57%
Test for overall effect: Z = 2.27 (P = 0.02)

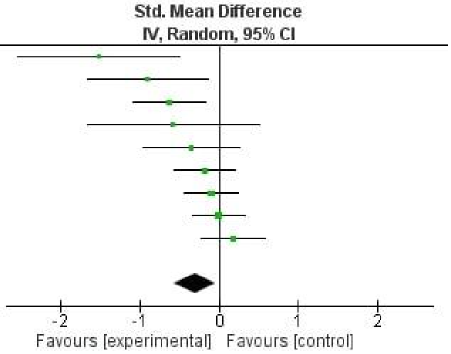

Figure 3.5 *Forest plot for the sleep outcome*

Note. Experimental: physical exercise intervention programmes or movement-based mind-body approaches of any duration. Control: controls receiving no intervention (e.g., wait-list or usual care), or controls included in a different programme.

3.3.5 Results of syntheses

The 10 RCTs included 756 participants (90% females), with mainly adults (27-64 years old) and no older adults (65+ years old). Most studies included females with breast cancer (n = 6) and used saliva samples (n = 7). The discrepancy in participants' characteristics across studies was visualised in diagrams (Appendix 3.5). Five studies measured the diurnal cortisol slope, one measured the cortisol awakening response (CAR), and one performed a one-point-in-time measurement to measure cortisol, and the Pittsburgh Sleep Questionnaire Index (PSQI) (n = 8) to measure sleep. A chart overview of study characteristics was made (Figure 3.2). Four studies were of low risk of bias, whereas six raised some concerns owing to not having an active control group. Knowledge of the assigned intervention could have influenced participant-reported outcomes in the subjective sleep questionnaires. However, all questionnaires used were validated for each of the participant groups. Further, many confounding factors could be at play in cortisol measurement. However, each study used standardised (*a priori*-defined) protocols for the cortisol sampling and randomisation strategies for control groups to account for most confounding factors.

Nine RCTs directly used cortisol and PSQI outcome measures with relevant control groups (Al-Sharman et al., 2019; Arikawa et al., 2013; Banasik et al., 2011; Bowden et al., 2012; Hilcove et al., 2021; Ho et al., 2016; Imboden et al., 2021; Payne et al., 2008; Ratcliff et al., 2016), and were deemed clinically and methodologically similar enough to be included in the meta-analysis. One study was deemed inappropriate to be included in the meta-analysis because it lacked a relevant control group, as it compared the effects of a brain wave training programme to a yoga and a mindfulness group.

Physical exercise was associated with reduced cortisol levels (SMD [95% CI] = -0.37 [-0.52, -0.21] $p < 0.001$) and improved PSQI outcomes (SMD [95% CI] = -0.30 [-0.56, -0.04], $p = 0.02$) compared to active controls or usual care among 651 and 660 (middle-aged) adults, respectively. With heterogeneity in the PSQI outcome (Chi^2 = 18,82 with df = 8), the quantified heterogeneity was deemed moderate (I^2 = 57%). The moderate heterogeneity could be explained by excluding studies with the highest SMDs without changing the overall effect. Further, although studies were deemed similar enough, clinical differences, e.g., differences between the health status of participants, could also explain the heterogeneity. No RCTs reported a correlation between cortisol and sleep outcomes. However, one non-RCT reported that decreases in cortisol were significantly correlated with increases in total sleep time and rapid eye movement (REM) sleep (Passos et al., 2014).

3.3.6 Sub-group Analyses

The magnitude of the direction of effect did not notably change among all sub-group analyses performed. Differentiating between sexes was deemed not valuable as insufficient data was retrieved to assess males as a distinct subgroup. Also, none of the analyses explained the moderate statistical heterogeneity in the PSQI outcome (Appendix 3.6). First, identified age groups were adults (26-47 years old) only (four studies (Al-Sharman et al., 2019; Arikawa et al., 2013; Hilcove et al., 2021; Imboden et al., 2021)), and adults and middle-aged adults (26-64 years old) (five studies (Banasik et al., 2011; Chen et al., 2013; Ho et al., 2018; Payne et al., 2008; Ratcliff et al., 2016)), sub-groups did not differ significantly ($p = .49$ for cortisol, and $p = .53$ for PSQI). No studies were performed on older adults (65 years and over). Second, cortisol measurement was done by measuring the diurnal cortisol slope (Banasik et al., 2011; Chen et al., 2013; Hilcove et al., 2021; Ho et al., 2018; Ratcliff et al., 2016), one point in time measurement (Al-Sharman et al., 2019; Arikawa et al., 2013; Bowden et al., 2012; Payne et al., 2008), or the CAR (Imboden et al., 2021). Sub-grouping between cortisol measurements revealed no significant differences ($p = .66$). Third, three studies used active control groups (Al-Sharman et al., 2019; Imboden et al., 2021; Ratcliff et al., 2016), while six studies used usual care or wait-list controls as comparison groups (Arikawa et al., 2013; Banasik et al., 2011; Chen et al., 2013; Hilcove et al., 2021; Ho et al., 2018; Payne et al., 2008), these two sub-groups did not differ significantly ($p = .89$ for cortisol, and $p = .73$ for PSQI). This analysis was also part of the sensitivity analysis (see below). Fourth, regarding intensity type, four studies used aerobic exercise (Al-Sharman et al., 2019; Arikawa et al., 2013; Imboden et al., 2021; Payne et al., 2008), and five studies used mind-body exercises (Banasik et al., 2011; Chen et al., 2013; Hilcove et al., 2021; Ratcliff et al., 2016). Again, these two sub-groups did not differ significantly ($p = .50$ for cortisol and $p = .27$ for PSQI).

3.3.7 Sensitivity Analyses

Sensitivity analyses were consistent with the main analysis, indicating the robustness of the synthesised results. Narrative analyses that included descriptive PICO characteristics of retrieved non-RCTs (n = 5) (Appendix 3.7) showed similar study characteristics compared to the included RCTs. Notable differences were mainly in the ‘participant’ domain: one study included older adults (Fouladbakhsh et al., 2014), and more men were included compared to in the RCTs (30% vs. 10% respectively). Further, none of the studies looked at breast cancer, whereas six out of 10 RCTs did. A summary of other measures for sleep, including both RCTs and non-RCTs, revealed seven other measurements of sleep, including four studies complementing a sleep questionnaire with measures of the architecture of sleep (polysomnography) (Imboden et al., 2021; Leone et al., 2018) and actigraphy (Al-Sharman et al., 2019; Garrido et al., 2017) (Figure 3.6).

Study	Study Design	PSQI	BFI	ISI	Fatigue likert scale	GSQ	SSQ	PRFS	Polysomno-graphy	Actigraphy
Payne, 2008	RCT	▲						◄►		
Arikawa, 2010	RCT	◄►								
Banasik 2010	RCT				▲					
Bowden, 2012	RCT	▲								
Chen, 2013	RCT	◄►	◄►							
Chandwani, 2014	RCT	▲								
Ho, 2016	RCT	▲	▲							
Al-Sharman, 2019	RCT	▲		▲						▲
Hilcove, 2020	RCT					▲				
Imboden, 2021	RCT	▲							◄►	
Fouladbakhsh, 201	nCT	▲								
Passos, 2014	nCT	▲							▲	
Leone, 2015	nCT						◄►			
Garrido, 2017	nCT	▲								▲
Zaccari, 2020	nCT	▲								

Figure 3.6 *Summary of measures for sleep, including both RCTs and non-controlled trials.*

Study design: RCT: Randomised Controlled Trial; nCT: non-Controlled Trial

Outcome: PSQI: Pittsburgh Sleep Quality Index; BFI: Brief Fatigue Inventory; ISI: Insomnia Severity Index; GSQ: Global sleep quality (item from PSQI), SSQ: Spiegel Sleep Questionnaire; PRFS: Piper Revised Fatigue Scale

Effect direction: upward arrow ▲ = positive health impact, downward arrow ▼ = negative health impact, sideways arrow ◄► = no change/mixed effects/conflicting findings

Sample size: final sample size (individuals) in intervention group Large arrow ▲ >300; medium arrow ▲ 50-300; small arrow ▲ <50

Colours: Green: Low risk of bias, Orange: some concerns, Red: High risk of bias

3.3.8 Reporting bias

A funnel plot by Egger revealed no visual asymmetry in the cortisol outcome and an asymmetry in the sleep outcome due to missing studies on the 'no intervention effect' (Appendix 3.3). Reporting bias is considered. However, this asymmetry could exist due to chance, as the analysis contained few studies with few participants (Sterne et al., 2011). Further, a sensitivity analysis that explored the impact of potential missing results in the main analysis showed that pilot studies without control groups reported similar results compared to the included RCTs.

3.3.8 Certainty of evidence

First, there was moderate certainty evidence that physical exercise probably decreases cortisol levels slightly compared to active controls or usual care. Second, there was low-certainty evidence that exercise interventions may improve PSQI outcomes slightly compared to active controls or usual care. The evidence was downgraded by one level for each outcome due to an issue with indirectness and another level in the PSQI outcome due to moderate heterogeneity. The explained wordings and judgements can be found in the footnotes of the accessory summary table (Appendix 3.8).

3.4 Discussion

3.4.1 Overall completeness and applicability of evidence

This systematic review and meta-analysis showed small beneficial effects of physical exercise interventions to decrease cortisol levels and improve adult sleep outcomes, compared to active controls or usual care. Caution is needed to generalise these findings to the general population, as of the nine meta-analysed studies, six included solely breast cancer patients, and only 10% of the participants were male. These findings agree nonetheless with separate systematic reviews on the topic that physical exercise improves cortisol levels (Anderson & Wideman, 2017; Duclos & Tabarin, 2016; Fragala et al., 2011) and sleep outcomes (Kredlow et al., 2015; Uchida et al., 2012) in adults. In addition, the analysis by Kredlow (2015) showed improvements in effect sizes for both subjective and objective sleep outcomes (i.e., the PSQI and data such as total sleep time and sleep efficiency (Kredlow et al., 2015)). This is consistent with the current sensitivity analysis finding similar results between subjective and objective sleep measures. However, this is the first systematic review to quantify the average effect of physical exercise on stress and sleep together.

Notably, meta-analytic data mainly consists of a unique sample of females with breast cancer. This is with good reason, as breast cancer is the most prevalent cancer among women worldwide (Miller et al., 2016). Further, patients often suffer from various side effects such as psychological distress or disruption in the HPA axis, fatigue, and sleep disturbances during or after radiotherapy (Noal et al., 2011; Roscoe et al., 2002; Sjövall et al., 2010) or chemotherapy (Byar et al., 2006), and sleep disturbance and fatigue are found to go hand in hand with disruption of cortisol rhythms in these patients (Tell et al., 2014). Interestingly, although breast cancer affects older post-menopausal women almost twice as much as younger pre-menopausal women (Jemal et al., 2007), this systematic review did not identify studies specific to older women with breast cancer. This indicates that minimal research has been explicitly conducted on this population.

Further, 90% of the participants included in this systematic review were female. Men and women tend to react differently to stress psychologically and biologically. Therefore, considerations about sex differences should be acknowledged. First, HPA axis responses to physical exercise do not differ between men and women (Friedmann & Kindermann, 1989; Kirschbaum et al., 1992; Kraemer et al., 1989). However, it appears that women react differently to chronic stress compared to men, displaying larger increases in cortisol levels when chronically stressed (Kunz-Ebrecht et al., 2004; Schulz et al., 1998; Steptoe et al., 2000). The general picture that emerges is that there are significant sex differences for ACTH and free salivary cortisol (measured in saliva) but not for plasma cortisol (Kirschbaum et al., 1999; Kudielka et al., 2004; Kudielka & Kirschbaum, 2005). Further, the HPA axis is influenced by sex hormones, particularly estrogen (Gillies & McArthur, 2010), which can modify stress responsiveness by regulating cortisol receptors (Oldehinkel & Bouma, 2011). This evidence highlights the importance of using standardised methodological protocols to strictly distinguish between the total cortisol secretion and the bioavailable cortisol levels and to differentiate between pre- and post-menopausal states and menstrual cycle phases to draw conclusions.

A concurrent wide variability for both outcomes in the effectiveness of the physical exercise interventions is seen in most trials, as indicated by wider 95% CIs. In line with this, previous research suggests that cancer patients with higher distress or depressive symptoms (Andersen et al., 2010; Antoni et al., 2001; Danhauer et al., 2009) or elevated sleep disturbance (Ratcliff et al., 2016) derive greater benefit from psychosocial or behavioural interventions. Further, a recent meta-analysis of 61 trials evidenced that baseline distress moderates the efficacy of such interventions for cancer patients (Schneider et al., 2010). This suggests that physical exercise interventions may be most beneficial for adults with current poor (mental) health states.

As *a priori* described in the protocol, any statistical correlation between changes in cortisol and sleep outcomes in the identified records would be documented, but no RCTs reported this. However, one identified non-RCT in middle-aged adults with chronic insomnia found that reductions in cortisol were significantly correlated with increases in total sleep time and rapid eye movement sleep (measured by polysomnography) after an aerobic exercise intervention of 12 weeks (Passos et al., 2014). In addition, previous literature also points to such an association: The conceptual model developed by Payne (2004) suggests that fatigue, sleep disturbances, and depressive symptoms may result from dysregulation of hormones such as cortisol (Payne & Nadel, 2004). Similarly, other studies in cancer research pointed out that sleep disturbance and fatigue were associated with disrupted cortisol rhythms (Schmidt et al., 2016; Tell et al., 2014). It seems that cortisol regulation and sleep quality are intertwined and that physical exercise could improve both in several ways. However, few intervention studies have examined this, thus indicating a fruitful line of future research.

This systematic review found that all studies modulating cancer-related fatigue were on women with breast cancer (Arikawa et al., 2013; Banasik et al., 2011; Chen et al., 2013; Ho et al., 2018; Payne et al., 2008; Ratcliff et al., 2016). Another systematic review and meta-analysis also found limited published evidence on modulating cancer-related fatigue in males (Brown et al., 2011). Further, a review with similar findings to this review described in depth the neuroendocrine-immune responses to exercise and sex (Fragala et al., 2011), which could be of particular interest to researchers seeking to design future physical exercise interventions on cancer-related fatigue, differentiating between males and females.

Although the present research set out to differentiate between different age groups (adults aged 26-47 years, middle-aged adults aged 48-64 years, and older adults aged 65 years or over), the search retrieved no RCTs that included older adults, and only one pilot study that included nine older lung cancer survivors. This was surprising for the following reasons. First, age-related changes are associated with a dysregulation of the circadian rhythm of the HPA axis (Al-Turk & Al-Dujaili, 2016; Heaney et al., 2012), further leading to sleep problems (Van Cauter et al., 2000). Second, many sleep disturbances in ageing parallel the age-related changes in the HPA axis and cortisol rhythm, suggesting that the HPA axis may play a key role in ageing-related changes with sleep (Buckley & Schatzberg, 2005a). Third, an established link exists between sleep quality and psychological well-being in older adults (Hanson & Ruthig, 2012).

Nevertheless, other trials in older adults did find improvements in quality of life, stress, and sleep outcomes after physical exercise interventions, with stress measured subjectively with questionnaires rather than with cortisol (Grahn Kronhed et al., 2020; Halpern et al., 2014; Innes & Selfe, 2012). Thus, quality research is lacking in measuring the effects of the joint effect of physical exercise interventions on cortisol and sleep in older adults. Future research should focus on this issue and the correlation between cortisol and sleep measures in this age group.

Another research question was to differentiate between different intervention types. The performed analysis did not find any significant sub-group differences, partially because the analysis yielded too few studies to make meaningful interpretations. However, regarding the cortisol outcome, a meta-analysis exploring the effect of different exercise interventions found that aerobic exercise in patients with major depressive disorder reduced cortisol levels the most compared to strength training (Beserra et al., 2018). Again, caution in interpretation is suggested due to the small number of studies, with substantial heterogeneity among them. Regarding sleep, reviews have shown positive effects on sleep quality across various exercise modalities (such as mind-body exercises and vigorous strength exercises) (Brupbacher et al., 2021) and levels of intensity (Lederman et al., 2019). More quality studies differentiating between different exercise types could deepen this understanding.

3.4.2 Strengths and limitations

This review process carefully followed the PRISMA guidelines (Page et al., 2021). The screening and selection of articles, risk of bias assessment, and rating of the certainty of the evidence were done independently by two reviewers. Also, the second reviewer carefully screened the data extraction performed by one reviewer. Reporting bias was addressed by a funnel plot and sensitivity analysis and properly reported. This rigorous methodology allowed for greater confidence in the objectivity of the results. Further, a meta-analysis was performed to increase the precision of the effect estimates.

However, to interpret the findings appropriately, several limitations of the evidence included in this review must be considered. First, this systematic review included a relatively small number of studies, only RCTs, mainly in breast cancer patients, including remarkably fewer males. In addition, it should be mentioned that positive outcomes are more likely to be published in English-language journals (Egger et al., 1997), which could lead to selection bias in systematic reviews and meta-analyses. Therefore, although the findings agreed with other systematic reviews on the topic, claims made regarding the effectiveness of physical exercise programmes should be interpreted within these limits. Second, recall and/or performance bias for the studies, including subjective outcome measurements (e.g., questionnaires or scales), should be considered. Objectivity would increase when these measurements are complemented with the architecture of sleep measures (e.g., polysomnography or actigraphy). However, this is often a cost/accuracy trade-off.

Further, several limitations of the review process should also be reported. First, moderate heterogeneity was found when pooling the studies within the sleep outcome, complicating a meaningful summary. Therefore, the certainty was downgraded based on existing GRADE guidance (Schünemann et al., 2013), and findings were reported appropriately. Second, sub-grouping pitfalls were considered (Burke et al., 2015). Therefore, sub-groups were mainly analysed to allow transparency in addressing the research question and should be interpreted cautiously. Third, sensitivity analyses were mainly performed narratively. This could solely indicate the robustness of the synthesised results rather than provide definitive conclusions.

3.4.3 Implications for practice

Findings from this review indicate that physical exercise is an evidence-based strategy within the holistic perspective to tackle stress and sleep complaints in adults, particularly in women with breast cancer. This adds to the current consensus that the benefits of physical exercise for people with long-term conditions outweigh the risks (Reid et al., 2021). Additionally, the results point out that light-to-moderate physical exercise, whether aerobic or mind-body, is beneficial to modulating stress and sleep. Given the noted wide variety in the effectiveness of the results and the established evidence that any physical exercise modality and intensity could improve these outcomes, it seems adults could benefit from individually tailored physical exercise interventions based on their preferences and needs.

3.4.4 Implications for research

The generalisability of the findings of this review would be enhanced by high-quality studies including different health states, both sexes and older adults. Previous research indicates that adults with current poor (mental) health states may benefit most from physical exercise interventions. Therefore, future research could hypothesise that baseline (mental) health states could moderate intervention effects. More specifically, understanding the value of physical exercise for cancer-related fatigue would benefit from the design of physical exercise interventions including males and differentiating between biological sexes. Also, given that in ageing, the changes in the HPA axis and cortisol rhythm and many sleep disturbances go hand in hand, quality studies on older adults would be a welcome addition to the literature. Further, more quality RCTs with a clear description of the participant's health status and physical exercise methodology would provide bigger sample sizes and possibly increase homogeneity in future reviews exploring which exercise modality is best for different health states.

3.5 Conclusion

This systematic review and meta-analysis set out to investigate the effects of PA on cortisol and sleep and provides insight into the bidirectional relationship between cortisol and sleep. Small beneficial effects of physical exercise interventions to decrease cortisol levels and improve adult sleep outcomes were identified. To establish a greater degree of accuracy on this matter, more information about (1) different participant demographics, as most studies included women with breast cancer and no older adults, (2) the effect of different intervention types, because the analysis yielded too few studies to make meaningful interpretations, (3) the bidirectional relationship between cortisol and sleep, as there is an established link between these two, but no RCTs researching this were identified.

Chapter 4: Intervention One, danceSing Care phase One: Feasibility of a digital music and movement intervention in older adults in care homes.

This Chapter is based on the peer-reviewed feasibility study published as “A realist evaluation of the feasibility of a randomised controlled trial of a digital music and movement intervention for older people living in care homes.” in *BMC Geriatrics* Volume 23, 125 (Ofosu et al., 2023).

4.1 Background

After conducting two systematic reviews, we identified key gaps in the literature regarding PA and its impact on healthy aging. These reviews laid the groundwork for our subsequent intervention studies. At this point, danceSing Care, a company dedicated to enhancing the well-being of care home residents through music and movement-based activities, approached the University of Stirling. Their goal was to scientifically validate their program in care homes. This presented a unique and timely opportunity to expand our research into a practical, real-world setting.

The danceSing Care company (https://dancesingcare.uk) provides a programme to promote physical, mental, and social well-being among older adults in care homes. Their activities are designed to be inclusive, engaging, and tailored to the needs of individuals with varying physical and cognitive abilities. The program includes structured music and movement sessions that can be adapted for both group and individual settings, thus fostering a sense of community and enhancing the quality of life for participants.

Recognising the alignment between the research objectives and the mission of danceSing Care, we decided to form a partnership. This collaboration was mutually beneficial: it allowed us to validate and refine the danceSing Care program through rigorous scientific methods while danceSing Care provided the practical resources and care home environments needed to conduct our interventions. Under the terms of our collaboration, the University of Stirling committed two PhD students (LDN and EO) to the project. These students were responsible for designing and implementing the research protocols, collecting and analysing data, and ensuring the scientific rigor of the intervention studies. In return, danceSing Care facilitated access to their network of care homes and provided the necessary resources, including digital tools, to support the interventions.

This partnership enabled us to conduct two key interventions:

- Intervention One: A feasibility study of a digital music and movement intervention in older adults in care homes. This phase focused on assessing the program's feasibility and gathering preliminary data on its impact on residents' well-being.

- Intervention Two: A pilot randomised controlled trial (RCT) to evaluate the efficacy of the digital music and movement intervention. This phase aimed to provide more robust evidence of the intervention's effectiveness and inform future large-scale RCTs.

The subsequent two Chapters are the peer-reviewed articles presenting 1) a feasibility study, leading to 2) a pilot RCT conducted after the systematic reviews. The methodology employed in this project is described in Appendix 4.1. It is important to highlight that this project was conducted in collaboration with danceSing Care company (https://dancesingcare.uk/), specialists in customised, on-demand digital music and movement sessions for older adults in care homes.

With advancements in communication technology, the COVID-19 pandemic provided an opportunity to explore the feasibility and effectiveness of a trial of a digital PA resource in care homes. The feasibility study examined the potential of a digital PA resource in care homes to improve the mental health of older adults, who are known to experience negative mental health consequences from low PA. A realist evaluation approach was used to identify the factors influencing the feasibility study implementation and to provide insights into how a digital music and movement programme would work and under what circumstances it would be most effective.

4.2 Introduction

4.2.1 Rationale for evaluation

The care home resident population is ageing in the UK (Office for National Statistics, 2014), following global trends (OECD, 2021), with residents often being diagnosed with more than one long-term health condition (multimorbidity) (Gordon et al., 2014). Multimorbidity increases the likelihood of hospital admission, length of stay and readmission, raising healthcare costs, polypharmacy and mortality and reducing the quality of life (Marengoni et al., 2011; Salive, 2013). While morbidity consistently predicts care dependence, physical multimorbidity conveys a lower risk than multimorbidity with mental and cognitive disorders

(Bao et al., 2019). This is a significant finding, as about 70% of all care home residents have dementia or other cognitive impairments (Alzheimer's Society, 2022). Further contributing to these issues, the adverse consequences of reduced or low PA or the cessation of exercise, which is common in a care setting, brings about its own negative mental health consequences, such as higher levels of depression (Sackley et al., 2006) and loneliness (Rodriguez-Larrad et al., 2021). Previous research has focused on developing PA interventions in care homes to improve the health of care home residents. With advancements in communication technology, particularly during the COVID-19 pandemic, the feasibility and effectiveness of digital PA resources deserve more research attention.

PA interventions may be an excellent means of improving multidimensional health in older adults (Lazarus & Harridge, 2018). This is evidenced by favourable effects on endocrine profiles implicated in human ageing (De Nys et al., 2022; Sellami et al., 2019). Further, these have shown improvements in physical health, such as gait speed, balance and performance in activities of daily living (Chou et al., 2012), as well as in cognitive function (Bherer et al., 2013) and mental well-being (Windle et al., 2010), such as anxiety (Ofosu et al., 2023) and depression (Strawbridge et al., 2002). Therefore, considerable effort has been devoted to increasing PA and prescribing exercise programmes to older adults, such as the care home resident population (de Souto Barreto et al., 2016). PA interventions, including multicomponent (chair-based) exercises or dancing, have been shown to improve cognitive function and physical and mental well-being in this population (Arrieta et al., 2018; Brustio et al., 2018; Cordes et al., 2021; Da Silva et al., 2022; Guzmán-García et al., 2013; Hwang & Braun, 2015; Low et al., 2016).

Increasingly, innovative digital resources have been developed to positively influence PA in care home residents. For the successful implementation of digital health interventions designed for older adults, understanding the feasibility regarding organisational and systems readiness and the acceptability of digital interventions are fundamental. Recent systematic reviews showed that digital resources to promote PA in older adults were reported as feasible and well-accepted (Diener et al., 2022; Valenzuela et al., 2018). The review by Diener et al. (2022) suggests considering one's physical and cognitive abilities and providing options for individual tailoring of these interventions. It further highlighted that conditions and resources in care homes, such as equipment, physical space, and financial capacities regarding technology, should be considered (Diener et al., 2022). Both reviews (Diener et al., 2022; Valenzuela et al., 2018) emphasised that, although technology-based interventions to promote

PA show promising future avenues, more quality studies reporting accurate exercise adherence and effectiveness measures are warranted.

Further, when designing and testing interventions in the complex situations that care homes reside in, it is important to address 'what works, for whom, under what circumstances, and how' (Moore et al., 2015). Few studies consider the role of context, mechanisms and external factors (moderators) affecting the effectiveness of a PA programme. In order to expand and translate the roll-out of effective interventions, more information is often needed about how a programme might be replicated in a specific context or whether trial outcomes are reproducible (Moore et al., 2015). Therefore, a realist evaluation (Pawson & Manzano-Santaella, 2012) was chosen for the present study to understand how a digital music and movement intervention might generate different outcomes in different circumstances. Exploring and identifying the how, why, for whom, to what extent, and in what context interventions work could allow researchers and practitioners to understand how to adapt interventions to a new context (Westhorp, 2014) and further inform decisions about scaling up the programme to deliver to more care homes and influence public health initiatives.

To this end, following the realist evaluation framework, a context (C), Mechanism (M), and outcome (O) configuration (Pawson & Manzano-Santaella, 2012) was identified to explain the role of the complex situation of UK care homes in which PA programmes are to be rolled out (see Table 4.1). The effects of a feasibility trial (danceSing Care programme) on multidimensional health outcomes were discussed in light of this CMO configuration. Thus, the two overarching aims of this project were: (1) to determine the feasibility of a future mixed-methods RCT of digital music and movement resources in a care home, and (2) to use a realist evaluation approach to evaluate the process, outcomes and influencing factors of the trial implementation to inform how this programme would work and under what circumstances this would be most effective. With insights into whether and how the outcomes were affected, the initial programme theory will be refined for future implementation in a randomised controlled design in other care home sites.

The programma theories and logic model underpinning the danceSing Care evaluation is shown in Figure 4.1 and 4.2, respectively.

Programme theories

Primary programme theories

(1) If the danceSing care resources are delivered to the care homes, the Activity Coordinators (ACs) would consistently deliver the programme to the residents.

(2) If the programme is delivered in the care homes, the residents would want to regularly take part.

(3) If the ACs provide the programme consistently, the participants would experience improved psychosocial health markers. Changes in pre-and post-survey data and qualitative interviews would evidence this.

Secondary programme theories

(1) If the ACs were given enough organisational support (e.g., resources and time), they would be engaged in this programme. This would establish shared learning and co-production between programme developers, care homes, and researchers.

(2) If the group sessions were adequately and consistently used, residents would feel more engaged in group activities, creating a ommunity. This communal feeling would increase self-confidence and quality of life and reduce loneliness. This could potentially inspire future usage of the programme's resources.

Assumptions

Care homes would:
- be able to cast laptops to large screen
- all have a dedicated activity coordinator

Activity coordinators would:
- be consistent and continuous in login and delivering the intervention
- see the programme as a core priority
- be able to engage all participants in a group setting
- be engaged and able to schedule the activities consistently and regularly
- have adequate cover for days off/leave
- need training on the use of the intervention only
- return attendance sheets regularly
- be easy to get in contact to make appointments with

Residents would
- be engaged in the programme from the start

Figure 4.2 *Programme theories of the danceSing care evaluation.*

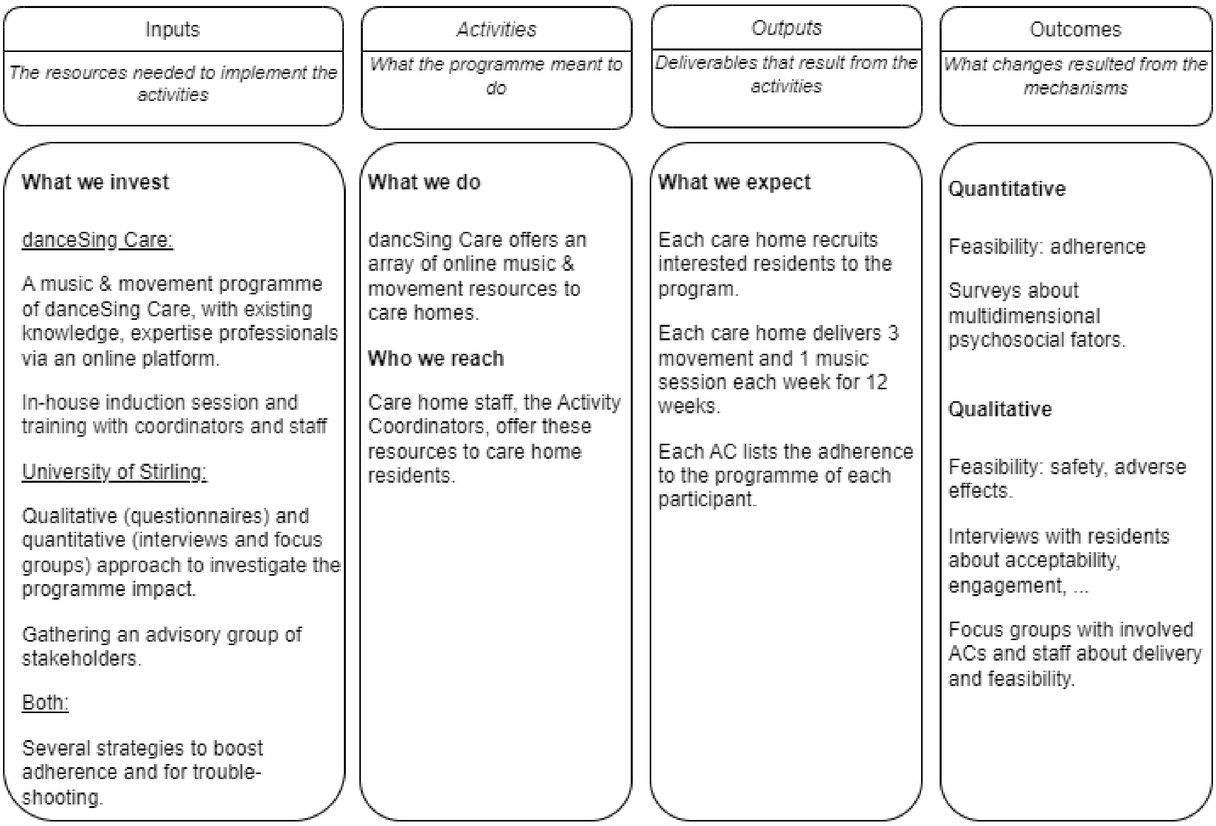

Figure 4.1 *Logic model underpinning the danceSing care evaluation.*

4.2.2 Programme theory

Programme theories are configured as "context-mechanism-outcome" (CMO) hypotheses in a realist evaluation. This explains how and why different outcomes are generated in different contexts. Linked sets of hypotheses are likely to be produced because different mechanisms will be activated in various contexts, resulting in various outcomes. Generally, hypotheses are developed by asking four questions: (1) For whom will this basic programme theory work and not work, and why? (2) In what contexts will this programme theory work and not work, and why? (3) What are the main mechanisms we expect this programme theory to work? (4) If this programme theory works, what outcomes will we see? The basic programme theory was in line to test the feasibility of an RCT implementing the danceSing Care programme in specific UK care homes and measuring psychosocial health markers. This is reflected by the stated realist assumptions (Table 4.1).

This programme theory could be further subdivided into the following theories:

(1) If the danceSing Care resources are delivered to the care homes, the Activity Coordinators (ACs) would consistently deliver the programme to the residents.

(2) If the programme is delivered in the care homes, the residents would want to participate regularly.
(3) If the ACs provide the programme consistently, the participants would experience improved psychosocial health markers. Changes in pre-and post-survey data and qualitative interviews would evidence this.
(4) If the ACs are given enough organisational support, such as resources and time, they would be engaged in this programme. This would, therefore, establish shared learning and co-production between programme developers, care homes, and researchers.
(5) If the group sessions are adequately and consistently used, residents would feel more engaged in group activities, creating a community. This communal feeling would increase self-confidence and quality of life and reduce loneliness. This could potentially inspire future usage of the programme's resources.

Further, researchers, stakeholders from the to-be-tested programme, and representatives from the UK care homes where the programme would be implemented developed the focused questions. They considered the set of conditions that existed (Context), how these contexts might create change (Mechanism), and what changes would result from the mechanisms (Outcomes). The study's hypotheses were developed based on the assumptions and the focused questions. Therefore, it was necessary to collect information about context, mechanism and outcome and identify features of implementation or organisation that affect whether or not the trial works (Wong et al., 2016). The different CMOs are listed in Table 4.1. Each row in this table represents the outcome of a particular mechanism in a particular context. This was followed by retroduction, a form of logical inference using abductive reasoning to identify the most likely explanations for an observed data set. This retroduction was done by interpreting and analysing the data and applying the configured CMO. Finally, as outlined in the discussion section, these interpretations served to refine the initial programme theory for future implementation.

Table 4.1 *Context-Mechanism-Outcome (CMO) hypothesis.*

Context-Mechanism-Outcome (CMO) hypothesis					
Realist assumption	Focused question	Realist programme theory	Contexts (set of conditions that exist)	Mechanisms (how might these contexts create change)	Outcomes (what changes result from the mechanisms)
1. Collect information about context, mechanism and outcome to evaluate the programme. 2. The programme intends to cause a change.	1. What information will be needed and could be collected about contexts? Mechanisms? Outcomes? 2. What change (outcome) does the trial intend to create Quantitative: Feasibility, adherence, surveys about psychosocial health markers Qualitative: Interviews and focus groups about acceptability, engagement, delivery and feasibility	1. Identifies intended outcomes 2. Identifies the data necessary to test the programme theory.	Situational High burden of the COVID-19 pandemic on the care home system in Scotland Little time and resources for the staff (already happening before COVID-19)	Little time and resources for the staff, understaffing, absence or isolation of staff and participants through restrictions	Complicate readiness for programme delivery and engagement
			Programme 1. Implementation of the danceSing Care programme 2. Flexibility from research staff and stakeholders from the danceSing Care team	Supporting care home staff, boosting feelings of connection and engagement through group training, meetings and welcoming participants in the ‘danceSing Care family’	1. Improve psychosocial health markers of residents 2. Improve programme delivery and engagement

4.2.3 Specific research objectives

In line with the overarching aims of this study outlined above, specific research objectives were to evaluate the following topics : (1) Feasibility: was the activity implemented and/or delivered as planned? Were adherence rates at an acceptable level? Were the outcomes adequate and realistic for this programme and setting? (2) Context: What were the potential barriers for care homes or ACs to provide these resources? Were the programme's resources suitable for this setting? (3) Mechanism: what underlying mechanisms made the danceSing Care programme work (or not)? Was it the situational context or the programme context? (4) Outcome: What changes resulted from the mechanisms?

4.3 Methods

4.3.1 Design

This study combined two evaluation approaches: a mixed methods feasibility approach and a realist one. Initially, a mixed-methods research approach to a 12-week feasibility trial in care homes with a pre-and post-intervention collection of quantitative and qualitative data about feasibility (adherence, safety, adverse events) and participants' multidimensional health. This was to determine (1) an appropriate way to deliver the programme in this setting and (2) the appropriate secondary outcome measures for a future RCT. This was preceded by the implementation of an expert advisory group (AG). The AG consisted of danceSing Care staff, the research team, representatives from care homes and older adult members of the 'Stirling 1000 Elders' (https://1000elders.stir.ac.uk/, a group of adults aged 60+ who have signed up to participate and engage in research on older adults at the University of Stirling). The outcomes were reported following appropriate CONSORT guidance for feasibility trials (Eldridge et al., 2016). The study was approved by the University of Stirling NHS, Invasive and Clinical Research ethics panel, project NICR 3735, and retrospectively registered at ClinicalTrials.gov, NCT05559203, on 29/09/2022.

Second, the evaluation questions and scope evolved beyond initial questions regarding feasibility throughout the evaluation because the capability of delivering the programme and engaging the residents by the ACs was lower than expected. To uncover the underlying factors that explained the implemented situation (such as relevant context (C), mechanisms (M), and outcomes (O)), we additionally used the realist evaluation methodology based on RAMESES II reporting standards (Wong et al., 2016). Given the difficulties with delivery, any attempts to establish linear, causal relationships between inputs and outcomes (e.g., by comparing 'pre' and 'post' data) would have been largely meaningless. Thus, using realist evaluation, the CMO configuration was identified to interpret the outcomes according to what happened. Pre- to post-intervention changes in secondary outcome measures were calculated to indicate effect sizes, implement the measures, and test their acceptability before integrating them into a larger RCT.

4.3.2 Environment surrounding the evaluation

The environment for the evaluation was across ten care homes in Scotland, United Kingdom. All care home ACs were provided with the danceSing Care digital resources login details to access weekly pre-recorded movement and music sessions. It was confirmed that all care homes had sufficient technological support to participate in this programme. Before the intervention, an in-person training session was organised for care home staff (ACs and operation managers). This training covered general instructions on rolling out the programme and addressing any staff concerns about the study, including any IT issues. In addition, a concise information pack was distributed to ACs, including the programme's and researchers' contact details for any questions or problem-solving. All study information was co-designed with the advisory group, which met four times to determine the amount and timing of programme delivery and priorities for and suitability of outcome measures.

4.3.3 Participant recruitment process and sampling strategy

Participants were recruited across ten care homes in the Balhousie Care group (https://balhousiecare.co.uk/) between December 2021 and January 2022. Inclusion criteria were (1) residents in care homes ≥ 60 years, (2) able to complete 12 weeks of a movement and music program, and (3) having the capacity to give informed consent. Participants were not eligible if they (1) were currently taking part in any other clinical trial which could potentially have an impact upon or influence the findings of the current study, (2) had pre-existing conditions or concurrent diagnoses which would profoundly impact their capacity to undergo the intervention, even once adaptations have been made (3) inability to understand written/spoken English adequately to participate in the measures and intervention (e.g., due to cognitive or sensory impairment). Care staff were asked to gauge the interest of residents in the programme and were provided with recruitment flyers. Care staff informally screened interested participants for eligibility with a simplified version of the information sheet.

Following this, the research team contacted the respective care homes, provided full participant information sheets, and obtained informed written online consent. Where this was not feasible online, care staff ensured the residents consented to the study on paper copies of the consent form provided at the start of the survey pack. In addition, in-person visits to the care homes were planned if COVID-19 restrictions allowed.

4.3.4 Programme

The programme was a digital movement and music programme with resources from danceSing Care (https://dancesingcare.uk/). It consisted of three movement sessions and one music session each week, the recommended dose agreed upon between danceSing Care and the AG, each lasting about 20 minutes. Also, the danceSing Care resources were designed to suit older adults with physical and cognitive impairments (residents with mobility aids and/or dementia). Movement sessions included chair and standing fitness, which started with a warm-up and finished with stretching exercises (see Appendix 4.4 for intervention description). Sessions were managed and supervised by care home ACs.

4.3.5 Measures

Feasibility: adherence and safety

Care home staff were asked to provide the danceSing Care PA resources three times per week plus one music session. Participants' adherence was assessed by asking homes to record how many sessions they offered each week and the participant's attendance at each of these using a provided register sheet (Appendix 4.5). This was then calculated as adherence for participants by computing the percentage attended out of the number of sessions offered by the care home. Care home adherence was calculated as the percentage of offered sessions from the recommended 3+1 x 12 weeks. Adherence data were requested weekly via a reminder email with a specific register provided to each care home. This was to indicate attendance at the sessions provided per participant and any additional attendance from non-participants. Researchers logged reasons for withdrawal weekly. Adherence data was followed up with phone calls to each home from the research team to help assess any difficulties in delivering the programme. Researchers kept a reflective log of any additional information gathered in this way.

As part of the care home staff workshop before the intervention, ACs were advised to ensure residents engaged in the danceSing Care programme according to their capabilities. Adverse events related and unrelated to the intervention were reported weekly by ACs via email or telephone in addition to the adherence reports.

Socio-demographics and multidimensional health

The pre-and post-intervention survey recorded basic demographics such as age, sex, relationship status, ethnic group and level of education. Postcodes were not included to compare against the Scottish Index of Multiple Deprivation because participants were residents of care homes.

After discussion with the AG, a list of priority and appropriate outcomes for limited efficacy testing in this feasibility study was devised. The key areas included the number of falls in the past three months, activities of daily living and health, psychosocial well-being (anxiety, depression, stress and loneliness), sleep satisfaction and frailty measures such as physical function, appetite and weight loss. These multidimensional health markers were assessed using standardised questionnaires validated in older adults with mild cognitive impairment. The internal consistency of the measures is reported as Cronbach’s alpha with values ≥ 0.70, indicating good levels of reliability.

Fear of falling was measured using the Falls Efficacy Scale – International (short form) (FES-I) (Kempen et al., 2008). It is a seven-item scale that measured participants' concerns about falling during social and physical activities on a Likert scale ranging from one (not at all concerned) to four (very much concerned). It has been validated in older adults with a Cronbach's alpha of 0.92. Total scores ranged from seven to 28, with higher scores indicating severe concern (Kempen et al., 2008).

Two measures were used for daily living and health-related quality of life. The Dartmouth Cooperative (COOP) Functional Assessment charts measured participants' physical fitness domains, feelings, daily and social activities, changes in health, using pictures (Nelson et al., 1987). The European Quality of Life 5 Dimensions 3 Level Version (EQ-5D-3L) (EuroQol Group, 1990a) evaluated five dimensions of health (mobility, self-care, usual activities, pain/discomfort and anxiety/depression) with responses ranging from no problems to considerable problems on a 3-point scale, and finally a rating of general health from 0 to 100.

Measures of anxiety, depression, stress and loneliness were used to assess psychosocial well-being. Anxiety and depression were measured using the Hospital Anxiety and Depression Scale (HADS) (Zigmond & Snaith, 1983), a 14-item questionnaire scored on a four-point scale that measures anxiety and depression on two subscales. Each HADS subscale has seven items with a maximum score of 21, with scores ranging from zero to seven considered normal, eight to 10 as borderline and 11 or more as a significant case of anxiety or depression (Zigmond & Snaith, 1983). The Perceived Stress Scale (PSS) (Cohen et al., 1983) measures how participants perceive life situations as stressful. It has ten items with responses ranging from zero (never) to four (very often) and total scores of 0 to 13, 14 to 26 and 27 to 40, depicting low, moderate and high perceived stress, respectively (Cohen et al., 1983). Also, the brief UCLA loneliness scale (ULS-6) (Neto, 2014) was used to assess subjective feelings of loneliness on a four-point scale (1-never to 4-often) with six items; the greater the ULS-6 score, the more significant the loneliness. Each measure has reported Cronbach’s alpha for reliability of > 0.7 (37–39) (Cohen et al., 1983; Djukanovic et al., 2017; Neto, 2014).

Sleep satisfaction was measured using the National Sleep Foundation's Sleep Satisfaction Tool (SST) (Ohayon et al., 2019). It is a nine-item scale with a Cronbach's alpha of 0.87 and a high score suggesting greater sleep satisfaction (Ohayon et al., 2019). In addition to the SST, an unstandardised item measured how often participants experienced disturbed sleep due to noise outside the room. Participants chose responses from options: "not during the past month", "less than a week", "once or twice a week", and "three or more times a week".

Appetite was assessed using the Simplified Nutritional Appetite Questionnaire (SNAQ) (Wilson et al., 2005), which has a maximum score of 20, where a score less than 14 specifies poor appetite and a Cronbach’s alpha coefficient of 0.7.

Participants' weight loss was measured on the weight loss item from the Fried Frailty Scale (Fried et al., 2001). Regarding frailty measures, it was set out to assess physical function through the Short Performance Battery (Treacy & Hassett, 2018), complemented with handgrip strength and Timed Up & Go test (Podsiadlo & Richardson, 1991) to indicate frailty. However, due to the COVID-19 restrictions, visiting care homes and undertaking these assessments was impossible.

4.3.6 Procedure

Surveys were completed at baseline and then again in the four weeks following the completion of the intervention. These were either completed online by residents with the help of the researchers via an online Microsoft Teams meeting or were administered in person by the care home staff using paper versions. All completed surveys were uploaded onto JISC online survey software (https://www.jisc.ac.uk/online-surveys).

Two focus groups were conducted online in the four weeks following the completion of the intervention, lasting on average of 55 minutes each. Collectively, five ACs participated in both focus groups carried out on Microsoft Teams and were recorded following informed consent from the care home staff and research team. Four residents from two care homes consented to be interviewed in person. Due to the changes in cognitive impairment of some residents, recruitment for interviews was streamlined to specific care homes and limited to residents with no or mild cognitive impairment. Data from interviews were audio-recorded on a password-secured voice recorder and transcribed verbatim. Semi-structured interviews lasted approximately 12 minutes each. The semi-structured interview and focus group questions covered general participation, adherence, programme outcome and programme delivery. These questions were devised by the research team and trialled and altered with the advisory group (Appendix 4.6 for the interview and focus group guide).

CMO configuration

The CMO factors were generated via monitoring the care home environment. Weekly phone calls and emails provided qualitative and quantitative data about the ongoing trial adherence and the situation in the care homes. The interviews and focus groups conducted post-intervention were adapted according to realist evaluation strategies (Manzano, 2016).

4.3.7 Data analysis

Quantitative data, such as primary outcomes of adherence rate or the secondary survey outcomes, were analysed using the IBM SPSS Statistics version 26.0. The means, mean differences and 95% confidence intervals (CI) were reported for continuous data, and a count (number, %) was reported for nominal data. Pre- to post-intervention scores for secondary outcomes were compared using the paired sample t-test. Cohen's d was calculated as a measure of effect size and was interpreted as small ($d = 0.2$), medium ($d = 0.5$), and large ($d =$

0.8) (Lachenbruch & Cohen, 1989). All testing was two-sided with a significance threshold of <0.05. Qualitative data from interview and focus group transcripts were analysed using NVivo (released in March 2020).

The research team then integrated and evaluated the outcomes of the feasibility trial according to the identified CMO configuration. Recurring resources or contexts in which the programme took place that the residents or ACs described as helpful or influential (or not) were considered as a Context (C) or Mechanism (M). These descriptors generated the overarching themes of the CMO configuration. The researchers then used these interactions as contextual narratives to identify why residents responded as they did. Accordingly, the research team, the AG, and the stakeholders discussed interpretations of actions or events. These interpretations were then tested by seeking data to either support or contradict the statements (either via data on current events or from the interviews and focus groups). Finally, these interpretations were considered when refining the programme theory for future implementation. The discussion section elaborates further on these refinements. Figure 4.3 shows the process of realist evaluation.

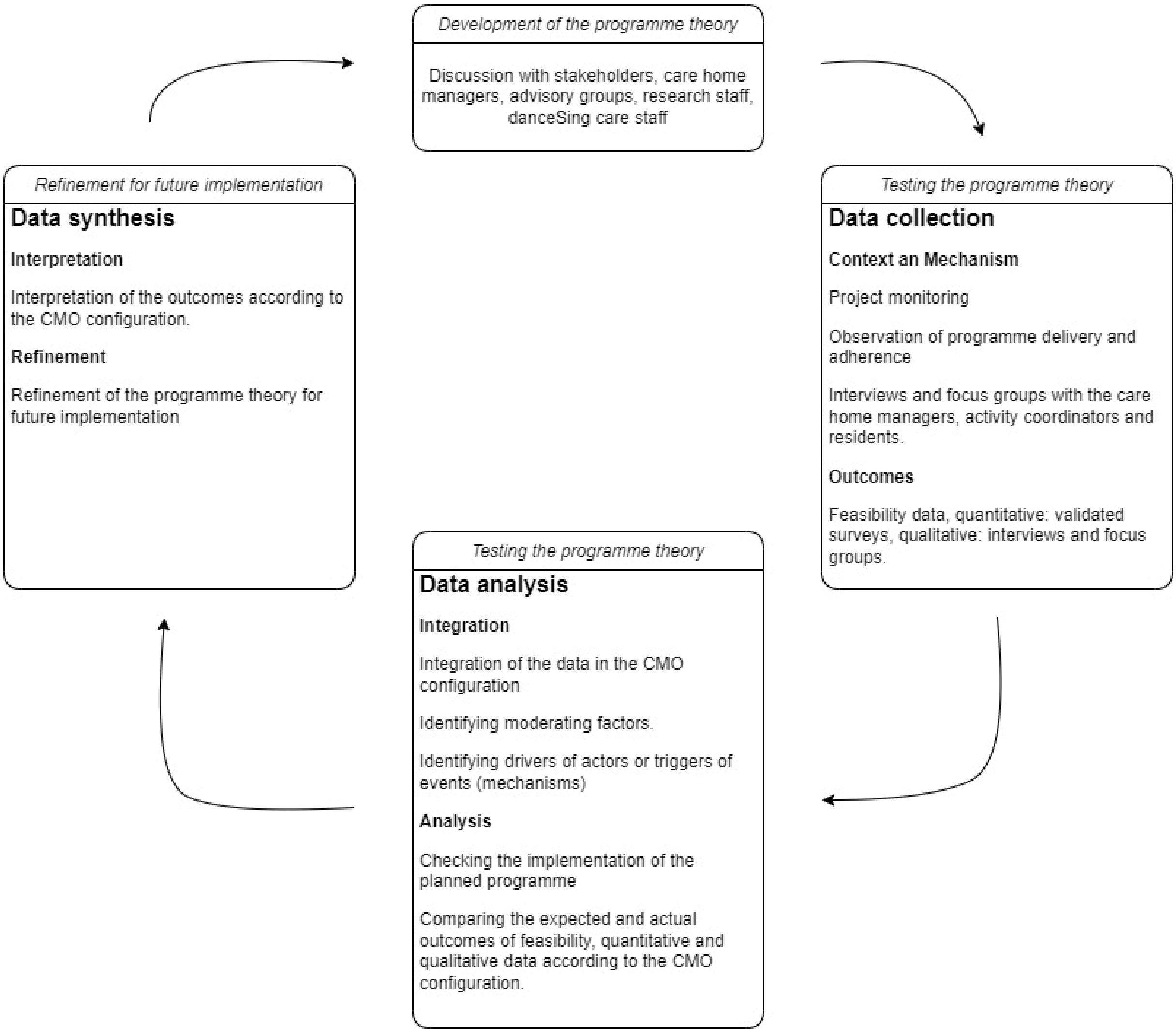

Figure 4.1 *Process of the realist evaluation***.**

4.4 Results

The following section consists of five sub-sections, including details of participants, the feasibility of the intervention, delivery challenges, intervention effects and refinement of the programme theory for future implementation. The qualitative and quantitative analysis findings are presented together in each section where data from both were available.

4.4.1 Participants

Of the 49 participants approached for recruitment, 47 were enrolled in the study and completed baseline measures, and 33 residents took part in the intervention; a CONSORT diagram of the progress through the study is shown in Figure 4.4.

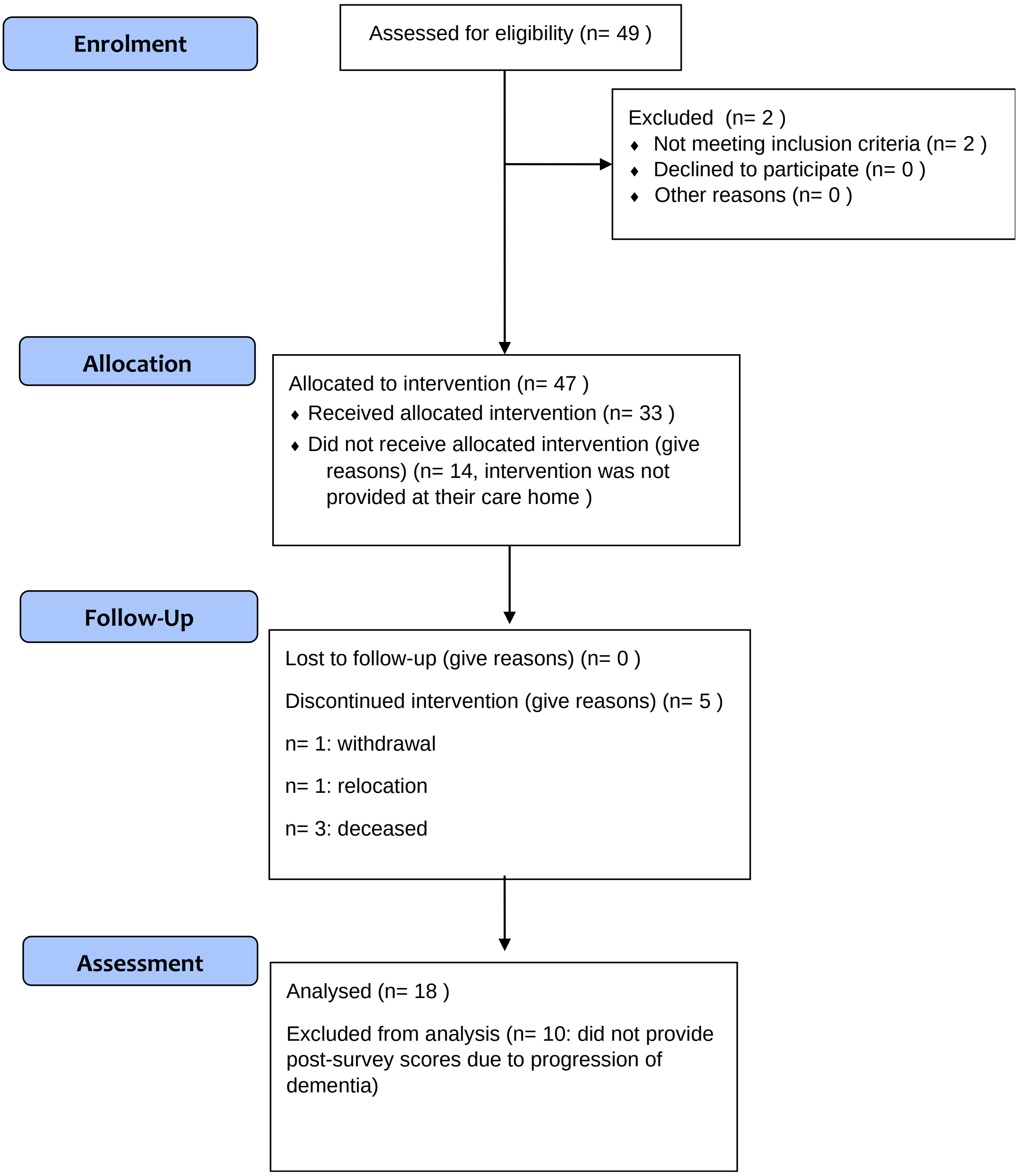

Figure 4.4 *CONSORT diagram modified for non-randomised feasibility trials.*

Most participants were females (84.8%) of White British ethnicity, with 84.9% aged 75 years and over. Most participants were selected from care home units for older adults with dementia. The four residents interviewed were between the ages of 75 and 90, and three were females. Baseline participant characteristics are detailed in Table 4.2.

Table 4.2 *Participant characteristics.*

Characteristic	**Description**	N(%)	
		N =33	N =18
Age group	60-74 years	5 (15.15)	2 (11.11)
	75-84 years	13 (39.39)	8 (44.44)
	85 or over	15 (45.45)	8 (44.44)
Sex	Female	28 (84.8)	15 (83.8)
Ethnic origin	White - British, Irish, other White	32 (96.97)	17 (94.44)
	Prefer not to say	1 (3.03)	1 (5.56)
Relationship status	Single, divorced, widowed	27 (81.82)	16 (88.89)
	In a relationship/married but living apart	2 (6.06)	1 (5.56)
	In a relationship/married and cohabiting	2 (6.06)	1 (5.56)
	Prefer not to say	2 (6.06)	0 (0)
Highest level of education	No qualifications	11 (33.33)	8 (44.44)
	Did not complete National 5s/Standard Grades/GCSE/CSE/O-levels or equivalent	3 (9.09)	1 (5.56)

Completed National 5s/Standard Grades/GCSE/CSE/O-levels or equivalent (at school till aged 16)	6 (18.18)	4 (22.22)
Highers/Advanced Highers/AS-levels/A-levels or equivalent (at school till aged 18)	6 (18.18)	2 (11.11)
Undergraduate degree or professional qualification	1 (3.03)	1 (5.56)
Prefer not to say	6 (18.18)	2 (11.11)

4.4.2 Feasibility of the intervention

Regarding feasibility, 47 participants from 10 care homes fulfilled the inclusion criteria, consented, and completed the pre-intervention surveys. Seven of these care homes provided the intervention programme, enrolling 33 residents. Five dropouts were noted: one due to withdrawal, one relocation and three residents who passed away during the intervention. Care homes delivered 57% of the sessions (193 of 336) over the 12-week intervention period, with an average resident adherence of 60%. Quantitative adherence statistics are shown in Table 4.3. Finally, 18 (54.55%) residents had sufficient cognitive ability at the follow-up to provide meaningful post-survey scores as informally assessed by the researchers with assistance from care home staff. When it became clear that participants had declined in their cognitive ability at follow-up beyond the ability to take part, the researchers immediately terminated the post-survey as it was not deemed ethical or meaningful to continue.

Table 4.3 *Adherence data*

	Number Sessions Offered														
Care Home	**Wk 1**	**Wk 2**	**Wk 3**	**Wk 4**	**Wk 5**	**Wk 6**	**Wk 7**	**Wk 8**	**Wk 9**	**Wk 10**	**Wk 11**	**Wk 12**	**Total**	**% Sessions Offered**	**Average sessions per week (median: 3)**
CH1	4	4	4	4	0	0	4	4	4	4	4	4	40	83.33%	3
CH2	4	4	0	0	0	0	0	0	0	0	0	0	8	16.67%	1
CH3	4	1	2	0	4	3	0	1	3	3	4	3	28	58.33%	2
CH4	1	4	3	3	1	3	4	3	4	3	3	4	36	75.00%	3
CH8	2	2	2	0	1	0	0	0	0	0	0	0	7	14.58%	1
CH9	4	4	4	0	0	4	2	4	0	0	4	4	30	62.50%	3
CH10	4	4	4	4	4	4	2	4	4	3	3	4	44	91.67%	4
	23	**23**	**19**	**11**	**10**	**14**	**12**	**16**	**15**	**13**	**18**	**19**	**193**	**57.44%**	

Note: CH-Care home. Seven of the ten care homes identified to start the programme started and completed the 12-week programme.

The interviews and focus group data derived five central themes with sub-themes on feasibility. For data integration and analysis, themes on feasibility were linked to the CMO configurations, which revealed sub-themes such as adherence, delivery challenges, modifications and intervention effects, as summarised in Table 4.4.

Table 4.4: *Data integration and analysis*

	Feasibility	Context	Mechanism	Outcome
Specific research objectives	Was the activity implemented and/or delivered as planned? Were adherence rates at an acceptable level? Were the outcomes adequate and realistic for this programme and setting?	What were the potential barriers to providing the resources for care homes or ACs? Were the programme's resources suitable for this setting?	What underlying mechanisms made the programme work (or not)? Was it the situational context or the programme context?	What changes resulted from this?
Themes derived from the data integration and analysis	- Adherence	- Delivery challenges - Facilitation resources - Cognitive impairment	- Motivation and engagement - Social support - Job satisfaction	- Qualitative and quantitative data about psychosocial health markers of participants

4.4.3 Adherence

Participation and class size were sub-themes from the central theme of adherence. Care home staff described residents' participation in sessions as 'not as expected' due to several delivery challenges. For example, one care home staff member who struggled to get residents to adhere to the recommended dose of the intervention mentioned:

> *"We (care home) did really struggle, especially at the start, and once the COVID cleared, it got a little bit better for a couple of weeks, and then it slipped back into them not really engaging in it."*

However, overall, the intervention was accepted by residents, which was seen in their participation and records of adherence. The digital intervention was an activity that the residents looked forward to. They referred to it as meaningful and purposeful. Some care home staff made comments like:

> "Most of our residents participated in all of the sessions. There were a couple of residents that missed a few; they just did not feel like it that day, or they were out with their families and things like that, but all in all, it was a good turnout."

and:

> *"They (residents) started to look forward to it. You know, they remembered it. It was really great. It was excellent."*

Also, regarding participation, the number of sessions offered to residents varied across care homes. Some care homes offered more sessions than the recommended dose, whereas others offered fewer. In the focus group discussions, care home staff stated in response to their being able to engage residents in three movement and one music session a week:

> *"I (AC) think we (care home) have done really well. The attendance was quite good. Actually, more residents participated, and we weren't doing this like three times a week, but probably four or five. I think it went great."*

but also:

> *"...I (AC) did probably, I have run it once per week, or maybe twice per week, sometimes in different parts of the care home."*

Class size differed in the various care homes, with some care homes recording an increase in the number of residents participating in the intervention and others seeing a decrease, again due to the challenges of delivering an intervention specifically in a care home setting. Care home staff explained that residents were lost to death, dementia and COVID-19 in comments such as:

> *"Two residents passed away, but we got a new resident, and then it was right up her street like music, dancing and exercise."*

and:

> *"Decrease for me (AC), but again it was like I said, the three residents in particular that their level of dementia got worse, they became unwell and just could not continue with the programme"*

and:

> *"I (AC) think I had the decrease just because we had COVID in the last month, just at the end of the 12 weeks. So that is why I could not really do any dancing and singing with people."*

4.4.4 Delivery challenges with the intervention

As mentioned above, difficulties with engagement and delivery were noted early on, and the CMO evaluation was applied. Difficulties noted in the researchers' logs implied a complex underlying situation in care homes vastly affected by, e.g., the COVID-19 pandemic, wider policy environment and understaffing (Context). This could affect motivation and engagement to deliver the programme or attend a session (Mechanism), affecting adherence rates and possibly implicating the psychosocial outcome measures. More details of these emerged in the qualitative adherence data below. However, Appendix 4.7 summarises the challenges that came with the delivery of the intervention.

Motivation and engagement

One integral part of the feasibility outcomes was delivery challenges which influenced adherence and informed the future modifications for the intervention discussed by the care home staff. The main challenge reported by care home staff was that participants were less motivated to engage in the programme, primarily at the initial stages. Also, participants initially keen to engage in the programme were demotivated when others withdrew or refused to participate. Participants also voiced that they were not enthused to participate all the time. In addition, residents' unavailability due to external visits to the care homes was a challenge. ACs and participants expressed these challenges by saying:

> *"The main difficulty was motivation, but that is really just at the start because once the residents are down and we begin, they are so happy, keen really focused on the exercise and things. So it was a small starting issue, but it did not last very long."*

and:

> *"Some weeks you are in the mood and other weeks you are not. You get in a mood. You know I (resident) am 76 now and some days you just cannot be bothered."*

and:

> *"There were a couple of residents that missed a few; they just didn't feel like it that day, or they were out with their families."*

and:

> *"There was one resident who enjoys exercises every day, she was always keen and motivated, but when it just came down to her participating alone, that was when she stopped. Nobody else was wanting to do it along with her, so she felt that she was on her own. She got less motivated to do it."*

Health Conditions

Further, cognitive impairment and disabilities of the older adults were potential barriers for ACs to provide the resources. One of the concerns raised by care home staff was the challenge of working with older adults with significant cognitive impairment and disabilities. Residents with dementia sometimes looked confused during sessions. Other residents with physical disabilities, such as mobility and hearing problems, did not participate fully in singing or movement sessions. ACs said:

> *"There were three residents in particular that their level of dementia got worse, they became unwell and just could not continue with the programme"*

and:

> *"Most residents have got difficulties with mobility, so some of the exercises were not very suitable."*

and:

> *"Like I (AC) said, the singing sessions did not go down well with people. They (residents) really didn't participate fully, for example, one resident has hearing problems and could not sing along.*

Death and hospitalisation

ACs explained that some participants were lost to death or admitted to the hospital and were unable to continue participation:

> *"There was one resident who went to hospital and was admitted to hospital. She was not able to participate anymore after that."*

and:

> *"We (care home) had two residents who passed away. Also, one was in the hospital for a few weeks as well."*

Moreover, the closure of care homes due to the COVID-19 outbreak disrupted participation in the programme as residents and care home staff were isolated for weeks. For example, an AC said:

> *"Our home was closed for about four weeks with COVID, so we had residents at all times isolate in their bedrooms. As we were all in bubbles, we did try one-to-one sessions, but obviously we would have to be in PPE and if they had COVID, they were not feeling up to. It was about four- or five-weeks chunk that we were not able really to participate much at all in the programme".*

Resources for delivery

ACs highlighted a lack of resources for delivery, including staff shortage and absence, technical problems and limited space for running sessions. As part of the discussions, it was recorded that there was a high staff turnover across care homes. ACs had no replacement care home staff to take up their duties when they were on holiday or isolated due to COVID-19 during the 12 weeks of the intervention. Also, ACs did not get any support from other care home staff. This was due to either the heavy workload on care home staff or a shortage of care home staff on duty. It was also reported by some care homes that poor internet connection and faulty display screens affected getting access to and viewing the digital intervention. Again, ACs expressed their struggles to set up lounges for sessions as the space is also shared with other residents not included in the study. In line with the sub-theme, 'facilitation resources' ACs put this across by saying:

> *"The internet over here (care home) is not great because we live in the countryside. Our signal is poor, so we have problems with buffering, loading and refreshing the page".*

and:

> *"We (care home) did have a technical hitch for about three weeks because we could not get the programme displayed on the TV's. Once the hitch was over, it was easy enough for the programme to go on our screens"*

and:

> *"...but it could have to do with our (care home) setting because they (residents) were in a lounge with other residents that were not participating. It was purely the fact we were short staffed, and the carers were not always there to transfer them into another room to do it."*

and:

> *"We (care home) found it difficult at times and just purely from separating the participants into another room due to staff shortages. We did come up with trouble of staffing."*

Progressive and future modifications

During the 12-week intervention, some changes were made by ACs to help residents adapt well to the intervention. Progressive modifications that care home staff found helpful in facilitating the programme included making participation a part of the care home schedule with an allocated time slot, playing music at the start of sessions, and briefing and encouraging residents before the start of sessions. These were expressed as:

> *"Well, I (AC) adopted an early pattern, about the 11:30 mark in the morning once everybody was up. They would have had their morning snack, the coffee and that time before lunchtime was always a good time. Before lunchtime is when I (AC) like to get the group together for activities. Whether crafts, music or live entertainment, it was a good period to get people together".*

and:

> *"We (care home) would always put the music on first, to lift their moods and try to get them to engage more in the exercises."*

and:

> *"We (care home) definitely found telling them in advance helped, so that they knew it (the intervention) was going to be happening the next day. Also, like I (AC) said, we did the music part first before the exercises to try and lift their mood and hope that more residents would take part."*

and:

> *"I (AC) spend lots of time trying to encourage people. I had to go and speak to them (residents)."*

Additionally, focus group discussions pointed to other alterations and actions that could be made to enhance the feasibility and future implementation of the intervention in care homes, leading to future modifications. It was suggested that the number of sessions be reduced from four to two or three sessions a week to recruit residents with low or no cognitive impairment and to play background music during movement sessions. Comments on future modifications included:

> *"Yeah, I (AC) would run the programme again, but not for four times per week. It is a little bit too much and you have to do other activities as well, not just sing and dance all the time. I will probably be doing it again once or twice per week. I think it is more than enough."*

and:

"I (AC) have noticed the music work. It is always better when they can hear songs they are familiar with. I think it would be better if there was louder music at the back in the background."

and:

"I (AC) definitely we would maybe choose a different group of people now because we have had different residents come in that I feel would probably be more suitable for it now than the initial ones we started with but certainly we would do it (intervention) again".

4.4.5 Intervention effects – Focus groups

From the qualitative data, perceived intervention effects were reported by both residents and care home staff. Sub-themes were improved mood and physical health, care staff job satisfaction and social support

Mood and physical health

It was mainly stated that the intervention improved the mood of residents. In some cases, an increase in residents' physical capabilities was seen:

"…and then as soon as the session starts their mood just goes up and up, and by the end of it (intervention session), they (residents) are so happy. We have got one lady who quite often would stand up and shake her hips and she was very motivated and excited. So, it was really great."

and:

"It (intervention) definitely improves moods. The difference between the start of the session and the end of the session with their moods was quite a big change."

and:

"Probably for one resident, I (AC) would say as the sessions went on, she done a little not much, but a little bit more each one so I do not know if that's been physical for her meaning it has made her physically a bit stronger."

Job satisfaction

Care home staff also acknowledged that facilitating the programme gave recognition to them in the care home, gave them a sense of fulfilment and added to their knowledge of PA. Some excerpts affirming the importance of the intervention to care home staff were:

> *"I think it made us feel good to see them happy and made you think that that you have done a good job. So it is just a feel good thing and makes you go home at night and think I have had a good day."*

and:

> *"I have gained loads through this experience, so I have learnt new movements which are safe and easy to follow. It was great to do some stretches in the morning as well for everyone and sometimes other staff would join and enjoy it too."*

and:

> *"It has been very beneficial for me. I was able to get to know people (residents) better as well and they (residents) recognise me now. They do recognise me and sometimes they would just follow me. Some residents would just follow me because they know there will be something fun happening."*

and:

> *"They look at us (ACs) different from the carers because we have the time to spend with them and have fun with them."*

Social support

Residents were happy to work with ACs, built friendships and loved participating in groups. Also, care home staff pointed out that engaging in the programme helped to establish positive resident-resident and resident-staff relationships. Some comments on social support included:

> *"I (AC) think just like the social kind of bonding, it has brought us (staff and residents) all a bit closer I think."*

and:

"They (residents) get really engaged and I think we (care home) have really enjoyed the social part of it as well. Just being with friends and doing something meaningful was great"

and:

"When there is a song playing, the carers around also join in and sing a couple of songs with residents and encourage them (residents) to do a couple of movements."

4.4.6 Intervention effects – Survey

Pre- and post-intervention data from the surveys provided insights into the multidimensional health outcomes of the participants. Significant changes were noted for anxiety and depression (HADS), loneliness (brief UCLA loneliness scale), perceived stress (PSS), and sleep quality (STT). However, given the feasibility nature of this study and the small sample size, more importance should be given to the mean differences and 95% CI and effect sizes (Cohen's d) presented in Table 4.5 to show that the intervention yielded positive effects across many measures

Table 4.5 *Effect of the intervention on well-being outcomes*

Variables	Baseline mean	Post-intervention mean	Mean diff	95% CI	p-value	Effect size (Cohen's d)
Falls Efficacy Scale (FES)	8.17	8.72	-.556	[-4.199, 3.088]	.752	-.076
Dartmouth COOP funnctional health assessment charts	16.33	15.17	1.167	[-.664, 2.998]	.197	.317
Hospital Anxiety and Depression Scale- Anxiety	6.22	4.11	2.111	[.373, 3.850]	.020*	.604
Hospital Anxiety and Depression Scale- depression	6.17	3.17	3.000	[1.303, 4.697]	.002*	.879
EuroQol 5-Dimension 3-level (EQ-5D-3L)	8.00	7.72	.278	[-.714, 1.270]	.562	.139
Brief University of California, Los Angeles	10.61	8.94	1.667	[.067, 3.267]	.042*	.518

Loneliness Scale (Brief UCLA loneliness scale)						
Perceived Stress Scale (PSS)	14.72	10.56	4.167	[.318, 8.016]	.036*	.538
National Sleep Foundation Sleep Satisfaction Tool (STT)	27.06	33.72	-6.667	[-9.174, -4.159]	<.001*	-1.322
Short Nutritional Assessment Questionnaire 4-Item (SNAQ4)	16.39	16.22	.167	[-1.078, 1.411]	.781	.067

4.4.7 Refinement of the programme theory for future implementation

The primary programme theories underpinning the danceSing Care programme were described in the Introduction. The outcomes of this study were interpreted according to the CMO configuration as outlined in the process of the realist evaluation (Figure 4.1). This revealed practical implications for future intervention in this particular care home setting (Table 4.6). The four main refinements towards a future intervention were: (1) implementing two or three sessions/week, (2) encouraging participation in the care homes, (3) adding questionnaires of multidimensional health markers complemented with objective measures in a possible future RCT, (4) considering dementia in the care home population. Consequently, refinements to the initial programme theories are offered to aid the future implementation of this digital music and movement resource in wider care home settings.

Table 4.6 *Refinement of the programme theory for future implementation*

Primary and secondary programme theories	Refinement of the programme theories for future implementation
(1) If the danceSing Care resources are delivered to the care homes, the ACs would consistently deliver the programme to the residents.	- Adherence was best when the programme was given two to three times/week out of the four sessions recommended. Therefore, future studies could implement two to three sessions/week.
	- For danceSing Care staff and researchers, fewer than ten participating care homes would facilitate and speed-up problem solving of any unforeseen barriers regarding the resources, such as tech issues or staffing problems.
(2) If the programme is delivered in the care homes, the residents would want to participate regularly.	- Participation could be improved if the danceSing Care resources were part of the regular care home schedule, with an allocated time slot, playing music at the start of the sessions and briefing and encouraging residents before the start.
(3) If the ACs provide the programme consistently, the participants will experience improved psychosocial health markers. Changes in pre-and post-survey data and qualitative interviews would evidence this.	- Questionnaires evidenced improvements in several multidimensional health outcomes of participants. Indicators of frailty should be complemented with physical function tests. Objective measures such as actigraphs or endocrine measurements could provide additional information about specific health parameters.

(4) If the ACs were given enough organisational support (e.g., resources and time), they would be engaged in this programme. This would establish shared learning and co-production between programme developers, care homes, and researchers.	- Wider contexts (e.g., the care home system in Scotland or the COVID restrictions) and organisational contexts (e.g., time and staffing) are out of our control. They are, therefore, not included in this programme refinement. However, before future implementation of the danceSing Care resources occurs, tech issues (e.g., internet access or big screens) and staff issues (e.g., a dedicated AC with back-up) could be factored in.
(5) If the group sessions were adequately and consistently used, residents would feel more engaged in group activities, creating a community. This communal feeling would increase self-confidence and quality of life and reduce loneliness. This could potentially inspire future usage of the programme's resources.	- Some care home residents who participated had cognitive impairment, influencing the adherence and understanding of measurement tools. Considering the cognitive status of care home residents and exploring how to tailor the intervention to those lacking the capacity to consent due to cognitive impairment could make findings more generalisable in a future intervention.

4.5 Discussion

The findings of this mixed-methods feasibility study on multidimensional health outcomes of a digital PA intervention using music and movement resources were evaluated through a context-mechanism-outcome (CMO) configuration using a realist approach. This method considered the challenging situation care homes in Scotland, UK, were in during the COVID-19 pandemic and the resources available to the care homes and staff. Consequently, the feasibility of this intervention was established as a component of how the programme would translate into the domain of policy and practice. Discovered delivery challenges were (1) motivation and engagement, (2) cognitive impairment and disabilities of the participants and changes in these, (3) death and hospitalisation of the participants and (4) limited staffing and technology resources to deliver the programme as intended. Regarding the secondary aim of performing limited efficacy testing on multidimensional health markers, ACs and residents commented on improved mood, physical health, job satisfaction and social support, with large effect size values and improvements in the questionnaire scores for anxiety, depression, feelings of loneliness, perceived stress and sleep satisfaction, but no changes in fear of falling, domains of general health and appetite. Due to the feasibility nature of this study and the small sample size, pre- to post-intervention data should be considered preliminary. Overall, these findings tentatively support the recommendation to implement a future RCT, with limitations discussed below. The initial programme theory was therefore refined as discussed below.

4.5.1 Refinement of the programme theory for future implementation

Refinement 1: Future intervention could be implemented two or three sessions/week.

The mean adherence to this 12-week intervention at a dose of 3+1 sessions per week was 57%. This is lower than the findings of a previous systematic review about adherence to supervised technology-based exercise programmes for 12 weeks in older adults, where the expected adherence range would fluctuate from 70% to 100% (Valenzuela et al., 2018). In this study, adherence was best when the programme was given two to three times/week. This aligns with the recommendations of a Taskforce Report about PA and exercise for older adults living in care homes, suggesting a frequency of twice a week, with an interval of at least 48 hours between sessions (de Souto Barreto et al., 2016)

Refinement 2: Encouraging participation in the care homes.

Participation and engagement are pertinent issues for developing trials and implementing interventions in practice (Yardley et al., 2007). Research staff and danceSing Care staff tried to engage the ACs to personally invite the care home residents into the programme and emphasise the multiple benefits of training programmes, as these strategies are suggested to be important to maximise participation in older adults (Yardley et al., 2006).

Further, throughout the intervention, the danceSing Care team attempted to create community groups to join the 'danceSing Care family'. However, these approaches need to be adjusted to get more appeal from ACs and residents in the future, for example, having more interaction on social media pages. Finally, to maximise adherence to these music and movement resources, special care should be given to making the sessions habitual in the care home, as adherence to PA interventions tends to taper off in the long run (Nyman & Victor, 2011).

Refinement 3: Adding questionnaires of multidimensional health markers complemented with objective measures in a possible future RCT.

The intervention effects on multidimensional health markers should be treated as tentative due to the feasibility nature of the study, i.e., the small sample and the lack of a control group. Nevertheless, the programme effects suggest benefits to participants' health and well-being, as evidenced by the large effect size values. A future larger-scale RCT would be necessary to confirm this. However, these findings are consistent with the literature on the effects of music and movement resources in older adults, indicating positive changes in mental well-being (Brustio et al., 2018; Cordes et al., 2021; Da Silva et al., 2022; Guzmán-García et al., 2013; Hwang & Braun, 2015; Low et al., 2016; Windle et al., 2010). Physical function tests could usefully complement frailty measurement to aid diagnostic accuracy (Clegg et al., 2013; Fried et al., 2001). Further, during ageing, the endocrine regulation of certain hormones gets challenged, e.g., the activity of the adrenocortical cells that produce the major sex steroid precursor dehydroepiandrosterone (DHEA) and dehydroepiandrosterone sulphate (DHEAS) decreases, often alongside a gradual rise in cortisol (stress hormone) release (Chehab et al., 2007; Heaney et al., 2014). Therefore, objective measures of this type could complement health outcomes, such as biomarkers of the hypothalamic-pituitary stress axis (cortisol and DHEA(S)) (De Nys et al., 2022).

The qualitative analysis showed improvements in ACs' and residents' mood and physical health, job satisfaction and social support. Similarly, in previous qualitative studies, older adults in interviews and focus groups have reported that PA interventions have improved their perceptions of their physical capacity and overall physical health. Previous observations in older adults also found psychological benefits of engaging in PA. These benefits include enjoyment and happiness, which comes not only with engaging in PA but also with enjoying the company of others in the group and connecting with people (Lindsay-Smith et al., 2019; Maula et al., 2019; Swales et al., 2022). Likewise, previous studies have described that care home staff job satisfaction is associated with high recognition of their contributions to the care home and a sense of belongingness, purpose and responsibility in the care home (Foà et al., 2020; Hirakawa et al., 2019; Moyle et al., 2003). Thus, these qualitative findings correspond with the belief that providing care and support to residents in the care home setting is challenging but exciting and fulfilling for care home staff. Similarly, conducting research in care homes has been reported to benefit care home staff through training and empowerment (Jenkins et al., 2016).

Refinement 4: Considering dementia in the care home population

Although no data about cognition was formally collected in the current study, it should be noted that it was observed that many of the included participants suffered a significant cognitive decline throughout the programme. This affected participation and, in this instance, significantly reduced the number of post-intervention assessments possible. One previous study showed that residents who accepted technology-based resources were significantly less cognitively impaired than those who did not (Ulbrecht et al., 2012), adding to the relevance of considering and measuring cognitive status and extending recruitment to those lacking the capacity to consent, where possible. In addition, the adherence to an exercise session of an RCT with residents having dementia showed similar adherence rates to this study (Henskens et al., 2018). The reason for the differences in adherence rates between residents with and without dementia could be that in people without or with only mild cognitive impairment, the instructions and explanations on exercise and its benefits usually used to promote PA (Spittaels et al., 2007) come across more clearly, possibly increasing adherence. This approach is not feasible in advanced cognitive impairment as individuals cannot process and remember verbal instructions, highlighting the need for individually tailored activities to functional ability and interest (Hill et al., 2010). However, real-time reinforcement and feedback while exercising could improve adherence and provide an opportunity to monitor performance over time (Valenzuela et al., 2018). This task could be attributed to the ACs in the care homes in a future RCT.

Further, studies including care home residents with dementia generally use the Mini-Mental State Examination (MMSE) (Folstein et al., 1975) or similar to screen for cognitive impairment (Henskens et al., 2018; Thurm et al., 2011). Thus, using a cognitive impairment measure could complement the understanding of the effects of dementia on the feasibility and effectiveness of future interventions. This would not be to screen out residents with dementia as those unable to consent to participate in a research study or complete survey measures might still benefit from participating in the intervention programme. This would need careful assessment and potentially repeated screening to assess changes in cognitive function across the intervention and repeated consent for measurements throughout such an intervention (Yardley et al., 2007). Further, a fruitful line of future research would be to explore how to tailor the intervention to those lacking capacity with cognitive impairment. A future trial could also extend to recruiting those with cognitive impairment who lack the capacity to consent via personal/nominated consultees.

4.5.2 Strengths and limitations

Realist evaluation approaches have been advocated for evaluating complex care interventions (Byng et al., 2005; Salter & Kothari, 2014). This approach steers away from a 'one-size-fits-all' problem-solving approach (Pawson & Manzano-Santaella, 2012). Indeed, it has some clear strengths. It uses a sound methodology to consider multiple actors at play in complex situations. It translates this into the world of policy and practice. However, these approaches are relatively new compared to the processes commonly used in feasibility studies evaluating health care interventions, with a less rigorous traditional methodology. Also, emphasis was placed on contextual factors during some COVID-19 restrictions in the care home system in Scotland. Therefore, the present conclusions may be subject to temporal and situational changes in how programmes are implemented.

Nonetheless, care was taken to reach optimal data integration at multiple levels (methods, interpretation and reporting) in the most objective ways possible. Also, stakeholders' feedback (via interviews, focus and advisory groups) was integrated during the data analysis. This acknowledges the importance of the co-production of stakeholders in terms of future programme implementation. Second, the present study is limited by the small sample size, high attrition, and lack of a control group. However, as this was primarily a feasibility study, an adequately powered RCT design was not implemented at this early stage and would form the next step in evaluating this intervention. Finally, it should be acknowledged that restricting recruitment to those with the capacity to consent means that we cannot generalise the present findings to that sub-population, a common sub-group of care home residents. However, we did not preclude inclusion in the intervention group from those lacking capacity, and some individuals who did participate had cognitive impairment, although this influenced adherence and understanding of the measurement tools. Ideally, future research would examine how best to tailor this intervention to the sub-group of individuals with cognitive impairment and lack of capacity to consent and then extend recruitment to those lacking capacity via personal/nominated consultees.

4.6 Conclusion

This realist evaluation of a feasibility study of a digital music and movement intervention in care homes suggests that such an intervention is feasible, at least in individuals with the capacity to consent and mild cognitive impairment. The adherence and delivery of the resources are likely to meet greater success when the following features are adopted: (1) implementing two to three sessions per week, (2) encouraging participation by personally inviting the care home residents into the programme or by making the resource a habitual activity and individually-tailoring the activity to the resident's functional/cognitive ability and interest, (3) complementing existing health questionnaires with physical function tests for frailty screening and/or other objective measures of health and well-being, (4) measuring and taking into account cognitive impairment of the participants including exploring ways to tailor the intervention to those lacking capacity to consent.

Chapter 5: Intervention Two, danceSing Care phase Two: Pilot RCT of a digital music and movement intervention in older adults in care homes.

This Chapter is based on the pilot RCT "Digital music and movement resources to improve health and well-being in older adults in care homes: a pilot randomised trial", currently under peer review by *BMC Geriatric*s (https://doi.org/10.21203/rs.3.rs-3658587/v1). The outline and conduct is based on the CONSORT 2010 statement extension to randomised pilot and feasibility trials (Eldridge et al., 2016).

5.1 Background

This Chapter presents the pilot RCT conducted as a logical final study in the context of the PhD project and provides insights for future interventions. The systematic reviews (Chapters Two and Three) identified gaps in the literature, and the preliminary feasibility study (Chapter Four) provided insights into the practical aspects of implementing a PA intervention in care homes. Thus, these studies allowed for further investigation of a digital music and movement intervention as a potential approach in the care home setting through a pilot RCT.

5.2 Introduction

As the demographic shift towards an ageing population accelerates (Office for National Statistics, 2021; United Nations Department of Economic and Social Affairs Population Division, 2022), a transition to care home or supported living facilities may become the most viable option for older individuals living alone and requiring high-level supervision and care (OECD, 2021; Wiener et al., 2009). The multifaceted challenges confronting older adults residing in long-term care settings, such as limited mobility, limited independent access to outside facilities/activities and lack of social interaction, present barriers to maintaining PA levels (Sackley et al., 2006). PA has been shown to have significant positive effects on the healthy ageing trajectories of older adults (Daskalopoulou et al., 2017), with favourable effects on the endocrine system (Kraemer et al., 2020; Kraemer & Ratamess, 2005; Sellami et al., 2019), anxiety and depression (Schuch et al., 2016; Stubbs et al., 2017) and physical function (Nusselder et al., 2008; Paterson & Warburton, 2010). With the rise in technological developments, an increasing number of innovative digital PA interventions have been developed for use in various populations and settings (Davies et al., 2012; Muellmann et al., 2018). However, research on the effectiveness of digital resources in promoting PA among older adults in care home settings remains limited (Muellmann et al., 2018). This study aimed to address this issue by investigating the effectiveness of digital PA resources for the health and well-being of older adults in care homes.

Several physiological and psychological challenges are evident in the context of ageing. First, there is a notable change in the functioning of the endocrine system, with the hypothalamic-pituitary-adrenal (HPA) axis being particularly affected, as indicated by changes in the secretion patterns of cortisol and dehydroepiandrosterone and/or its sulphated form (DHEA/S) (Ferrari et al., 2001; van den Beld et al., 2018). This can substantially affect the immune system (Buford & Willoughby, 2008; Butcher et al., 2005; Phillips et al., 2007). Second, older adults, whether community-dwelling or in care homes, experiencing reduced social support, chronic disease, and decreased self-esteem are at an increased risk of mental health issues such as anxiety and depression (Alipour et al., 2009; Boyd, 2007), which negatively impacts their well-being and quality of life (Olatunji et al., 2007; Vancampfort et al., 2017). Finally, a decline in physical function is commonly observed with ageing, increasing older adults' vulnerability to falling, frailty, rising healthcare costs and premature death (Stenholm et al., 2015; Taekema et al., 2012; Tolley et al., 2021). While these challenges can have profound negative impacts on older adults, research has demonstrated that PA can counterbalance these challenges and positively influence healthy ageing by improving cortisol and/or DHEA(S) levels (De Nys et al., 2022), anxiety and depression (Ofosu et al., 2023), muscle mass, strength, and thus physical function, frailty, and quality of life (de Vries et al., 2012; Pedersen & Saltin, 2015; Sherrington et al., 2008; Swales et al., 2022; Warburton et al., 2006) Therefore, PA interventions are a viable approach to mitigating the adverse effects of ageing on the endocrine system, psychological well-being, and physical function in older adults.

However, poor adherence to PA programmes is often reported in institutional settings such as care homes (Nyman & Victor, 2011). To improve adherence, innovative digital PA resources have been developed for delivery with older adults, showing promising results to impact health, e.g., by improving quality of life (Chan et al., 2021), muscle mass and physical function (Kraaijkamp et al., 2021; Nishchyk et al., 2021) and decreasing feelings of anxiety and depression, dementia (Preschl et al., 2011) (for reviews, see (Davies et al., 2012; Muellmann et al., 2018)). However, although most trials showed a positive trend towards the efficacy of digital interventions, better quality evidence is needed considering the heterogeneity in the measures used across studies and to address limitations associated with modest sample sizes and relatively short intervention durations. Further research is warranted to evaluate the effectiveness of digital PA resources on physiological, psychological and social dimensions of healthy ageing (Buyl et al., 2020; Tonga et al., 2022). In particular, the evidence for the effects of digital PA resources on steroid hormones in older adults is scarce. For example, several studies have noted a lack of quality evidence for the impact of PA interventions in care home residents on anxiety symptoms, cortisol and DHEA(S) (De Nys et al., 2022a; De Nys et al., 2022b; Ofosu et al., 2023). In addition, there is evidence that conducting PA in a group can enhance the effects of the intervention by enhancing social connectedness and reducing loneliness (Lindsay-Smith et al., 2019; Maula et al., 2019; Swales et al., 2022). Thus, interventions combining the digital delivery of PA with a group exercise setting should be examined.

Music, as a common component of group PA delivery, also warrants attention due to the health benefits demonstrated in studies on dance (Hwang & Braun, 2015; Liu et al., 2021; Sooktho et al., 2022) and music interventions (Dingle et al., 2021). The intervention evaluated in this study combined group participation with multicomponent exercises and added a music and singing aspect because music has been shown to positively impact mood, anxiety, and stress, making it an effective tool for improving mental health outcomes (Dingle et al., 2021; Lai & Lai, 2017; Taylor et al., 2023). Music can also enhance the enjoyment of PA, increasing adherence and compliance with exercise programmes (Clair, 1996; Priest et al., 2004; Vaz et al., 2022). Additionally, the use of music may help evoke positive memories and emotions, contributing to overall emotional well-being through reminiscence (Ellis & Salmoni, 2021). However, the effectiveness of music interventions can vary significantly based on individual preferences and the type of PA (Petrovsky et al., 2015). The intervention evaluated in this study used a combination of digital delivery and in-person support aimed to address the challenges and maximise the benefits of both group PA and music for older adults in care homes.

To this end, a preliminary study tested the feasibility of a digital music and movement resource in care homes (Ofosu et al., 2023). Key outcome measures were determined by an advisory group consisting of the research team, care home staff, older adult representatives and representatives from danceSing Care, the company that devised the digital intervention. The study results determined that such a programme was feasible with recommended adjustments for future implementation (Ofosu et al., 2023). In light of these recommendations, a pilot RCT was designed to investigate whether a 12-week digital music and movement resource, compared to a waitlist control group, would improve some of the same measures from the original study (anxiety, depression, fear of falling, loneliness, quality of life, perceived stress and sleep satisfaction) in addition to measures that are deemed important in previous literature but not possible to measure during the first study (salivary cortisol and DHEA levels and physical function). The primary aim of this pilot RCT was, therefore, 1) to evaluate the efficacy of a digital movement and music intervention within care home settings and its subsequent impact on a range of health and well-being outcomes and 2) to decide whether and how to proceed with a future definitive randomised controlled trial by interpreting specific progression criteria, following the previous feasibility study.

5.3 Methods

5.3.1 Design

The danceSing Care evaluation trial was a mixed-methods multicentre Randomised (1:1), waitlist-controlled, parallel-group Trial (RCT). Participants in the intervention group and waitlist controls were recruited from care home facilities in central Scotland. Data were collected through salivary endocrine measurements, physical assessments, self-reported questionnaires, and semi-structured qualitative interviews.

Ethics approval was given by the University of Stirling Non-invasive Clinical Research panel: NICR 2021 3735 3607. This pilot study protocol is registered with the Clinical Trials Register: NCT05601102.

5.3.2 Procedure, setting and locations

The study occurred at care homes in central Scotland from March to July 2023. Residents capable of giving informed consent were invited to participate in the study after a brief introduction through posters utilised by care home staff and face-to-face interaction with the researchers. Researchers, with the help of care home staff, recruited residents from four Holmes Care Group care homes. Recruitment started four weeks before the intervention with a live meeting and initiation session for the ACs in the care home. Initially, two homes were recruited, but within a week, it became apparent that a further two would be needed to reach the target sample size. Participants recruited to both intervention and waitlist control groups completed baseline and post-intervention questionnaires with the assessors (LDN & EO) in private areas (empty lounges, bedrooms) in their respective care homes to ensure privacy and confidentiality. Physical function tests and saliva samples were measured in empty hallways and private rooms. A random sub-sample of seven participants was interviewed two weeks after completing the post-intervention measures to report additional and in-depth intervention effects that were not captured in the survey measures. Five care home staff (ACs and/or carers) who facilitated the online intervention were also interviewed in person to share their experiences throughout the process.

5.3.3 Participants

Eligibility criteria for participants

Eligible participants were adults aged 65 or older living in care homes with an established connection to the digital music and movement provider. They needed to be capable of completing a 12-week movement and music program, providing informed consent, and comprehending the research measures, as evaluated by care staff. Cognitive decline experienced during a previous feasibility study (Ofosu et al., 2023) influenced eligibility, particularly regarding understanding research measures among those with cognitive impairment. Due to time constraints and ethical considerations, addressing capacity-related issues for individuals lacking both consent capacity and understanding of measures was not feasible. Eligibility assessment followed the British Psychological Society capacity checklist (British Psychological Society, 2010), and verbal consent was reaffirmed at each interaction. Ineligibility criteria included participation in concurrent clinical trials that could affect this study's outcomes, pre-existing conditions significantly impacting their ability to undergo the intervention, and insufficient English proficiency to engage in measures and intervention due to cognitive or sensory impairments.

Sample size

G*power was used to determine the sample size. The statistical test (ANOVA: Repeated measures, within-between interaction) and the power of the analysis (*A priori*: compute required sample size) were selected, with $\alpha = .05$ and power = .80. The standardised mean difference (SMD) (= .80) for the cortisol outcomes was used from a previous systematic review (De Nys et al., 2022) to determine the effect size for this study. This revealed a required total sample size of n = 16. To account for a possible 20% attrition, group sample sizes were inflated to n = 20. Similarly, the effect size for the anxiety outcome in this pilot RCT was based on an SMD of .27, which was recorded from the previous systematic review (Ofosu et al., 2023). This revealed a required total sample size of n = 110. To account for a possible 20% attrition, the total sample size was inflated to n = 132. However, consultation with the care home management suggested that this sample size would not be pragmatic given the high level of cognitive impairment among residents and, thus, the small number of residents eligible for recruitment. Further, the previous feasibility study showed effects in n = 18 for the psychosocial outcomes, so the target sample in this pilot study was set at 36, based on a general rule of thumb of 30 (Browne, 1995) and accounting for a possible 20% attrition while considering that in a future full-scale RCT, a minimum of 132 participants should be recruited. Given the feasible sample size, it was determined that individual randomisation (i.e., by the participant) would be more pragmatic than cluster randomisation (i.e., by care home), which requires larger sample sizes due to other cluster/site differences (Rutterford et al., 2015).

5.3.4 Intervention

Participants were randomly assigned to participate in a digital movement and music programme with resources from danceSing Care for 12 weeks or a waitlist for 12 weeks before participating. This programme consisted of two movement sessions and one weekly music session, each lasting about 20 minutes. This was the recommended dose based on the refinements made by the preliminary feasibility study (Ofosu et al., 2023). These sessions were delivered in a group-based setting, with the digital resources displayed on a large screen under the supervision of the care home’s AC in a communal room. The sessions were low-to-moderate intensity, including a warm-up and cool-down period. Care home AC(s) led the sessions and received training on engaging participants and using the digital resources from danceSing Care programme trainers. The danceSing Care programme could be tailored to accommodate the preferences and needs of the participants, with sessions labelled according to their dementia-friendliness, and ACs could select the most appropriate session for those taking part. Instructions were integrated into the digital resource to adapt the exercises for sitting or standing postures during movement sessions according to ability, and the music and sing-along sessions were personalised based on the music preferences of older adults. In line with the recommended methods of reporting intervention designs, a TiDieR checklist is detailed in Appendix 5.1.

5.3.5 Outcome Measures

The primary and secondary outcome measures and when they were implemented are summarised in Table 5.1. The primary outcomes were salivary cortisol, DHEA levels, and anxiety symptoms. Secondary outcomes were fear of falling, loneliness, quality of life, stress, sleep satisfaction, physical function and frailty phenotype.

Table 5.1 *Summary table of outcome measures*

Baseline measures	**Source**	**Time point**
Demographic information	Self-report	Baseline
Primary measures		
Salivary cortisol and DHEA	Assessor	Baseline and post-intervention.
Hospital Anxiety and Depression Scale	Self-report	Baseline and post-intervention.
Secondary measures		
Questionnaires • Falls Efficacy Scale • Dartmouth Cooperative Functional Assessment Charts	Self-report	Baseline and post-intervention.

• Brief UCLA loneliness scale • Perceived Stress Scale • Sleep Satisfaction Tool		
Physical function tests • Short performance battery • Hand grip strength • Fried frailty phenotype criteria	Assessor	Baseline and post-intervention.
Qualitative data	Semi-structured interviews	Post-intervention
Progression criteria • Recruitment rate	Assessor	Post-intervention
• Intervention fidelity • Attendance • Retention rate • Safety		Monitored during and completed after the intervention

5.4.5.1 Questionnaires

Demographics

Standardised socio-demographic questions about age, sex, ethnicity, relationship status and education were included.

Anxiety and Depression

Symptoms of anxiety and depression were measured using the Hospital Anxiety and Depression Scale (HADS) (Zigmond & Saith, 1983). The HADS consists of two subscales with seven items, each measuring anxiety or depression on a four-point response scale from zero to three, resulting in a maximum score of 21 on anxiety or depression. Specifically, the anxiety subscale covers symptoms of generalised anxiety disorder, whereas the depression subscale focuses on anhedonia (Snaith, 2003). This measure has been validated in older adults with or without cognitive impairment, making it suitable for residents in care homes (Cronbach's alpha for HADS anxiety= 0.87, HADS depression = 0.81) (Djukanovic et al., 2017). The present study's internal consistencies for anxiety and depression were 0.85 and 0.66, respectively.

Falls

The FES-I short form (Kempen et al., 2008) validated in older adults (Cronbach's alpha = 0.92) measured fear of falling while carrying out daily activities such as getting dressed or attending social events. The FES-I is a seven-item scale with responses on a Likert scale from zero (not at all concerned) to three (very much concerned) and total scores ranging from zero to a maximum score of 21. Internal consistency in the present study was 0.93.

Health related quality of life

Participants' health-related quality of life across domains of physical fitness, activities of daily living, feelings, social activities, and change in health and overall health status for the past two weeks was measured with the Dartmouth COOP charts (Nelson et al., 1987) which has test-retest reliability coefficients ranging from 0.67 to 0.82 (Jong & Smith, 1990). This measure has six charts with responses on a five-level ordinal scale ranging from one (no limitation at all) to five (severely limited) for all items except the change in health item, which is reverse scored so that one and five mean much better and much worse, respectively (Nelson et al., 1987). A high score indicates poorer health-related quality of life, with scores ranging from six to a maximum of 30. Internal consistency in the present study was 0.80.

Loneliness

The short-form UCLA loneliness scale (ULS-6) (Neto, 1992) measured feelings of loneliness among participants. The ULS-6 has a Cronbach's alpha for the reliability of > 0.7 and is made up of six items and response options on a four-point scale (1-never to 4-often), where a high score shows increased subjective feelings of loneliness, and scores range from six to a maximum of 24 (Neto, 2014). The Cronbach's alpha in the present sample was 0.85.

Perceived Stress

The Perceived Stress Scale (PSS) (Cohen et al., 1983) was used to measure how participants experienced their stress during the past month. It consists of ten items with a five-point Likert scale ranging from zero to four that indicates to what extent people perceived stress (depicting low, moderate, and high perceived stress), resulting in a higher total score indicating higher perceived stress from zero to a maximum of 40. Reliability in this study was 0.91.

Sleep Satisfaction

The National Sleep Foundation's Sleep Satisfaction Tool (SST) (Ohayon et al., 2018) was used to measure sleep satisfaction. It is a nine-item scale scored on Likert response scales (one to four) with a Cronbach's alpha of 0.87 and a high score suggesting greater sleep satisfaction, where scores can vary from nine to a maximum of 36. In the present study, the alpha for reliability was 0.90.

5.4.5.2 Salivary cortisol and DHEA

A one-point saliva sample for cortisol and DHEA concentration measurement was obtained in the morning by a cotton wool swap (between 10:00 and 12:30), at least 30 minutes after the first diurnal food intake. This was optional, requiring consent to opt in. Participants were asked not to eat, drink (other than water), or smoke for two hours before obtaining the salivary samples (Stalder et al., 2016). The field researcher provided detailed verbal and visual instructions on obtaining the samples to help with compliance. Samples were collected at baseline and post-intervention at the same time of day, and each participant's waking time and sampling time were recorded in a participant case report form upon sampling completion.

Saliva samples were collected in universal tubes, centrifuged at 4,000 rpm for 5 minutes, and the supernatant was transferred to Eppendorf tubes (Eppendorf, Hamburg, Germany) for storage at –20 °C until assay. Cortisol and DHEA concentrations were determined using ELISA kits from Salimetrics LLC, USA, following the manufacturer's protocols. Both assays were conducted in one batch, with samples assayed in duplicate with intra-assay coefficients of <10%. The assays utilised a competitive immunoassay method, where the unknown cortisol or DHEA in the sample compete with a fixed amount conjugated to horseradish peroxidase for antibody binding sites on a microtitre plate. After incubation and enzymatic reaction, the hormone concentrations were inversely proportional to the optical density read at 450 nm, with a secondary filter correction at 490 to 492 nm. All procedures were executed with precision to prevent contamination.

5.4.5.3 Physical function

The short physical performance battery (SPPB) (Guralnik et al., 1994) was used to assess physical function among older adults. It comprises three tests: balance, 4-metre gait speed, and a chair stand test to assess leg strength. A score between 0 and 4 is assigned for each test, and the three tests are weighted equally. Therefore, the maximum score is 12 points. The cut-off value used to assess poor physical performance is ≤8 points, according to the European Working Group on Sarcopenia in Older People (EWGSOP) (Cruz-Jentoft et al., 2010). The interrater reliability of the SPPB in older adults is shown to be excellent (ICC = 0.81 to 0.91) (Medina-Mirapeix et al., 2016; Olsen & Bergland, 2017), and test-retest reliability in people with dementia is also excellent (ICC = 0.92) (Olsen & Bergland, 2017).

Grip strength was utilised as a surrogate measure of overall muscular strength, predicting health and mortality risk (Gale et al., 2007). An analogue hand-held dynamometer (JAMAR 5030J1, Sammons Preston) was used to measure the hand grip strength of the dominant hand, taking the best score of three attempts with 20 seconds rest between the attempts (Bohannon, 2008). The test-retest reliability of grip strength in older adults is good (ICC ≥.85) (Wang & Chen, 2010).

The Fried frailty phenotype assessment was used to evaluate frailty (Fried et al., 2001) and is well-established and validated (Bieniek et al., 2016). It considers five criteria: (1) unintentional weight loss measured through the question 'In the last year, have you lost more than 10 pounds unintentionally (i.e. not due to intentional dieting or exercise)?' (1 point if present); (2) walk time measured across a 4.57 (15-foot) distance and stratified by sex and height (1 point if above the specified cut-off); (3) grip strength as described above and stratified by sex and BMI (1 point if below the specified cut-off); (4) physical exhaustion measured through two questions from the Center for Epidemiologic Studies Depression (CES-D) (Radloff, 1977) asking about feelings or behaviours related to depression in the past week. Participants were asked to reflect on the past week and indicate how often they felt a certain way on statements indicative of depressive symptoms or statements (1 point if present); (5) energy expenditure through the Minnesota Leisure Time Activities Questionnaire (MLTAQ)

(Taylor et al., 1978) assessment of leisure-time PA and used in conjunction with weight and kcals per activity, (1 point if below the threshold: <383 Kcals/week for men and <270 Kcals/week for women). Positive criteria thus score 1 point, dividing participants into three categories. Scores range from 0 (not frail), 1-2 (prefrail), to 3-5 (frail).

5.4.5.4 Interviews

The researchers devised the semi-structured interview guide (see Appendix 5.2) in consultation with the study advisory group and focused on the general overview of what participants and ACs thought of the programme and the benefits they derived. Interviews lasted approximately 12 minutes with 15 to 25 questions, including follow-up questions that probed further into responses.

5.4.5.5 Delivery outcome - Progression criteria

This trial employed a traffic light or Red Amber Green (RAG) approach, with red indicating major problems requiring urgent attention, amber indicating minor problems requiring attention, and green indicating no concern (Eldridge et al., 2016). The criteria were developed in consultation with the advisory group (Table 4) This extended the preliminary realist evaluation that thoroughly documented the feasibility of the delivery and the acceptability of this intervention. The group further assessed the feasibility of specific trial objectives, inclusion and exclusion criteria, and outcomes (Ofosu et al., 2023). Thus, the criteria of this trial were based on recruitment, intervention fidelity, attendance, retention rates, and safety. Data were reviewed against the progression criteria, and the research team held regular meetings to discuss progress and concerns.

5.3.6 Randomisation

For the allocation of the participants, the Randomization Allocation Software (Saghaei, 2004) was used for sequence generation in a 1:1 sequence by individual participants. Two researchers enrolled and assessed the participants in the study and allocated ID numbers to each of them. The random allocation sequence was concealed from the researchers at baseline testing as the principal investigator generated the assignment sequence of ID numbers. Details about the intervention and waitlist control allocation groups, including attendance sheets with names of the participants receiving the intervention to enable ease of matching prior to pseudo-anonymisation, were provided to the ACs to return attendance sheets at the end of each week via email.

5.3.7 Blinding

Blinding the participants is not possible when participants are allocated to a waitlist-control group. The researchers taking the measurements were blinded to the allocation of the participants at baseline assessment, but this was not possible at post-intervention assessment. However, the researchers strictly followed approved protocols and guidelines, ensuring the handling of saliva and physical function measurements and questionnaire assessment was as standardised as possible across participants and time points.

5.3.8 Data analysis

Intention to Treat analysis of questionnaire, physical function and saliva assay outcomes

Baseline clinical and demographic characteristics were summarised and reported using descriptive statistics. Quantitative data from primary and secondary outcomes were collected, and intention-to-treat (ITT) analyses were performed in IBM SPSS Statistics (version 28.0) to examine the effects of the intervention and the waitlist comparison control group on the primary study outcomes. As stated *a priori* in the protocol, the intention was to conduct an ITT analysis using repeated-measures between within-groups ANOVA with pre- and post-intervention as the repeated measures and intervention versus waitlist control as between-group variables. However, discussions while collecting follow-up data and through interviewing ACs made it evident that the randomisation protocol had not been adhered to at all sites, resulting in participants in both groups receiving the intervention simultaneously. As a result, a true control group was not established. Consequently, an ITT analysis was conducted on pre-post-intervention change in the whole sample. As a sensitivity analysis, a per-protocol analysis was conducted on the sample with available data, i.e., complete cases only, not ITT.

Estimated effect sizes (Cohen's d – interpreted as small ($d = .2$), medium ($d = .5$), and large ($d = .8$) based on Cohen (1988), means, mean differences and their precision (95% confidence interval (CI)) were calculated for continuous data and a count (number, %) for nominal data.

5.3.9 Ancillary Analysis

Between-group ANOVAs with *post-hoc* comparisons were conducted to assess the intergroup variations based on care home adherence levels on pre- to post-intervention change scores across all questionnaires, physical function and physiological metrics. Additionally, a series of correlation analyses were conducted to explore whether psychosocial and physical changes elicited by the intervention might be related.

Intervention fidelity and attendance

Intervention fidelity was analysed for the duration of the 12-week intervention as the total number of sessions delivered divided by the intended number of sessions (3 per week). Participant attendance was analysed as the number of sessions attended divided by the total number of sessions delivered. The raw fidelity and attendance data were multiplied by 100 for a percentage representation.

Qualitative analysis of interviews

Based on the research objectives, a thematic analysis (Braun & Clarke, 2006) was performed on the qualitative data to identify, analyse, organise, and communicate themes emerging from the interviews. After each interview, one researcher (EO) reviewed the audio recordings and field notes. After transcribing the interviews, the researcher synthesised the data into relevant themes with NVivo 12 and coding was independently reviewed by a second researcher (LDN). Thematic analysis was done independently, but the themes derived were linked to the progression criteria, thus the qualitative results have been presented in association with the progression criteria.

5.4 Results

5.4.1 Participant flow

Initially, 37 participants were identified by care home staff as eligible and approached for recruitment. Thirty-four were recruited and randomised into 17 in the intervention group and 17 in the waitlist control group. Figure 1 shows participant flow through the study. In the intervention group, all 17 received the intervention. However, one died, and one withdrew, resulting in 15 participants with complete data for the intervention group. As the interventions took place in the communal living rooms where the waitlist-control group was also present, this group at times, also received the intervention. Further, two participants passed away, one left the care home, one lost the capacity to consent, and one withdrew (n=12 with complete data for the waitlist control). There were no other missing survey data except for the UCLA Loneliness scale, which one participant chose not to complete. Also, four participants did not undergo the physical function tests, and 16 either opted out or could not provide saliva measurements. Therefore, the dataset included 27 participants with pre-post data and 34 for ITT analysis. The subsequent analyses reported here are full sample pre- and post-intervention comparisons. Non-adherence to the delayed delivery of the intervention to the waitlist control group was not evident during the collection of adherence/attendance registers because the attendance of participants on the waitlist was not recorded on the weekly attendance register. This only became apparent in post-intervention data collection and discussion with ACs when arranging testing sessions and interviews.

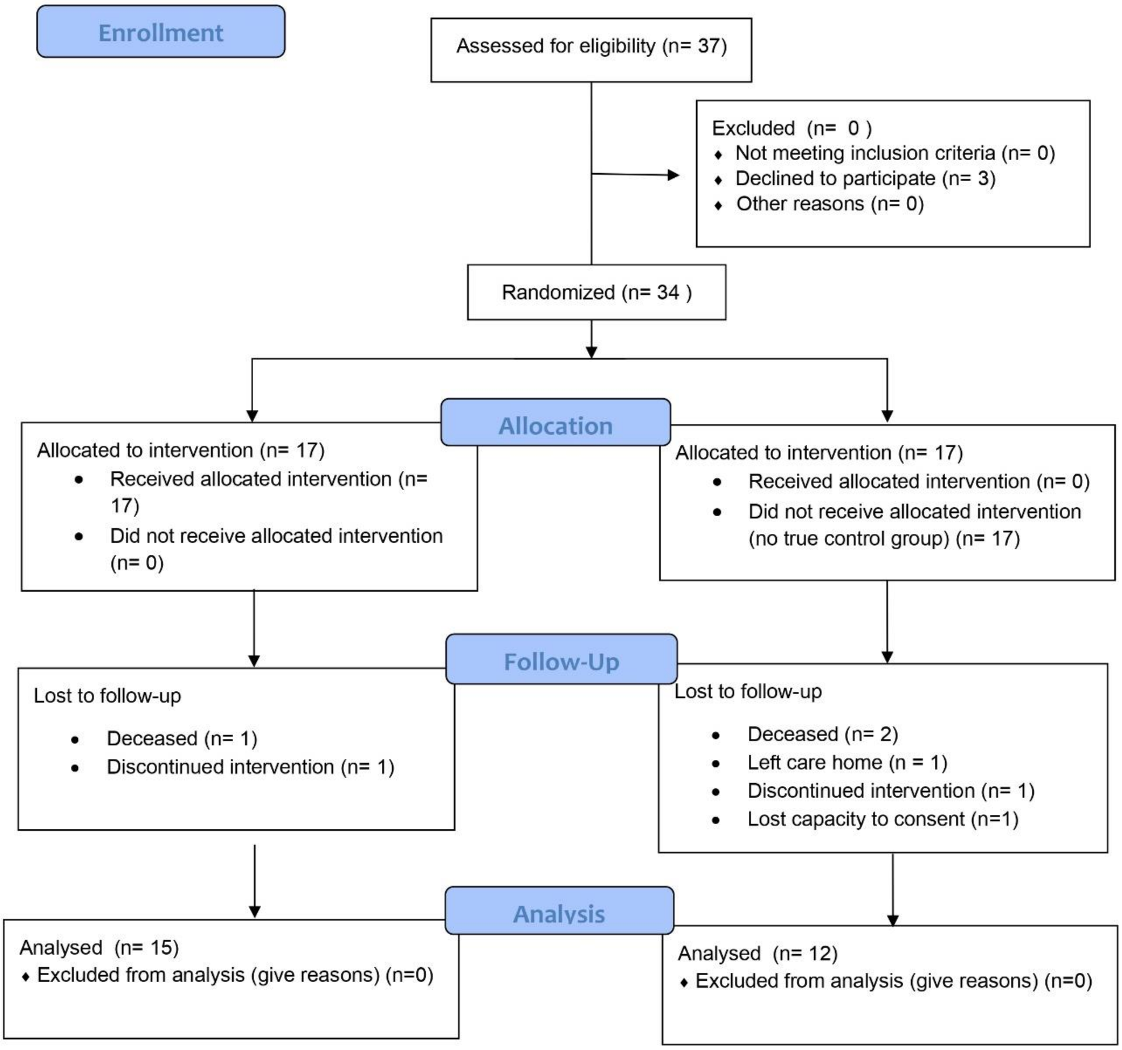

Figure 5.1 CONSORT flow diagram

5.4.2 Baseline data

Baseline demographics and clinical characteristics for each group are presented in Table 5.2. Chi-square tests (for categorical data) revealed no significant differences in these characteristics. Most participants were female (59% in the intervention group and 82% in the control group). All participants identified as White: British, Scottish, Welsh, English, Irish, or other. The most common educational attainment was no qualifications (38%).

Table 5.2 *Baseline characteristics per group based on randomisation.*

Variables	Mean (SD) / n (%)		p
	Intervention group (n = 17)	**Waitlist control group (n = 17)**	
Age group			.31
65-74	3 (18)	3 (18)	
75-84	10 (59)	6 (35)	
85 or over	4 (24)	8 (47)	
Sex (Female)	10 (59)	14 (82)	.13
Ethnic origin (White)	17 (100)	17 (100)	1.00
Relationship status			.25
Single, never married	4 (24)	2 (12)	
Single, divorced or widowed	9 (53)	14 (82)	
Living apart	2 (12)	1 (6)	

Cohabiting	2 (12)	0	
Highest level of education			.09
No qualifications	8 (47)	5 (29)	
Completed National 5s/Standard Grades/GCSE/CSE/O-levels or equivalent (at school to age 16)	5 (29)	4 (24)	
Highers/Advanced Highers/ AS levels/A-levels or equivalent (at school to age 18)	4 (24)	1 (6)	
Did not complete National 5s/Standard Grades/GCSE/CSE/O-levels or equivalent	0	4 (24)	
Completed post-16 vocational course	0	1 (6)	
Undergraduate degree or professional qualification	0	2 (12)	

5.4.3 Primary and Secondary Outcomes

Table 5.3 presents the ITT results of all participants' within-group analyses of pre- and post-intervention change. For salivary cortisol and DHEA, there was no significant change in salivary cortisol or the cortisol:DHEA ratio, however, salivary DHEA levels showed a significant increase [$t(17) = -5.25$, $p < .001$]. For anxiety symptoms from the HADS, a significant anxiety reduction was observed [$t(33) = 2.78$, $p = .01$].

For the secondary outcomes, significant improvements were observed in loneliness [$t(32) = 2.50$, $p = .02$], and fear of falling [$t(33) = 2.11$, $p = .04$]. However, no significant changes were observed in depression scores, health-related quality of life, perceived stress, sleep satisfaction, the SPPB total or individual scores, handgrip strength, or Fried Frailty phenotype.

Table 5.3 *ITT analysis of all outcome variables.*

Variables, desired direction of effect on health	**n**	**Baseline mean**	**Post-intervention mean**	**Mean difference**	**95% CI**	**p**	**Effect size (d)**
Cortisol (ug/dL), -	18	0.30	0.40	-0.10	[-.34, .15]	.41	-0.20
DHEA (pg/mL), +	18	1455.40	2359.21	-903.81	[1267.26, -540.36]	<.001*	-1.24
Cortisol:DHEA, -	18	0.00028	0.00029	0.00001	[-.00011, .00018]	.61	0.12
HADS-Anxiety (0-21), -	34	6.00	4.50	1.50	[.40, 2.60]	.01*	0.48
FES (0-21), -	34	5.29	3.47	1.82	[.07, 3.58]	.04*	0.36
Dartmouth COOP (6-30), +	34	15.97	14.85	1.12	[-.41, 2.64]	.15	0.26
HADS-Depression (0-21), -	34	6.44	6.03	0.41	[-.62, 1.44]	.42	0.14
Brief ULS (6-24), -	33	12.27	10.64	1.64	[.30, 2.97]	.02*	0.44
PSS (0-40), -	34	12.94	11.56	1.38	[-.84, 3.61]	.22	0.22
STT (9-36), +	34	29.61	30.57	-0.96	[-2.79, .86]	.29	-0.18
SPPB total score (0-12), +	30	4.67	4.67	0.00	[-.73, .73]	1.00	0.00
SPPB balance (0-4) **, +**	30	1.87	1.70	0.17	[-.36, .70]	.52	0.12
SPPB gait speed (sec) (0-4), +	30	2.17	2.37	-0.20	[-.45, .05]	.11	-0.30
SPPB chair stand (0-4)**, +**	30	0.63	0.60	0.03	[-.25, .32]	.81	0.04
Handgrip strength (kg)**, +**	30	15.73	16.00	-0.27	[-1.30, 0.76]	.60	0.10
Frailty total score (0-5), -	30	2.63	2.63	0.00	[-.20, .20]	1.00	0.00

*Note: FES: Falls Efficacy Scale International (7-item), Dartmouth COOP: Dartmouth Cooperative Functional Assessment Charts measure of health-related quality of life, HADS: Hospital Anxiety and Depression Scale, ULS: UCLA Loneliness Scale PSS: Perceived Stress Scale, STT: National Sleep Foundation Sleep Satisfaction Tool. * significance* $p < 0.05$

5.4.4 Sensitivity analysis

As described above, a sensitivity analysis per protocol on those retained in the study, which provided data at baseline and post-intervention (n = 27), was conducted. The summary results in the same format as for the ITT are presented in Appendix 5.3. In brief, the primary and secondary outcomes largely remained consistent between the ITT and sensitivity analyses. However, there were slight differences in the effect sizes for anxiety, fear of falling, and loneliness, with the sensitivity analysis showing slightly larger effect sizes for these outcomes than the ITT analysis.

5.4.5 Exploring progression to an actual RCT – Mixed methods

The outcomes of these progression criteria, which were recruitment, intervention fidelity, attendance, retention rates, and safety, are found in Table 5.4: Progression criteria.

Table 5.4 Progression criteria

Progression criteria	Cut-off scores for each progression criterion	Grading with traffic light system	Meaning	Recommendations
Recruitment rates	Green (No Concern): Recruitment meets or exceeds the expected target. Amber (Minor Problem): The cut-off for amber is set at achieving 70-90% of the expected recruitment target. Red (Major Problem): Recruitment falls significantly below feasibility, with less than 70% of the expected target achieved.	Green: Slightly lower than expected but feasible (94%)	If the recruitment rate is lower than expected but still feasible to achieve the required number of participants, additional efforts can be made to improve recruitment.	Additional efforts such as extending the recruitment period, implementing additional recruitment strategies (such as reaching out to more care homes or collaborating with other organisations), intensifying recruitment efforts (e.g., increasing advertisement or utilising referrals), modifying the design to include those without the capacity to consent can be considered.
Intervention Fidelity	Green (No Concern): High fidelity to the intervention protocol, with minimal or no deviations observed.	Amber: Moderate intervention fidelity (88%)	This indicates room for improvement and adjustments in future implementations to enhance fidelity and ensure closer adherence	First, strategies can be implemented to enhance fidelity to the planned frequency, such as making it part of the weekly care home routine. Second, efforts should be

	Amber (Minor Problem): Moderate fidelity with some deviations from the protocol. The amber threshold is defined as adherence to 70-90% of the key elements of the intervention. Red (Major Problem): Poor fidelity with significant deviations. Less than 70% adherence to the key elements of the intervention.		to the intervention protocol. Attention should be given to addressing the identified deviations and barriers to ensure the integrity of the intervention delivery.	made to promote adherence to the randomisation process by providing the ACs with clear written guidelines and training. Addressing the identified barriers, such as providing additional support and training or allocating a separate ‘exercise room’, may also improve fidelity. Third, tracking adherence rather than calculating it at the end would help identify if randomisation protocols need addressing early on.
Attendance rate	Green (No Concern): High attendance rates, with participants attending 75% or more of the scheduled sessions. Amber (Minor Problem): Moderate attendance, with	Amber: Moderate attendance rates (56-89% depending on the care home, with 72% overall attendance)	This category signifies participants completed the intervention or followed the protocol with minimal deviations or non-compliance, and there are some concerns regarding adherence.	Continuous attendance monitoring remains essential to identify any potential barriers or challenges that may impact attendance in the future. Ongoing assessment can help inform adjustments to the study protocol or provide additional support or reminders, if necessary, to improve attendance further.

	participants attending 60-75% of the sessions. Red (Major Problem): Low attendance, with less than 60% attendance.			
Retention rate	Green (No Concern): High retention rates, with 80% or more of the participants remaining in the study until its conclusion. Amber (Minor Problem): Moderate retention, with 60-79% of participants retained until the end of the study. Red (Major Problem): Low retention, with less than 60% of participants retained.	Green: High retention rates	This indicates that 80% or more participants were successfully retained with no immediate concerns and suggests that the study effectively maintained participant involvement and minimised attrition during the 12-week intervention period.	Ongoing efforts such as proactive communication with participants, offering incentives or support, and ensuring clear expectations and benefits of participation can further enhance retention rates in future studies.
Safety rates	Green (No Concern): No significant adverse events reported. Amber (Minor Problem): Minor adverse events reported,	Green: No significant adverse events were reported, with no concerns.	This indicates that the study can proceed as planned without substantial safety issues.	Continuous monitoring allows for identifying and appropriately managing potential adverse events, even if they are minor or expected.

but these do not significantly impact the overall safety of the intervention. The amber threshold is defined as less than 5% of participants experiencing minor adverse events.

Red (Major Problem): Significant adverse events reported, affecting more than 5% of participants, or any severe adverse event, regardless of frequency.

5.5.5.1 Recruitment rates

The recruitment rate of 34 participants falls slightly below the target sample size of 36. The categorisation as green indicates that while the recruitment rate was slightly lower than anticipated, it is still considered feasible to attain the desired sample size through additional recruitment efforts.

5.5.5.2 Intervention fidelity

The ACs in the care homes demonstrated moderate fidelity to the intervention protocol, with some deviations identified in frequency and randomisation. The overall average session delivery rate among the care homes was 88% (127 sessions out of the intended 144 sessions, three sessions each week over 12 weeks) over the intervention period. However, some variability was noted between care homes: one care home delivered 97% of the intended sessions, a second care home provided even more sessions than intended (119%), while a third and a fourth care home provided only 78 and 58% of the sessions. Overall, this indicated moderate fidelity. Quantitative adherence statistics are shown in Appendix 5.4

The variability of adherence among care homes could have resulted from some barriers encountered during the facilitation of the intervention. From interviews with the ACs (facilitators of the intervention), circumstances in the care home context made delivery of the recommended weekly sessions difficult and, in some cases, impossible. For some care homes, the barriers included a staff shortage, creating additional responsibilities for all staff, poor internet connection and scheduling of the intervention as part of the busy routines in care homes.

For example, ACs said:

> *"No, the three sessions a week didn't hold very well, but that wasn't because we didn't want to do it, it was because of certain circumstances. We couldn't do it. Holidays, people being off sick, staff shortages and things like that. We have to help out wherever we can and, so if we're not able to do the activities we (ACs) could be put on care and kind of things like that and so that stopped us from doing it, but we always try to manage to do at least once or twice a week. We thought that's better than nothing"*,

and,

"*The Wi-Fi in here was really shocking and we had someone come out to try and fix it. We bought those Wi-Fi boosters. We bought them for all over here. It's just [the] building. That was hard. Unless we had someone that had their hotspot from their phone, it constantly cut out. It constantly froze. So that was one of the most difficult things*",

and,

"It was time factor for me. Getting everybody together. If they had visitors in, I had to wait till their visitors went and then get them together. And I tried to organise, like a set time, but then when the visitors come in, the visitors are important, so we had to wait longer and longer, but I would say that, and fitting it in around our other activities was the only thing".

Other than the contextual barriers, ACs also reported poor engagement from participants and influenced weekly sessions' delivery and frequency. For some participants, poor engagement was due to cognitive impairment. For others, it was poor physical health, individual preferences, low motivation, and enthusiasm towards the intervention. To explain the challenges, ACs said:

"I think for some of them, it was as a result of their dementia or things like that. They have a shorter attention span and sometimes when they're sitting there, they will all of a sudden not realise why they're there. We have (Participant A) in particular who would always say, "what am I doing here? What am I doing here?" but after we'd explained to her about a good few times what we were doing, she calms down. So some of them were just like that",

and,

"It depended on the mood of the day. You could get one resident that is absolutely amazing one time and then on another day they just don't want to do anything",

and,

"I think some of them (participants) did enjoy the programme and some didn't. I think we struggled with the movement sessions. There were a few of them that didn't really want to do any kind of dances or a lot of the movements, but they loved the singing ones, they absolutely loved them"

One participant also said,

"Well, I'm just not as able as I was. I think it's a struggle to me now, even getting up and about. It just changed overnight. I like to do it but sometimes I'm just not able, like last night, I just wasn't well at all."

Despite the deviations in frequency per week, it is noteworthy that once a session was conducted, the ACs adhered to the planned intervention components, including duration and intensity. This suggests a level of commitment to maintaining fidelity within the delivered sessions. Also, from the interviews, ACs reported that the intervention has gradually been integrated into the care home routine and expressed interest in its continuity. The statement below from one AC showed positive acceptability and satisfaction with the intervention:

"We are going to continue using it, we are going to continue it as much as we can. I mean if we don't get it all the time, if we're only able to maybe do the once or twice a week or even if it only goes down to one, it's still going to get done. It's part of the curriculum now, so it's going to stay".

However, it is essential to re-emphasise that none of the care homes followed the waitlist control group randomisation process as instructed in the protocol, indicating low fidelity in that aspect.

To improve adherence and participation among participants, ACs adopted mechanisms that made facilitation easier in their respective care homes, irrespective of the difficulties at the onset of the intervention and the challenges during the intervention period. For some care homes, the ACs joined in the sessions to help motivate and maintain enthusiasm. For other care homes, it was adding it to the schedule and telling visitors ahead of time when sessions would start. In line with this, ACs said:

"Sometimes, not always, it was easy to get them back to continue the sessions. We just kind of started dancing with them and kind of danced them back towards where they were. It was kind of sneaky but we liked it",

and,

> *"I think when we (ACs) are up moving about more instead of sitting and doing the exercises they're more inclined to get involved. Even though I'm sweating at the end of it, they're more inclined to enjoy it. I think they get a good laugh out of it",*

and,

> *"Well, I spoke to some of their families, and they said don't worry about it just come and get her (participant) if she's to go to that (intervention session). It'll be fine and so the families were really good",*

and,

> *"Probably like doing it with them. I wasn't like just letting them do it by themselves I was actually involved and liked engaging with them".*

5.5.5.3 Attendance of participants

Although the intended controls received the intervention, the ACs provided no data on these participants' retention or attendance rates. Therefore, the data provided below, and in Appendix 5.4, consists of the residents initially randomised in the intervention group. The mean participant attendance rate out of the possible total number of sessions delivered, thus available to them in one care home, was 82%. In another care home, it was 60%; in the third care home, it was 89%; and in the fourth care home, it was 56%. Attendance of participants was influenced by several factors, including personal, social and the intervention design as described above. In addition, the interviews from both residents and ACs revealed that participants' positive engagement in the programme was motivated by their personal history and the memories the intervention brought back, the conversations it started and the opportunity to do something different. Participants said:

> *"Well, it's easy dancing, so you can do that. I quite liked getting a bit of fun out of it",*

and,

> *"I liked the singing, I liked us all singing together and people up dancing",*

and,

> *"It was past the morning and it was something to do, something to listen to rather than just sitting up here doing crossword. It brought us all together and we all got up, we danced and it was a good atmosphere. I thought it brought everybody together and so it was a good change from just sitting in here doing nothing",*

and,

> "*I used to be a singer. I am good at singing and so I was happy to join the programme*"

In support of how well participants accepted the intervention, ACs said:

> *"I must admit they liked Alan the singer. When we put that up, they get really involved in. The exercises they've done but not with the same gusto as the singing",*

and,

> *"Oh definitely, because sometimes they'll come and say, "what time are we doing that thing at the day"? They don't say danceSing. It is good that they looked forward to it",*

and,

> *"…because even when they're dancing with you, they start chatting away to you as well, and when they're doing certain songs, they'll say, "I did this such a time". They remember when they've heard a song, which is kind of cute. The songs brought back good memories".*

Participants in these care homes demonstrated a commendable commitment to completing the intervention or following the protocol as instructed. With attendance rates at 72% overall, the relatively high adherence rates suggest that participants actively engaged in the intervention activities as intended, increasing the likelihood of achieving the desired outcomes.

5.5.5.4 Retention rates

During the 12-week intervention period, one participant of the intended intervention group discontinued the intervention. This signifies a high retention rate, with most participants retained throughout the study. The retention rate of 94% reflects a strong participant engagement and commitment to the study.

Other than engagement, commitment and other factors that influenced participant attendance, and the high retention rate in this study can also be attributed to the perceived impact of the intervention on their physical and psychosocial well-being. Participants and ACs described the benefits of the intervention as boosters that fuelled participation and continuity throughout the intervention period. Specifically, one participant said:

> *"I think I am getting a little bit stronger. The fear is going away and I want to try things"*

Also, ACs explained the impact of the intervention by saying:

> *"It was good. It was good because they (participants) improved a lot. Like, I had one resident downstairs, if she's not doing something, she's overthinking. When she wasn't in the programme, she was overthinking but because she distracted herself with the dance and singing, it made her happy because she was quite depressed. So, it was good for some residents obviously. It distracted them from overthinking by doing something else and by moving about. So, I think it's a really good programme",*

and,

> *"It helped them to move a lot more and obviously coming down and socialising in a group",*

and,

> *"It was good. It was getting a lot of them together including those that weren't involved in the research. It was good to see everyone being engaged and taking part in the programme. It brought them together",*

and,

> *"Well, they were a lot happier, they were upbeat, they had a laugh… And they spoke about it afterwards. They were very enthusiastic, put it that way",*

5.5.5.5 Safety rates

Throughout the intervention period, no significant adverse events were reported among the participants. This indicates a favourable safety profile, with no adverse events of significant concern observed during the study.

5.4.6 Ancillary analyses

The between-group ANOVAs with *post-hoc* comparisons revealed no significant differences across adherence groups (groups were: low adherence at 58%, moderate adherence at 78%, and high adherence at either 97% or 119%) on change scores of the study outcomes, except for the Dartmouth COOP health-related quality of life scores [$F(2,33) = 4.52$, $p = .02$]. Subsequent *post-hoc* tests revealed that this score was significantly different in the low adherence group compared to both the moderate ($p = .01$) and high ($p = .04$) adherence groups. Scores stayed the same in the low adherence group but improved slightly in the moderate and high adherence groups.

As anticipated, due to theoretical links between these constructs, results from the correlation analyses (see Appendix 5.5) revealed several noteworthy associations, including reductions in fear of falling linked to enhanced quality of life, reduced anxiety and depression, decreased feelings of loneliness, lowered perceived stress, and improved sleep satisfaction. Further, significant associations were detected between frailty and sleep satisfaction. An improvement in SPPB scores related to an increase in anxiety, however, the mean change in SPPB was zero.

5.5 Discussion

5.5.1 General discussion

The primary aim of this pilot RCT was twofold: 1) to evaluate the efficacy of a digital movement and music intervention within care home settings and its subsequent impact on a range of health and well-being outcomes; and 2) to decide whether and how to proceed with a future definitive randomised controlled trial. The main findings revealed a significant increase in salivary DHEA levels and reduced anxiety, loneliness, and fear of falling. The study's qualitative insights also provided a deeper understanding of the intervention's progression criteria. Participants expressed enjoyment and appreciation for the opportunity the intervention provided to come together, fostering a sense of community and shared experiences. The music component of the sessions was a favourite, evoking positive memories and emotions. However, the implementation of the intervention faced challenges, including time constraints due to care home routines, understaffing, and technical issues like unreliable Wi-Fi connections. The trial's analysis was complicated by care homes' non-adherence to the waitlist control condition, resulting in all participants receiving the intervention simultaneously.

The finding of a significant increase in salivary DHEA levels aligns with studies highlighting the positive effects of PA on older adult's endocrine function, specifically the improvement of DHEA levels even in small samples (De Nys et al., 2022; Heaney et al., 2014; Zouhal et al., 2022). Such increases have been associated with improved immune function, enhanced cognition, and reduced risk of chronic diseases of older adults (Kroboth et al., 1999; Maninger et al., 2009; Phillips et al., 2010b). The lack of significant change with PA in cortisol levels contrasts with previous literature showing that PA improved cortisol output (Anderson & Wideman, 2017; De Nys et al., 2022; Duclos & Tabarin, 2016; Fragala et al., 2011). However, this could be explained by this study's lack of statistical power and/or the fact that training intensity has to exceed 60% VO2 max to impact the HPA axis (Caiozzo et al., 1982; Hill et al., 2008), and the current digital PA intervention was of lower intensity. It is also suggested that the exercise effects on the HPA axis differ from person to person and depend on the person's personal choice of PA, needs, values and circumstances (Bouchard et al., 1994; De Nys et al., 2022; Kubzansky et al., 1999). More person-tailored interventions and objective metrics like heart rate monitors could provide more accurate insights into the programme's intensity.

Further, a single daily measurement of saliva was opted for, a decision driven by practical and financial constraints. While a single sample in the morning is often and reliably used to assess diurnal secretory activity to assess within-subject variations over a certain period in an older population (Kraemer et al., 2006), this approach does not comprehensively reflect the diurnal fluctuations of cortisol nor account for inter-individual day-to-day and intra-individual variations, especially within a smaller sample (Coste et al., 1994; Pruessner et al., 1997). To gain a more nuanced understanding of cortisol dynamics and its relationship with DHEA, future studies should integrate multiple measurements across consecutive days (Segerstrom et al., 2014).

The research also indicated a significant reduction in anxiety symptoms post-intervention, reinforced by qualitative findings of participants experiencing diminished 'fear'. This aligns with literature emphasising the benefits of PA on mental health parameters, specifically anxiety (Ofosu et al., 2023; Stonerock et al., 2015). PA has been shown to reduce anxiety symptoms through multiple mechanisms: improved brain circulation, increased release of endorphins, and enhanced self-efficacy (Petruzzello et al., 1991). The care home environment, where residents might often feel confined or limited in their autonomy (Moilanen et al., 2021), could heighten feelings of anxiety. Thus, interventions that encourage movement and social interaction might offer considerable benefits in reducing such feelings.

The non-significant present findings for depression symptoms contrast with some previous studies. While numerous studies have highlighted the antidepressant effects of PA (Barbour et al., 2007; Blumenthal et al., 2007), the results did not indicate a significant change in depression levels post-intervention. It is worth considering the intervention's duration, intensity, or the specificities of the current cohort, which may account for the lack of observed change (Ofosu et al., 2023). Although changes in anxiety were statistically significant, in this cohort, the baseline mean scores for both anxiety and depression fall within the "normal" range. This could imply that participants had relatively low levels of these symptoms to begin with, making significant reductions more challenging to achieve. This supports the hypothesis of a potential floor effect contributing to the absence of a significant change in depression scores (Djukanovic et al., 2017). Additionally, the chronicity and aetiology of depressive symptoms in a care home population might be multifactorial (Milne, 2016), requiring interventions beyond PA.

One of the most intriguing findings was the disparity between psychological well-being improvements and the lack of significant changes or substantial effect sizes in physical function tests and frailty markers. The significant improvements in well-being markers echo the idea that psychosocial factors, like social engagement in group-based PA, play a critical role in older adults' mental health (Holt-Lunstad et al., 2015; Sebastião & Mirda, 2021). On the other hand, the lack of improvements in physical function and frailty was surprising, given substantial evidence of the benefits of PA on physical function and frailty in other research (Dugan et al., 2018; McPhee et al., 2016; Mollinedo Cardalda et al., 2019; Morucci et al., 2022; Paterson & Warburton, 2010). This intervention might not have improved these measures due to the limited tailoring and intensity of the programme. Research showed that different types of physical exercise yielded varied effects on frail institutionalised older adults' cognitive state, functionality, and general health, suggesting that a tailored approach could be more effective (Mollinedo Cardalda et al., 2019). There is also a shown correlation between higher levels of PA and reduced risks of functional limitations, disability, and cognitive impairments, implying that interventions with higher intensity could potentially yield better outcomes in older adults (McPhee et al., 2016; Paterson & Warburton, 2010). Given this, future interventions may need to be more tailored to the individual and aim to employ strategies to ensure higher intensity is achieved when performing the activity sessions.

Feedback from the participants highlighted the added value of the music and dance components. These elements have been successfully integrated into intervention programmes for older adults, improving balance, physical function, muscle strength and endurance (Hwang & Braun, 2015; Liu et al., 2021; Rodrigues-Krause et al., 2019; Sooktho et al., 2022; Vordos et al., 2017). Concurrently, the profound emotional resonance of music, with its capacity to evoke cherished memories and stimulate dopamine release, has been previously identified as a powerful tool for enhancing mental well-being (Bromberg-Martin et al., 2010; Dingle et al., 2021; Jakubowski & Eerola, 2022; Menon & Levitin, 2005). This was also noted during the interviews, where participants highlighted their enjoyment of the music components, suggesting these played an essential role in the positive outcomes observed. Beyond their direct benefits, the music and dance elements may also have acted as motivators, potentially increasing participation and commitment to the programme, as studies in older adults have found that adding music to PA can increase enjoyment and, as a result, participation in PA programmes (Clair, 1996; Priest et al., 2004). Thus, combining music and movement in intervention programmes holds promise for future research programmes targeting older adults’ well-being.

The qualitative analysis revealed recurrent barriers and facilitators influencing intervention efficacy, mirroring findings from other studies, such as logistical challenges and staff enthusiasm (Hoben et al., 2017; Nocivelli et al., 2023). Participant feedback emphasised the acceptability of the programme. However, some suggested tailoring for enhanced engagement, such as using motivational facilitators to make the programme fun and sociable with relevant short-term benefits, aligning with previous findings (Devereux-Fitzgerald et al., 2016) or strategically incorporating the programme part of the weekly care home schedule, with advance notice of session commencement times. Organisational culture in care homes and ACs’ support levels critically impacted intervention fidelity, underscoring the need to foster a conducive organisational environment (Caspar et al., 2020; Nakrem, 2015).

5.5.2 Strengths and limitations

This study has several strengths, such as adopting a mixed-methods approach, lending depth and granularity to the insights, and facilitating a holistic understanding of the intervention's impact and implementation. Further, the use of progression criteria as guidelines helped identify potential challenges and develop solutions to improve the quality and feasibility of the intervention (Mellor et al., 2023). However, it is important to acknowledge certain limitations. The control group's non-adherence to the waitlist condition caused a deviation from the protocol and compromised the ability to make direct comparisons, forcing reliance on within-group analyses. This provides a strong rationale for using cluster-randomisation in a future RCT and adjusting the sample size accordingly. Further, while not uncommon in these settings recruitment challenges may have introduced a selection bias and produced underpowered results (Witham & McMurdo, 2007). Therefore, effect sizes are presented alongside p-values, and it is recommended that these results be interpreted cautiously. Nevertheless, the consistency of the observed outcomes in ITT and sensitivity analyses makes the results more reliable. However, the variance in effect sizes between the two analytical approaches for specific outcomes underscores the significance of accounting for participant adherence and attrition in future research. This variance emphasises that participant engagement and adherence factors may moderate the intervention's potential benefits. Further, the study's scope was limited to 12 weeks. A more extended observation period might provide deeper insights into the sustainability and long-term effects of the intervention. This concern was also raised in a preliminary systematic review regarding the effects of PA on cortisol and DHEA(S) in older adults (De Nys et al., 2022), although adopting a longer duration was out of scope for the present study.

5.5.3 Future directions to progress to an RCT and future research

This study emphasises the potential benefits of PA interventions in care homes, especially when enriched with music and dance components. The study's application of the Red Amber Green (RAG) progression criteria offers valuable insights for future trials. The recommendations about recruitment, programme fidelity, attendance and retention rate and safety are outlined in Table 4. However, several critical future directions should be emphasised. First, the experience with non-adherence from the control group underscores the significance of robust protocol adherence mechanisms. Future studies should prioritise establishing strict guidelines and transparent communication channels between researchers and involved care home staff. Regular audits, complemented by frequent check-ins, can ensure the consistent application of the study protocol across care homes. Alternatively, as suggested above, cluster-randomisation could be used.

Second, the care home staff play an integral role in the successful deployment and fidelity of interventions. Hence, ongoing training, mentorship, and support are of paramount importance. Future studies should focus on initial training sessions followed by regular refresher courses and workshops. Creating an accessible helpline or a designated liaison for care homes with researchers or programme instructors may provide immediate solutions to challenges, bolstering staff confidence and adherence to the study design. Third, the ancillary analyses showed that adherence levels in care homes significantly affected the Dartmouth COOP health-related quality of life scores, demonstrating improvement only in moderate and high adherence groups, contrasting with a stable score in the low adherence group. These findings accentuate the importance of future studies adhering to the prescribed three sessions per week to maximise intervention benefits. Correlation analyses revealed that reductions in the fear of falling were significantly associated with several enhanced physical and psychological well-being indicators. These observations suggest future interventions could research further the interplay between physical health (e.g., frailty, SPPB scores) and psychological well-being (e.g., quality of life, fear of falling, anxiety levels). Finally, the reassuring safety profile, high participant attendance, and retention rates observed pave the way for subsequent larger-scale RCTs sufficiently powered to explore the intervention's efficacy. Although the study design utilised a generalised approach to the digital movement and music intervention, the responses among participants highlighted the potential benefits of personalisation. Future research should consider methods for individualised customisation, ensuring that interventions are tailored to each participant's unique needs, preferences, and physiological responses. Employing adaptable digital platforms, offering a range of activities within the digital PA sessions or interactive features that encourage personalised engagement could facilitate this customisation.

5.6 Conclusion

The study contributes insights into implementing tailored digital PA interventions in care homes. Preliminary significant findings over time emphasise the programme's positive influence on resident well-being, as evidenced by enhanced salivary DHEA levels, reduced anxiety and other well-being markers. Specific recommendations regarding recruitment and programme fidelity strategies were made to proceed to a subsequent full-scale RCT. For recruitment rate, additional efforts such as extending the recruitment period, intensifying recruitment efforts, and modifying the design to include those without the capacity to consent can be considered to achieve the required number of participants. Regarding intervention fidelity, strategies to enhance adherence to the planned frequency and randomisation process were proposed, including making the intervention part of the weekly care home routine, providing clear guidelines, and training for ACs. Addressing identified barriers through additional support and allocating a dedicated ‘exercise room’ were also recommended. Further, more proactive adherence tracking could help in early identification and address any deviations from randomisation protocols. These results underline the potential for this digital PA intervention to shape subsequent research and the practical application of similar interventions in care settings, fostering a more multi-dimensional and evidence-driven approach to care home interventions.

Chapter 6: Discussion and Conclusion

6.1 Summary of main findings

This PhD thesis explored the impact of PA on cortisol and DHEA(S) regulation, sleep quality, physical function and well-being in older adults, focusing on those in care homes. Further, it advanced the understanding of how a digital music and movement intervention could be implemented in care homes.

In the first systematic review and meta-analysis (Chapter Two), findings suggest that regular PA could beneficially reduce cortisol levels and increase DHEA(S) levels in older adults. This conclusion is based on evidence of low to moderate quality. Subgroup analyses showed no significant differences between males and females, exercise modalities, or health states. It was concluded that regular PA of older adults' own choice that they find enjoyable may be recommended to improve cortisol and DHEA(S) levels. However, the review identified a need for more research and higher-quality evidence on the mechanisms behind the effects of PA on cortisol and DHEA(S) levels in older adults.

The second systematic review and meta-analysis (Chapter Three) explored how PA affects cortisol and sleep in adults. It indicated that PA could effectively lower cortisol levels and improve adult sleep quality, with moderate to low certainty evidence. However, the included studies were predominantly conducted on women with breast cancer; few males or older adults were included. Therefore, caution should be exercised when generalising these findings to the population. Thus, PA programmes may improve adults' cortisol regulation and sleep quality. However, more research is needed to fully understand the relationship between cortisol, sleep, and PA, particularly in males and older adults.

The feasibility study (Chapter Four) demonstrated the feasibility of the digital music and movement intervention. However, the intervention delivery was challenged by COVID-19 restrictions in care homes and other challenges, including motivation and engagement, changes in cognitive impairment and disabilities of the participants, death or hospitalisation of the participants, and limited staffing and technology resources. Despite these challenges, group participation and encouragement from the ACs supported the delivery and acceptance of the intervention, made evident by focus groups and interviews. Exploratory pre-post analyses of the investigated outcomes showed improvements in anxiety, depression, loneliness, perceived stress, and sleep satisfaction. However, there were no changes in fear of falling, general health, or appetite. Based on these findings, it was concluded that the intervention was feasible, thereby justifying proceeding to a more extensive pilot RCT.

The pilot RCT (Intervention Two, Chapter Five) evaluated the effects of a revised 12-week, online-delivered music and movement intervention on the well-being of care home residents. In contrast to the preliminary feasibility study, this study additionally explored physical function using various tests, including frailty indicators in older adults and salivary hormone markers (cortisol and DHEA). It also included qualitative data from interviews and focus groups. Due to implementation problems across the four care homes that only became evident during the follow-up qualitative interviews with staff and residents, it became apparent that this study, in fact, had no formal control group despite initial random allocation and explanation of how a waitlist control group works. This meant that analyses were confined to a pre-post intervention comparison across all participants rather than between groups (intervention versus waitlist control) comparison of pre- to post-intervention change. The primary outcomes showed a significant change over the intervention period, with an increase in DHEA and a decrease in anxiety but no change in cortisol or the cortisol:DHEA ratio. Regarding secondary outcomes, the study showed significant improvements in loneliness and decreased fear of falling in care home residents. However, there were no changes in depression, perceived stress, sleep satisfaction, general health, physical function or frailty markers. Also, the study assessed progression criteria to proceed to a full-scale RCT. This provided insights into improving recruitment rates and intervention fidelity among the ACs, attendance of participants, retention rates and safety.

Overall, this PhD project elucidated the impact of PA on cortisol and DHEA(S) levels, sleep, and well-being in older adults, particularly those residing in care homes. It has also demonstrated the feasibility of a digital music and movement intervention in the complex care home setting while identifying important challenges that need to be addressed for potentially better effects. While this PhD project advances our understanding of PA's role in older adults' health, especially in care home settings, it also underscores the necessity for further research. Future studies are required to further investigate the mechanisms driving the observed effects and to refine the intervention design for a full-scale RCT. The insights hold promise for enhancing care practices and informing policy, particularly regarding integrating digital interventions for promoting physical and mental well-being among older adults in care homes.

The first section of this Discussion will delve into the PhD project's critical considerations. The following sections will address the selection of participants and setting of this project, the PA interventions employed, and the outcomes and measurements used. The final part suggests future directions and the potential societal impact.

6.2 Critical considerations of the PhD project

6.2.1 Adaptations to the PhD project due to COVID-19 and cognitive impairment

This PhD project underwent substantial methodological adaptations in response to the COVID-19 pandemic, particularly in conducting the interventions in care homes (detailed in Appendix 4.1). These changes reflected the evolving literature advocating for flexible research designs in response to global health emergencies (Akacha et al., 2020; Lauffenburger et al., 2022). The pandemic constrained in-person evaluations in the feasibility study (Chapter Four), limiting the depth of data from interviews, focus groups, and physical assessments.

The intervention research involving the implementation of a PA programme in care homes can be considered in four phases: development of an intervention, assessment of the feasibility of the intervention, evaluation of the intervention, and implementation (Skivington et al., 2021). The intervention implementation during this PhD project encountered several challenges, such as limited engagement of some of the involved ACs, motivation difficulties and changes in cognitive impairment of the participants, and limited resources and time constraints, all of which may have impacted the current findings. These concerns are echoed by a recent systematic review of PA programmes in care homes (Agbangla et al., 2023). This is investigated in depth in the conducted realist evaluation of Intervention One (Chapter Four). The experienced changes in cognitive impairment underscore the need for future research to explore strategies to enhance participant engagement and adapt interventions to the cognitive capacities of older adults. Therefore, future studies should consider these challenges when working with cognitively impaired individuals and/or those lacking consent.

6.2.2 Generalisability and interpretation of the findings

Despite the unprecedented challenges posed by the pandemic, this PhD thesis offers new insights into the role of PA's impact on healthy ageing (for reviews on this topic, see (Chodzko-Zajko et al., 2009; Daskalopoulou et al., 2017)). It extends the understanding of PA’s impact on the endocrine system (Kraemer et al., 2020; Kraemer & Ratamess, 2005;

Sellami et al., 2019), anxiety and depression (Bigarella et al., 2022; Catalan-Matamoros et al., 2016; Schuch et al., 2016; Singh et al., 2023; Stubbs et al., 2017), and physical functioning (Nusselder et al., 2008; Paterson & Warburton, 2010).

The findings, particularly regarding cortisol and/or DHEA(S) levels (De Nys et al., 2022a; De Nys et al., 2022b), and anxiety and depression (Ofosu et al., 2023), align with this existing body of work, however, also reveal research gaps. These include limited changes in physical function and endocrine markers in care home settings as seen in Intervention Two (Chapter 5), warranting further investigation. The reasons for these remain elusive but could potentially stem from the fact that the studies were designed and powered to assess feasibility and progression to a full-scale RCT rather than to assess efficacy. The reliance on self-reported measures for specific outcomes, such as sleep quality and mental well-being, may also have introduced biases, which is further discussed in Section 6.5. Additionally, using single morning cortisol measurements, while practical, did not capture the full diurnal variation, thus limiting the understanding of cortisol rhythms. Further, the observed impact on mental well-being rather than physical or physiological systems suggests that the digital music and movement intervention might have been more effective in enhancing motivation and pleasure in group participation. These limitations are discussed in Section 6.5.

Recent research underscores the consideration of inter- and intra-individual differences among older adults for the heterogeneous ageing process (Brach et al., 2023). These variations highlight the need for rigorous study designs, especially in assessing the efficacy of interventions. The challenges in data collection and participant diversity observed in this study reflect a broader issue in gerontological research, necessitating improved recruitment strategies and assessment tools (Brach et al., 2023; Gichu & Harwood, 2023). The feasibility study discussed the assessment tools used (Chapter Four and Appendix 4). Further, Intervention Two (Chapter Five) elaborated on recruitment strategies, as this was highlighted as a potential issue in future RCTs.

In addition, the demographic profile of the study participants, primarily older adults of white ethnicity in Scottish care homes, limits the generalisability of the findings to other settings and populations. There are distinct neuropsychological and cognitive differences across ethnic groups, highlighting the need for more inclusive and culturally sensitive study designs in older adults (Werry et al., 2016). However, this can be challenging in Scotland outside the main cities where diversity is limited. This limitation is particularly relevant given the cross-cultural differences in attitudes towards ageing and dementia care (Ackerman & Chopik, 2021; Sayegh & Knight, 2013). Thus, future research should focus on diversity in participant recruitment and develop methodologies that reflect the wide spectrum of ageing experiences across different cultures and ethnic groups.

The role of personalised PA recommendations in enhancing daily activities and functional capacity of older adults is evident (Izquierdo & Singh, 2023). However, the global low adherence to these guidelines (Garcia-Hermoso et al., 2023; Gomes et al., 2017) emphasises the need for strategies that reduce sedentary behaviour and promote PA. Future research should focus on developing and testing tailored interventions that effectively address the unique needs and preferences of older adults in these settings.

An integrated approach of "sitting less and moving more," holds promise for mitigating cardiovascular risk factors and improving well-being. Rather than focusing solely on accumulating a specific duration of exercise, the emphasis should be on reducing passive sitting time and gradually increasing light-intensity activities, which can serve as a starting point for individuals, e.g. those with compromised cardiovascular health (Dunstan et al., 2021), multimorbidity (Dogra et al., 2022) and frailty (Del Pozo-Cruz et al., 2017). By integrating more movement into daily lives, older adults can enhance functional capacity, physical conditioning, and overall PA levels, ultimately benefiting their health (Garcia et al., 2023; Warburton & Bredin, 2017).

An effective strategy could be implementing a "staircase" approach, starting with reducing and interrupting sitting time, gradually increasing light-intensity PA, and eventually progressing to moderate-vigorous-intensity activity (Dunstan et al., 2021). Such an approach can be adapted to various settings, providing a feasible pathway for older adults to enhance their PA in an achievable and sustainable manner.

Although further research and evidence are needed to refine guidelines and understand the optimal dose-response relationships for sedentary behaviour, PA, and optimal health, the music and movement intervention validated throughout this PhD project could be used as a practical tool to reduce and interrupt sitting time in care home residents, while also improving other health markers. Admittedly, to test this formally, researchers would need to implement accelerometry to assess the impact of the intervention on sedentary time, which was different from the initial aims of the intervention studies reported here but is an area of potential future research.

6.2.3 Impacting older adult behaviour in complex care home situations

The influence of physical and social environments on human behaviour is well-recognised (Davies et al., 2014). Consequently, modifying these environments holds potential as a catalyst for behavioural change (Das & Horton, 2012). While these aspects were not the focus of the current interventions, they represent critical areas for future research. Notably, studies with older adults have shown that many behaviour change techniques effective at increasing PA in younger adults, such as self-regulatory or planning principles, may have more limited success in an older population (French et al., 2014). An explanation is that older people find self-regulatory behaviour change techniques more cognitively challenging or less acceptable. Recent studies echo the suggestions of this PhD thesis to utilise exercises that are social and enjoyable and tailor the programme to an individual's needs (Cross et al., 2023). Future studies could elaborate on behaviour change techniques for successful programme implementation in care homes. A proposed starting point for researchers is providing an overview of empirical research on behaviour change techniques such as self-efficacy (Bill et al., 2023).

The concept of "choice architecture," which posits that behaviour changes can be induced by altering the environments in which individuals make decisions, has been a longstanding area of focus in psychological and behavioural sciences (Marteau et al., 2011). These findings suggest that choice architecture interventions may improve health behaviours by altering the environments or contexts (Hollands et al., 2013). The digital music and movement intervention evaluated during this PhD project could be considered a choice architecture intervention. This is because the research team, in collaboration with the DSC team and ACs, modified the care home environment to encourage PA. This was achieved without being excessively prescriptive or restrictive. For instance, residents were automatically enrolled in the exercises as the programme took place in the communal living room unless they opted out, thereby establishing a default choice that fosters PA. In addition, ACs were instructed to engage with residents, prompting them to participate. Further, equipment barriers were addressed to minimise friction.

This concept was further explored in the realist evaluation conducted as part of this PhD project (Ofosu et al., 2023), where the given context (or the set of pre-existing conditions) was identified as a critical component in the trial implementation. The method of realist evaluation used in this feasibility study followed a context (C), mechanism (M), and outcome (O) configuration (Pawson & Manzano-Santaella, 2012). This approach has reinforced the refinement of future trial implementation, thereby underscoring its utility in developing complex care interventions. Researchers who design and test interventions in the inherently complex environment of care homes should address the parameters of 'what works, for whom, under what circumstances, and how'. While often overlooked, these considerations are critical for successful trial implementation (Moore et al., 2015). Future studies can yield more precise and applicable results by including these parameters, significantly contributing to the field.

In conclusion, environmental modifications in care homes can effectively promote PA. Future research should focus on co-creating interventions with care home residents and staff for more effective implementation (Jepson et al., 2023). The challenges encountered, such as staffing issues, highlight the need for future research to explore personalised strategies and co-created designs, tailoring interventions to the unique dynamics of care homes.

6.3 Participants and setting

6.3.1 Participants

This thesis contributed to the literature on the benefits of PA (Chodzko-Zajko et al., 2009; de Souto Barreto et al., 2016), responding to recent calls for integrating PA into older adult care (Izquierdo & Singh, 2023). However, conducting research in care homes, especially among residents with cognitive impairments, presents unique challenges. These include difficulties in structured interviews and questionnaire completion (Kutschar et al., 2022; Towers et al., 2023, 2021). Such complexities necessitate accessible formats such as proxy questionnaires and easy-read versions to accurately assess quality of life, a key aspect of care improvement and benchmarking (Aznar et al., 2021).

This research did not find significant sex disparities, contrasting with existing literature on age-related hormonal changes (Laughlin & Barrett-Connor, 2000). Prior observations indicate distinct cortisol:DHEA(S) patterns in ageing women due to lower levels of DHEA(S) (Berr et al., 1996; Mazat et al., 2001; Zumoff et al., 1995) and higher levels of cortisol (Zhao et al., 2003). This underscores the necessity for future studies to explore sex-specific physiological responses to PA. In addition, a recent longitudinal study has uncovered notable sex disparities in the adherence levels to moderate to vigorous PA among community-dwelling older adults (Chen et al., 2023). However, the findings of this thesis did not extensively investigate the impact of sex on adherence due to the low sample size. Recognising the growing evidence of sex differences in health outcomes, future studies should prioritise this area to develop more tailored intervention strategies (Chen et al., 2023).

Additionally, the ethnic homogeneity of our study participants, predominantly white due to the demographic profile of Scottish care homes (GOV.UK, 2023) highlights a diversity gap. Understanding ethnic variations in affect and stress biology is vital (Deer et al., 2018). Future studies should aim for greater ethnic diversity, incorporating broader demographic groups and considering socioeconomic and cultural factors to enhance the external validity and applicability of the findings.

6.3.2 Setting

The feasibility study of this thesis confirmed the potential applicability and efficacy of the digital music and movement intervention in care homes, agreeing with existing literature (Diener et al., 2022; Guzmán-García et al., 2013; Low et al., 2016; Vankova et al., 2014). These findings align with recent systematic reviews underscoring the positive impact of PA programmes in care home settings (Agbangla et al., 2023). This digital music and movement intervention, emphasising motivation and pleasure to increase overall PA in daily life, group participation, and personalised exercise routines, aligns with recommendations for older adults' PA in care homes (de Souto Barreto et al., 2016). However, there are several implementation challenges for these resources in care homes (Granja et al., 2018). The feasibility study (Intervention One) elaborates on this. It underscores the need for future research to consider resource availability, social support, and contextual differences within care home environments (Ofosu et al., 2023).

Given the geographical scope of the conducted studies, caution must be exercised when generalising these findings beyond Scottish care homes. Different settings or regions may entail different challenges. Further, the studies acknowledged that larger sample sizes could yield more robust and reliable results, and both intervention studies encountered recruitment challenges. The pilot RCT elaborated on these challenges, suggesting additional efforts can be considered, such as extending the recruitment period, implementing additional recruitment strategies (such as providing an in-person taster session in each care home, reaching out to more care homes or collaborating with other organisations), or intensifying recruitment efforts (e.g., increasing advertisement or utilising referrals). Proper recruitment rates are essential in clinical trials, as failure to achieve the predetermined sample size can lead to trial extensions or compromised statistical power (Bell et al., 2018). In publicly funded trials in the UK, 45% of trials fail to reach their intended target sample size (Sully et al., 2013). The feasibility study's insights into the digital music and movement intervention in care homes underline the importance of addressing implementation challenges and recruitment strategies in future research, ensuring broader applicability and more robust evidence.

6.4 Intervention

6.4.1 Evaluating the interventions

The systematic reviews used the FITT-D framework (Frequency, Intensity, Type, Time, Duration) to assess different exercise interventions (Burnet et al., 2019). This framework provides a structured approach and covers essential dimensions like training frequency, workout intensity, exercise type and time, and intervention duration. It further highlights the varied efficacy of PA in older adults. However, the effects can vary significantly, especially among older adults with multimorbidity, suggesting a more complex relationship between PA and health outcomes in different age groups (Fessler et al., 2023).

The danceSing Care intervention aimed to align with effective intervention characteristics and recent PA guidelines for care homes (de Souto Barreto et al., 2016). It spanned an initial duration of 12 weeks, with 3-4 sessions weekly and session durations from 20 to 40 minutes, which included balance and aerobic exercises. This design was intended to cater to the diverse abilities and preferences of participants.

The current evidence base suggests that any form of safe PA, regardless of its specific type or intensity, can improve health outcomes in older adults (Bull et al., 2020). This finding underscores the value of creating physical exercise programmes tailored to older adults' unique preferences and needs. A systematic review further supports this concept of individualised intervention design (King et al., 1998). The findings from this PhD thesis reinforce the notion that PA is an effective strategy for enhancing well-being in older adults, including those with existing (multi)morbidities. This conclusion aligns with the growing consensus that the benefits of PA generally outweigh the risks, even for chronically ill or frail populations residing in care homes (Reid et al., 2022).

6.4.2 Long-term maintenance of PA

Long-term PA engagement post-intervention requires innovative strategies for sustained motivation and adaptive programme design (Morelhao et al., 2017; Sansano-Nadal et al., 2019; Zubala et al., 2017). This aligns with the consensus that PA of any kind needs to be maintained to sustain health benefits (Elsawy & Higgins, 2010). However, a systematic review on digital health and older adults found that evidence on the long-term effects of digital interventions is still lacking (Muellmann et al., 2018). Thus, future studies should investigate the long-term maintenance and effects of these interventions.

The continued utilisation of the danceSing Care digital resources by the care homes after the research project indicates the success of the sustained efforts by the research team and danceSing Care staff. These efforts include ongoing monitoring of resource usage, providing regular feedback, continued training and upskilling of staff, and dedicating time to integrate the danceSing programme into the core well-being ethos of the care homes. Future research should explore these strategies further, particularly their effectiveness in maintaining PA engagement and their impact on the overall health and well-being.

6.4.3 'Hormonal conditioning' hypothesis of PA

The HPA axis adapts to repeated and prolonged exercise (Sothmann et al., 1996), evidenced by a decreased hormonal stress response to submaximal exercise in trained subjects (Hackney, 2006b, 2006a; Silverman & Mazzeo, 1996). This indicates one's 'hormonal conditioning' (Cadegiani & Kater, 2019), which implicates neuroendocrine system adaptations and increased tissue sensitivity to glucocorticoids (Duclos et al., 2003; Sapolsky et al., 2000). The exact mechanism by which exercise influences the HPA axis is complex, but it is recognized as a significant physiological stimulus (Fragala et al., 2011; Luger et al., 1987; Mastorakos & Pavlatou, 2005).

The HPA axis response to exercise intensity varies, with a threshold generally above 60% of VO2 max (Caiozzo et al., 1982; Hill et al., 2008; VanBruggen et al., 2011). This threshold aligns with the concept of allostasis, representing the level of activity required to adapt to psychosocial or physical challenges (Goldstein & McEwen, 2002; McEwen, 1998; Sterling &

Eyer, 1988). PA acts as a regulatory mechanism, counteracting the age-related decline of the HPA axis and promoting more favourable endocrine profiles in older adults (Karlamangla et al., 2002; Kubzansky et al., 1999; Seeman et al., 1997). However, both underexposure and overexposure to stressors can harm health (Calabrese et al., 2013). Thus, identifying the individualised threshold that enhances healthy ageing is essential, and the sweet spot differs from person to person, e.g., due to socioeconomic status (Kubzansky et al., 1999), and must be considered from subjective and objective points of view. That is the exercise type, intensity and frequency, the individual's perceptions of the activity and how it 'fits' with personal needs, values, and circumstances (Bouchard et al., 1994).

The danceSing Care intervention may not have consistently reached the person-dependent sweet spot or exceeded the 60% VO2 max intensity threshold to sufficiently impact the HPA axis. This could partly explain the lack of significant changes in cortisol levels observed in Intervention Two. Future interventions could incorporate objective metrics, like heart rate monitors, to accurately gauge exercise intensity.

6.4.4 'Neuroendocrine' hypothesis and mindfulness element of PA

Mind-body exercises have been shown to reduce elevated cortisol levels in older adults (Lu et al., 2020; Prakhinkit et al., 2014; Tsang et al., 2013). A proposed exercise mechanism includes stress responsiveness, which is regulated by two neuroendocrine pathways: the HPA axis and the autonomic nervous system (Tsigos & Chrousos, 2002). The 'neuroendocrine hypothesis' states that the mindfulness element of, e.g., qigong exercise, could reduce stressful signals sent to the hippocampus and amygdala of the limbic system (Tsang & Fung, 2008). As a result, it lowers the secretion of corticotrophin-releasing factor in the periventricular hypothalamus and the release of adrenocorticotropic hormone from the anterior pituitary gland. It follows that these kinds of exercises down-regulate the hyperactivity of the HPA axis among depressed individuals, which therefore intervenes in the further release of glucocorticoids from the adrenal cortex that circulates into the body. This hypothesis seems reasonable for any mind-body exercise programme where a mindfulness element is provided to reduce chronic high cortisol levels.

The digital music and movement programme brings forward certain mindful body relaxation elements, however not as a key component, and Intervention Two showed no significant cortisol decrease. The outcomes and evaluation section (6.5) will delve deeper into the specificities of cortisol and DHEA measurements in the intervention study, paving the way for future research to integrate mindfulness elements in PA programmes.

6.4.5 Digital music and movement component

Various studies on dance (Hwang & Braun, 2015; Liu et al., 2021; Sooktho et al., 2022) and music interventions (Dingle et al., 2021) have demonstrated health benefits. However, the current digital music and movement intervention differs in several ways. For instance, most interventions use dance as the primary mode of movement. In contrast, the present intervention combined group participation and multicomponent exercises and added a music and singing component. Additionally, the current intervention was designed to be delivered digitally, with in-person support, to older adults residing in care homes with a range of morbidities and frailty. In this context, cognitive impairment, disabilities, multimorbidity and limited resources pose unique challenges. Therefore, in-person support was integral to the programme design to adjust for these unique challenges. It has been shown that a digitally delivered intervention, especially in combination with another non-digital intervention (in-person support), such as the digital music and movement intervention, is most feasible and can potentially improve health outcomes (da Fonseca et al., 2021; Kraaijkamp et al., 2021). The digitally delivered PA programme from Intervention One and Two showed encouraging outcomes. Recent systematic reviews highlight the promising role of digitally delivered interventions in improving PA levels (Davies et al., 2012), and the health and well-being of older adults (Muellmann et al., 2018; Solis-Navarro et al., 2022). However, other research tempers the optimism with a recognition of the varied and sometimes limited evidence supporting their efficacy (Burton et al., 2015; McGarrigle & Todd, 2020), further suggesting higher quality RCTs in care homes are needed to gain ‘real-world’ knowledge of the intervention’s feasibility and effectiveness.

The effects of music may have contributed to the observed changes in well-being. Music has been shown to positively impact mood, anxiety, and stress, making it an effective tool for improving mental health outcomes (Dingle et al., 2021), including in older adults in care home settings (Lai & Lai, 2017; Taylor et al., 2023). However, some studies indicate variability in effectiveness (Petrovsky et al., 2015). Additionally, music may enhance the enjoyment of PA, increasing adherence and compliance with exercise programmes (Clair, 1996; Priest et al., 2004; Vaz et al., 2022), although there are significant individual differences regarding music preferences for each type of PA (Ellis & Salmoni, 2021).

Therefore, integrating music into the intervention may have affected its effectiveness. This is echoed in qualitative findings in both conducted intervention studies, where several participants emphasised that they particularly enjoyed the music parts of the intervention. Future research should explore optimal strategies for incorporating music into PA interventions to maximise their effectiveness.

6.5 Outcomes

6.5.1 Cortisol and DHEA(S) and its ratio

Building on prior research suggesting that PA can modulate this ratio through decreased cortisol output and elevated DHEA(S) levels (Butcher et al., 2005; Heaney et al., 2014; Phillips et al., 2007; Zouhal et al., 2022), the findings align with research showing that engaging in a physically active lifestyle or participating in exercise interventions may improve these hormonal levels (Heaney et al., 2013), which could promote better control of the HPA axis and resilience to stress (Fragala et al., 2011; Hackney, 2006b; Heaney et al., 2014; Sellami et al., 2019).

The systematic reviews conducted during this PhD project extend the understanding of the benefits of PA on these hormones, particularly on the potential to increase DHEA(S) (Chapter Two). These outcomes were replicated in Intervention Two, showing statistical significance in DHEA levels from baseline to post-intervention. However, the study was underpowered to detect clinically meaningful differences in DHEA levels, so caution is needed not to overestimate the effect sizes. The lack of differences in favourable cortisol changes could be due to the intervention specifics, such as the intensity not exceeding 60% of VO2 max (see Section 6.4.2) or the lack of the critical mindfulness element to influence the autonomic nervous system (see Section 6.4.3). Further study designs could consider sufficient power and the above hypotheses investigating HPA axis responses.

Moreover, the use of non-invasive salivary cortisol (Hellhammer et al., 2009; Kirschbaum & Hellhammer, 1994) and DHEA (Ahn et al., 2007; Whetzel & Klein, 2010) samples used in Intervention Two provide a reliable and cost-effective method to assess HPA axis activity. However, limitations arose from the conducted study that relied on a single morning cortisol measurement. While this is often used to assess within-subject variations over a certain period in an older population, it has limited prognostic value due to intra-individual differences (Coste et al., 1994; Pruessner et al., 1997). It should be recognised that the focus of PA interventions should not solely be on decreasing cortisol levels at a specific point in the day but rather on influencing the overall diurnal cortisol rhythm. PA has been shown to play a more regulatory role in the diurnal cortisol slope (Heaney et al., 2014), aligning with positive health behaviours (Dmitrieva et al., 2013). By relying solely on single pre- and post-intervention cortisol measurements, the study may not have fully captured the complexities of cortisol fluctuations and may have overlooked potential changes that occur at different times of the day (Coste et al., 1994; Pruessner et al., 1997). Therefore, future research should incorporate multiple measurements across consecutive days to accurately capture the diurnal pattern of cortisol fluctuations and intra-individual variations (Segerstrom et al., 2014). An accepted sampling design for cortisol involves, e.g. measurements immediately after awakening, 30 minutes post-awakening, noon, late afternoon, and immediately before bed (Hellhammer et al., 2007). The challenge of identifying individual mechanisms underlying the components of the stress response system advocates for a patient-centric approach (Kudielka et al., 2009).

6.5.2 Cortisol and sleep

Building upon the relationship between PA, the HPA axis, and sleep, Systematic review Two aligns with prior findings showing that PA improves HPA axis regulation (Duclos & Tabarin, 2016; Fragala et al., 2011) and promotes better sleep (Kredlow et al., 2015; Uchida et al., 2012; Youngstedt, 2005). Chapter Three further delves into the bidirectional association between stress and sleep (Kim et al., 2019).

However, caution in generalising these findings is needed, considering the specific demographics of the study. Notably, most studies focused on women with breast cancer, resulting in a lack of representation from male participants and older adults. While Intervention One showed encouraging initial results, with a significant increase in sleep satisfaction over time, this outcome was not replicated in the subsequent Intervention Two. Although certain prior studies have reported no significant changes or even elevated cortisol levels post-PA intervention (Borst et al., 2002; Häkkinen et al., 2005; Hayes et al., 2013), the positive impacts of PA on sleep have been consistently recognised (Kredlow et al., 2015).

Given the demographic limitations of the participants of Systematic review Two (Chapter Three), future research should explore this relationship in a more diverse population, including a broader age range and male participants. More objective measures, such as activimetry and sleep architecture assessments, alongside self-reported questionnaires, will also improve the understanding of the link between cortisol and sleep phases. However, these measures were beyond the scope of the intervention studies conducted within the framework of this PhD project, which primarily aimed to ascertain the feasibility of a digital music and movement intervention and lay the groundwork for a future full-scale RCT.

6.5.3 Physical function, well-being and frailty

Existing research indicates that PA can ameliorate frailty and enhance physical function in older adults in care homes (Arrieta et al., 2019, 2018; Ferreira et al., 2018; Swales et al., 2022). This thesis examined the effects of a digital music and movement intervention in care home settings. However, Intervention Two did not find any improvement in physical function over the time of the intervention period. This contrasts with the existing literature suggesting PA, in any form (including dance (Zhang et al., 2023)) or intensity, can be effective in improving strength, gait speed, balance and functional independence and reduce falls in older adults (Dugan et al., 2018; Mollinedo Cardalda et al., 2019; Nagata et al., 2023; Paterson & Warburton, 2010; Peterson et al., 2009; Sherrington et al., 2020). Further, individualised and progressive multicomponent exercise interventions at a moderate intensity, such as the investigated danceSing Care intervention, effectively prevent falls and reduce frailty and mortality among older care home residents (Arrieta et al., 2019). This again suggests that the investigated intervention may impact emotional rather than physical states. However, adequately powered RCTs are needed to make more firm conclusions.

Apart from the salivary cortisol and DHEA measurements and the physical function tests, self-administered questionnaires, complemented with interviews, were used to assess the intervention effects on well-being markers. While these approaches offer valuable insights into participants' subjective experiences and perceptions (Zhu et al., 1999), they are not without limitations. Self-reporting has several potential concerns, such as social desirability bias, confirmation bias, and subjective interpretation (Althubaiti, 2016). The lack of objective measures may restrict the ability to corroborate self-reported findings, impacting the study's overall reliability. Moreover, recall biases could introduce further challenges in interpreting the data and limit its generalisability. However, the chosen tools were a cost-accuracy trade-off. Future research should consider integrating more objective physiological assessments such as more objective devices measuring PA (accelerometers, pedometers, heart rate monitors or arm-band technology (Sylvia et al., 2014)) and sleep ((bed)actigraphy, observation, bed sensors, eyelid movement- and non-invasive arm sensors, a sleep switch and a remote device (Van de Water et al., 2011)), complementing well-being markers throughout the intervention period. The main aims of the conducted intervention studies were to provide a foundation for further research in this area, focusing on feasibility and implementation strategies for a full-scale RCT.

6.6 Future directions for research

Future research should build on the findings of this PhD project by exploring the impact of PA intensity and type on cortisol and DHEA(S) regulation in a more diverse older adult population. Additionally, given the preliminary results regarding PA's influence on physical function, mental well-being and sleep quality, subsequent studies should investigate these relationships using quantitative and qualitative measures.

6.6.1 Progression to a full-scale RCT

Given the promising findings and feasibility demonstrated in this PhD project, future research could consider a full-scale Randomised Controlled Trial (RCT) to evaluate the efficacy of the digital music and movement intervention in care homes. A full-scale RCT would enable a more definitive assessment of the intervention's impact on cortisol and DHEA(S) regulation, sleep quality, physical function, and well-being among older adults.

To progress to a full-scale RCT, several steps should be undertaken. First, robust protocol adherence mechanisms are crucial. This includes establishing strict guidelines and transparent communication channels between researchers and care home staff. Regular audits and frequent check-ins can ensure consistent application of the study protocol. Additionally, initial training sessions for care home staff and regular refresher courses and workshops are essential to maintain intervention fidelity. Creating an accessible helpline or a designated liaison for care homes can provide immediate solutions to challenges and bolster staff confidence.

Second, future studies should aim to recruit a broader spectrum of older adults, including those with varying cognitive capabilities and from different ethnic backgrounds. Employing cluster randomisation could help manage adherence issues observed in the control group by assigning entire care homes to either the intervention or control group, thus minimising contamination and enhancing protocol adherence.

Third, incorporating objective measures of PA, such as accelerometers or heart rate monitors, alongside subjective self-reports can provide a more comprehensive assessment of the intervention's impact. Multiple daily cortisol measurements can better capture diurnal variations and offer a more detailed understanding of the HPA axis dynamics.

Lastly, future research should consider methods for customising the digital music and movement programme to individual participants' needs and preferences. Using adaptable digital platforms that offer a range of activities and interactive features can facilitate this personalisation, ensuring the intervention is engaging and effective for a diverse population of older adults.

6.6.2 HPA axis dynamics

Future research should aim for a more comprehensive examination of HPA axis dynamics, particularly addressing the limitation of single morning cortisol measurements in the intervention study. Implementing multiple daily cortisol assessments could provide a better understanding of diurnal variations and their relationship with PA in older adults. An accepted sampling design for cortisol involves multiple measurements throughout the day, e.g. immediately after awakening, 30 minutes post-awakening, noon, late afternoon, and immediately before bed (Hellhammer et al., 2007) (further detailed in Chapter 2.5.6). This could provide a better understanding of cortisol's diurnal variation and the cortisol awakening response, which is under separate regulation (Clow et al., 2004).

Additionally, future studies should address the challenges encountered in collecting salivary DHEA, particularly when using the Salivette device (cotton swabs) (Gallagher et al., 2006; Granger et al., 1999). An awareness of the impact of collection methods on steroid levels in saliva is essential. Alternatively, future research might consider collecting DHEAS, unaffected by the cotton collection process (Shirtcliff et al., 2001). Further, it is important to consider factors impacting the HPA axis, such as PA intensities exceeding 60% of VO2 max or incorporating mindfulness practices to influence the autonomic nervous system. Lastly, adopting a patient-centric approach is vital in understanding the individual mechanisms of the stress response system, building on the findings of this and other studies (Kudielka et al., 2009).

6.6.3 Demographics and diverse populations

Given the limited diversity in the presented participant demographics, future research should prioritise the inclusion of a broader spectrum of older adults, especially regarding sex, ethnicity and cognitive capabilities. In addition, ensuring that future studies have a well-defined control group is also essential for a more precise investigation of the intervention's efficacy.

Importantly, research should include individuals who lack the capacity to consent and those with more advanced cognitive decline, as these often-marginalised groups may respond differently to interventions. When involving these populations, ethical considerations take precedence, necessitating close collaboration with caregivers, legal representatives, or family members to ensure informed consent. Additionally, tailoring interventions to this demographic, particularly focusing on sensory-rich experiences due to cognitive impairments, is important. Music and movement programmes that emphasise auditory, visual, and tactile elements can enhance engagement and responsiveness (Juntunen & Sutela, 2023). Traditional outcome measures may not be suitable for these groups. Therefore, observational techniques, such as noting shifts in mood, behavioural changes, or physiological indicators, might provide more accurate insights. Feedback from caregivers or nursing staff who understand participants' baseline behaviours can further support and enrich these findings.

6.6.4 Broader health outcomes

Incorporating a wider range of physical and mental health measures would address the current studies' limitations in capturing the relationship between PA and older adult well-being. Future studies should integrate subjective and objective measures to assess well-being and physical function. For instance, complementing self-reported tools with technological aids like accelerometers or bed sensors can provide a more detailed assessment of health outcomes. Standardising these measures across studies will facilitate comparisons and enhance the quality of meta-analyses. In addition, multi-site studies could be considered to enhance external validity of the findings.

6.6.5 Intervention optimisation

Reflecting on the limitations in implementing the interventions in care homes, future research should develop and test strategies for better integrating PA programmes in clinical practice. This includes addressing challenges in resource availability and staff training that were notable constraints in the intervention studies.

Future research should expand the scope to include investigating the efficacy of behaviour change techniques in promoting PA among older adults in care settings. This includes investigating motivational strategies, habit formation, and reinforcement methods that can encourage regular participation in PA. Understanding the psychological and social factors influencing PA behaviour in this demographic is important for designing effective interventions. Another promising avenue for research is examining the role of choice architecture in promoting PA. This involves creating environments and contexts that subtly guide behaviour towards more active lifestyles, such as strategically placed cues, default options for activity participation, and the physical layout of care settings that encourage movement. Methodologically, future research in this area could benefit from (1) utilising mixed-methods research to gain understanding of how behaviour change techniques and choice architecture influence PA, (2) implementing RCTs to assess the efficacy of specific interventions and choice architecture designs, (3) collaborating with care homes to design and implement interventions that are feasible and sustainable in real-world settings.

In addition, future research should tackle the challenges related to staffing, resources, and engagement in care homes. Optimising interventions in these settings requires exploring personalised approaches, enhancing social support structures, and fostering co-creation with care homes. These strategies could significantly improve the involvement of ACs and participants, leading to more effective interventions in these environments. For instance, ACs could use a range of approaches, such as involving family members or volunteers, to provide more one-on-one support to participants. Additionally, incorporating technology-based solutions, such as virtual reality or interactive games, could enhance engagement and provide new avenues for PA. Finally, fostering strong partnerships with care homes and other relevant stakeholders, such as policymakers or funding agencies, is essential to ensure that interventions are sustainable and scalable.

6.7 Recommendations for clinical practice.

6.7.1 PA recommendations

PA recommendations should be personalised for effective clinical application, considering each patient's age, health status, and preferences. For instance, intensity should be balanced with patient capabilities, pairing slow melodies with lighter exercises for those with limited mobility. Frequency should align with current evidence suggesting two to three sessions per week for habit formation and adherence (de Souto Barreto et al., 2016). Regarding duration, focused sessions ranging from 20-minute music-movement routines to longer 40-minute sessions with breaks and varied musical themes are advisable. The type of activity should leverage the diversity of music: aerobic movements with energetic tracks, strength movements timed with the beat using resistance bands or weights, flexibility and balance exercises with slow tunes, and memory and cognitive connection activities using nostalgic songs.

6.7.2 Implementation strategies

Health professionals should actively promote interprofessional collaboration to facilitate movement behaviour change, fostering a positive cultural perception of such behaviours. This includes utilising person-centred communication strategies, understanding various determinants, obstacles, and enablers of movement behaviours, and communicating their health implications. Professionals should also be self-aware of how their actions influence their ability to support behaviour change in others (Alsop et al., 2023). Collaboration with digital platforms, like the danceSing Care programme, offers a practical solution for providing diverse music and movement exercises tailored to older adults. Training caregivers and facilitators to guide these sessions safely and engagingly is important, along with scheduling regular sessions when older adults are most active and receptive.

6.7.3 Feedback mechanisms

Regular feedback from participants is essential, as it allows for adjustments to the intervention, addressing challenges, and ensuring alignment with individual health goals. Implementing digital or paper-based feedback forms to capture insights on the effectiveness and reception of various interventions can be highly beneficial. Conducting periodic feedback sessions encourages open dialogue and helps understand areas for improvement. Monitoring feedback through wearables or apps to track activity levels, provide reminders, and offer feedback is also effective in maintaining adherence and motivation. This feedback should be utilised to continually refine programmes, ensuring they remain aligned with the needs and preferences of residents. This ongoing feedback loop is crucial for successfully integrating PA recommendations into clinical practice, ultimately enhancing the well-being of older adults.

6.8 Societal impact

The societal impact of this PhD research extends to public health initiatives, highlighting the potential for community-based programmes that encourage active lifestyles among older adults. Given the benefits of PA on health parameters, there is a societal imperative to encourage active lifestyles. This can be achieved through various avenues such as public health campaigns, care homes offering digital music and movement resources, as investigated in this study or alternatives, and collaborations with health care initiatives.

In terms of health education and awareness, disseminating the findings of this project through lay papers or presentations at conferences can significantly raise public knowledge. An informed public is better positioned to make health-related decisions and prioritise interventions that are relevant to their needs.

The findings highlight the potential of digital and patient-centred interventions in care home settings. Societal shifts towards care homes that embrace health and wellness programmes can significantly enhance residents' quality of life.

Additionally, engaging residents in interventions like the digital music and movement programme benefits them and may elevate job satisfaction among carers. Working in a care home environment is often challenging due to low pay and time constraints. Providing carers with tools and interventions that enable meaningful connections with residents can boost morale and job fulfilment. This enhancement in care homes' atmosphere, moving towards a more active environment, can significantly improve the well-being of residents and caregivers, thereby benefiting society.

6.9 Policy Implications

Although further research is necessary to strengthen these findings, they offer a foundation for early discussions and considerations in policy-making spheres. Policymakers should consider providing resources and training for care home staff to implement such programmes effectively. Further, based on this study's findings, policies encouraging active lifestyles among older adults could improve health and well-being outcomes. Implementing these changes requires collaboration between researchers, policymakers, and practitioners to ensure the interventions are feasible, effective, and sustainable in the long term.

To enhance engagement, various strategies could be implemented to raise awareness and encourage discussion. This could include drafting summaries or reports to detail the findings, initiating webinars for academic peers and interested parties, or facilitating discussions that bring together researchers, care home representatives, and policymakers. Such engagement efforts would serve to disseminate the research and to stimulate a broader conversation about its implications. Such policy implications underscore the potential of this research to influence and shape future health and ageing policies, ultimately contributing to improved care standards and quality of life for older adults.

6.10 General conclusion

This PhD project provided insights into the role of PA in modulating cortisol and DHEA(S) levels, enhancing sleep quality, physical function and improving well-being in older adults, particularly in care home settings.

Systematic reviews and meta-analyses conducted within this project have demonstrated that regular PA can beneficially influence cortisol and DHEA(S) levels and sleep quality in older adults. However, due to limited participant diversity, especially regarding ethnicity, age and sex, these findings necessitate cautious interpretation and highlight the need for further research to understand the mechanisms involved and extend these benefits to a wider demographic.

The feasibility study of a digital music and movement intervention, although challenged by COVID-19 restrictions and participant-related factors, showed improvements in anxiety, depression, loneliness, perceived stress, and sleep satisfaction. However, these results are preliminary due to the absence of a control group, indicating the need for further adaptation and refinement of such interventions in care home contexts.

The pilot RCT, which aimed to test a refined version of the intervention, faced implementation challenges but offered initial evidence of its efficacy, particularly regarding DHEA levels and improvements in anxiety, loneliness and fear of falling. This study lays the groundwork for future large-scale RCTs by detailing progression criteria such as recruitment, programme fidelity, and participant safety.

To conclude, this thesis has advanced our understanding of PA's impact on older adults' well-being, especially in care home settings. While significant insights were gained, the necessity for further research, particularly full-scale RCTs, is evident. These findings hold promise for enhancing clinical practice and policy in older adult care, emphasising the importance of personalised, digital and context-sensitive interventions to promote physical and mental well-being among older adults in care home settings.

References

Chapter 1

Abbasi, A., Duthie, E. H., Sheldahl, L., Wilson, C., Sasse, E., Rudman, I., & Mattson, D. E. (1998). Association of dehydroepiandrosterone sulfate, body composition, and physical fitness in independent community-dwelling older men and women. *Journal of the American Geriatrics Society*, *46*(3), 263–273. https://doi.org/10.1111/j.1532-5415.1998.tb01036.x

Aldred, S., Rohalu, M., Edwards, K., & Burns, V. (2009). Altered DHEA and DHEAS response to exercise in healthy older adults. *Journal of Aging and Physical Activity*, *17*(1), 77–88. https://doi.org/10.1123/japa.17.1.77

Alghadir, A. H., & Gabr, S. A. (2020). Hormonal Function Responses to Moderate Aerobic Exercise in Older Adults with Depression. *Clinical Interventions in Aging*, *15*, 1271–1283. https://doi.org/10.2147/CIA.S259422

Aronson, L. (2020). Healthy aging across the stages of old age. *Clinics in Geriatric Medicine, 36*(4), 549–558. https://doi.org/10.1016/j.cger.2020.06.001

Arrieta, H., Rezola-Pardo, C., Gil, S. M., Virgala, J., Iturburu, M., Antón, I., González-Templado, V., Irazusta, J., & Rodriguez-Larrad, A. (2019). Effects of Multicomponent Exercise on Frailty in Long-Term Nursing Homes: A Randomized Controlled Trial. *Journal of the American Geriatrics Society*, *67*(6), 1145–1151. https://doi.org/10.1111/jgs.15824

Arrieta, H., Rezola-Pardo, C., Zarrazquin, I., Echeverria, I., Yanguas, J. J., Iturburu, M., Gil, S. M., Rodriguez-Larrad, A., & Irazusta, J. (2018). A multicomponent exercise program improves physical function in long-term nursing home residents: A randomized controlled trial. *Experimental Gerontology*, *103*, 94–100. https://doi.org/10.1016/j.exger.2018.01.008

Arvidson, E., Dahlman, A. S., Börjesson, M., Gullstrand, L., & Jonsdottir, I. H. (2020). The effects of exercise training on hypothalamic-pituitary-adrenal axis reactivity and autonomic response to acute stress-a randomized controlled study. *Trials*, *21*(1), 888. https://doi.org/10.1186/s13063-020-04803-3

Banitalebi, E., Faramarzi, M., Bagheri, L., & Kazemi, A. R. (2018). Comparison of performing 12 weeks' resistance training before, after and/or in between aerobic exercise on the hormonal status of aged women: a randomized controlled trial. *Hormone Molecular Biology and Clinical Investigation*, *35*(3), 20180020. https://doi.org/10.1515/hmbci-2018-0020

Barnett, K., Mercer, S. W., Norbury, M., Watt, G., Wyke, S., & Guthrie, B. (2012). Epidemiology of multimorbidity and implications for health care, research, and medical education: a cross-sectional study. *The Lancet*, *380*(9836), 37–43. https://doi.org/10.1016/S0140-6736(12)60240-2

Barrett-Connor, E., Khaw, K. T., & Yen, S. S. (1986). A prospective study of dehydroepiandrosterone sulfate, mortality, and cardiovascular disease. *The New England Journal of Medicine*, *315*(24), 1519–1524. https://doi.org/10.1056/NEJM198612113152405

Beard, J. R., Officer, A., de Carvalho, I. A., Sadana, R., Pot, A. M., Michel, J.-P., Lloyd-Sherlock, P., Epping-Jordan, J. E., Peeters, G. M. E. E. G., Mahanani, W. R., Thiyagarajan, J. A., & Chatterji, S. (2016). The world report on ageing and health: A policy framework for healthy ageing. *The Lancet*, *387*(10033), 2145–2154. https://doi.org/10.1016/S0140-6736(15)00516-4

Bennell, K. L., Lawford, B. J., Metcalf, B., Mackenzie, D., Russell, T., van den Berg, M., Finnin, K., Crowther, S., Aiken, J., Fleming, J., & Hinman, R. S. (2021). Physiotherapists and patients report positive experiences overall with telehealth during the COVID-19 pandemic: a mixed-methods study. *Journal of Physiotherapy*, *67*(3), 201–209. https://doi.org/10.1016/j.jphys.2021.06.009

Bherer, L., Erickson, K. I., & Liu-Ambrose, T. (2013). A review of the effects of physical activity and exercise on cognitive and brain functions in older adults. *Journal of Aging Research*, *2013*, 657508. https://doi.org/10.1155/2013/657508

Bonnefoy, M., Kostka, T., Patricot, M. C., Berthouze, S. E., Mathian, B., & Lacour, J. R. (1998). Physical activity and dehydroepiandrosterone sulphate, insulin-like growth factor I and testosterone in healthy active elderly people. *Age and Ageing*, *27*(6), 745–751. https://doi.org/10.1093/ageing/27.6.745

Born, J., & Fehm, H. L. (1998). Hypothalamus-pituitary-adrenal activity during human sleep: a coordinating role for the limbic hippocampal system. *Experimental and Clinical Endocrinology & Diabetes*, *106*(3), 153–163. https://doi.org/10.1055/s-0029-1211969

Born, J., Hansen, K., Marshall, L., Mölle, M., & Fehm, H. L. (1999). Timing the end of nocturnal sleep. *Nature*, *397*(6714), 29–30. https://doi.org/10.1038/16166

Borst, S. E., Vincent, K. R., Lowenthal, D. T., & Braith, R. W. (2002). Effects of resistance training on insulin-like growth factor and its binding proteins in men and women aged 60 to

85. *Journal of the American Geriatrics Society*, *50*(5), 884–888. https://doi.org/10.1046/j.1532-5415.2002.50215.x

Brach, J. S., Simonsick, E. M., Kritchevsky, S., Yaffe, K., Newman, A. B., & Health, Aging and Body Composition Study Research Group. (2004). The association between physical function and lifestyle activity and exercise in the health, aging and body composition study. *Journal of the American Geriatrics Society*, *52*(4), 502–509. https://doi.org/10.1111/j.1532-5415.2004.52154.x

Britten, L., Addington, C., & Astill, S. (2017). Dancing in time: feasibility and acceptability of a contemporary dance programme to modify risk factors for falling in community dwelling older adults. *BMC Geriatrics*, *17*(1), 83. https://doi.org/10.1186/s12877-017-0476-6

Bromberg-Martin, E. S., Matsumoto, M., & Hikosaka, O. (2010). Dopamine in motivational control: rewarding, aversive, and alerting. *Neuron*, *68*(5), 815–834. https://doi.org/10.1016/j.neuron.2010.11.022

Brustio, P. R., Liubicich, M. E., Chiabrero, M., & Rabaglietti, E. (2018). Dancing in the golden age: a study on physical function, quality of life, and social engagement. *Geriatric Nursing (New York, N.Y.), 39*(6), 635–639. https://doi.org/10.1016/j.gerinurse.2018.04.013

Buckley, T. M., & Schatzberg, A. F. (2005). Aging and the role of the HPA axis and rhythm in sleep and memory-consolidation. *The American Journal of Geriatric Psychiatry*, *13*(5), 344–352. https://doi.org/10.1176/appi.ajgp.13.5.344

Buijs, R. M., van Eden, C. G., Goncharuk, V. D., & Kalsbeek, A. (2003). The biological clock tunes the organs of the body: timing by hormones and the autonomic nervous system. *The Journal of Endocrinology*, *177*(1), 17–26. https://doi.org/10.1677/joe.0.1770017

Bull, Fiona C, Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., Carty, C., Chaput, J.-P., Chastin, S., Chou, R., Dempsey, P. C., DiPietro, L., Ekelund, U., Firth, J., Friedenreich, C. M., Garcia, L., Gichu, M., Jago, R., Katzmarzyk, P. T., … Willumsen, J. F. (2020). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British Journal of Sports Medicine*, *54*(24), 1451–1462. https://doi.org/10.1136/bjsports-2020-102955

Bull, F C, Jamrozik, K., & Blanksby, B. A. (1999). Tailored advice on exercise--does it make a difference? *American Journal of Preventive Medicine*, *16*(3), 230–239. https://doi.org/10.1016/s0749-3797(98)00160-3

Butcher, S. K., Killampalli, V., Lascelles, D., Wang, K., Alpar, E. K., & Lord, J. M. (2005). Raised cortisol:DHEAS ratios in the elderly after injury: potential impact upon neutrophil function and immunity. *Aging Cell*, *4*(6), 319–324. https://doi.org/10.1111/j.1474-9726.2005.00178.x

Cadegiani, F. A., & Kater, C. E. (2019). Enhancement of hypothalamic-pituitary activity in male athletes: evidence of a novel hormonal mechanism of physical conditioning. *BMC Endocrine Disorders*, *19*(1), 117. https://doi.org/10.1186/s12902-019-0443-7

Caspersen, C. J. (1989). Physical activity epidemiology: concepts, methods, and applications to exercise science. *Exercise and Sport Sciences Reviews*, *17*, 423–473.

Ceresini, G., Morganti, S., Rebecchi, I., Freddi, M., Ceda, G. P., Banchini, A., Solerte, S. B., Ferrari, E., Ablondi, F., & Valenti, G. (2000). Evaluation of the circadian profiles of serum dehydroepiandrosterone (DHEA), cortisol, and cortisol/DHEA molar ratio after a single oral administration of DHEA in elderly subjects. *Metabolism: Clinical and Experimental*, *49*(4), 548–551. https://doi.org/10.1016/s0026-0495(00)80024-4

Chapie, A., & Arena, S. (2020). Benefits and barriers of activity trackers among older adults. *Home Healthcare Now*, *38*(3), 165–166. https://doi.org/10.1097/NHH.0000000000000868

Cherrington, A. D. (1999). Banting Lecture 1997. Control of glucose uptake and release by the liver in vivo. *Diabetes*, *48*(5), 1198–1214. https://doi.org/10.2337/diabetes.48.5.1198

Cheung, D. S. K., Ho, L. Y. W., Chan, L. C. K., Kwok, R. K. H., & Lai, C. K. Y. (2022). A Home-Based Dyadic Music-with-Movement Intervention for People with Dementia and Caregivers: A Hybrid Type 2 Cluster-Randomized Effectiveness-Implementation Design. *Clinical Interventions in Aging*, *17*, 1199–1216. https://doi.org/10.2147/CIA.S370661

Chin A Paw, M. J. M., van Poppel, M. N. M., Twisk, J. W. R., & van Mechelen, W. (2004). Effects of resistance and all-round, functional training on quality of life, vitality and depression of older adults living in long-term care facilities: a “randomized” controlled trial [ISRCTN87177281]. *BMC Geriatrics*, *4*, 5. https://doi.org/10.1186/1471-2318-4-5

Chin A Paw, M. J. M., van Uffelen, J. G. Z., Riphagen, I., & van Mechelen, W. (2008). The functional effects of physical exercise training in frail older people : a systematic review. *Sports Medicine (Auckland, N.Z.)*, *38*(9), 781–793.

Chodzko-Zajko, W., Schwingel, A., & Chae Hee Park. (2009). Successful aging: the role of physical activity. *American Journal of Lifestyle Medicine*, *3*(1), 20–28. https://doi.org/10.1177/1559827608325456

Chou, C.-H., Hwang, C.-L., & Wu, Y.-T. (2012). Effect of exercise on physical function, daily living activities, and quality of life in the frail older adults: a meta-analysis. *Archives of Physical Medicine and Rehabilitation*, *93*(2), 237–244. https://doi.org/10.1016/j.apmr.2011.08.042

Chrousos, George P. (2009). Stress and disorders of the stress system. *Nature Reviews. Endocrinology*, *5*(7), 374–381. https://doi.org/10.1038/nrendo.2009.106

Chrousos, G P. (1995). The hypothalamic-pituitary-adrenal axis and immune-mediated inflammation. *The New England Journal of Medicine*, *332*(20), 1351–1362. https://doi.org/10.1056/NEJM199505183322008

Clair, A. A. (1996). Therapeutic uses of music with older adults. In *Music in physical exercise.* (pp. 151–167). Health professions.

Clark, I. N., Taylor, N. F., & Baker, F. (2012). Music interventions and physical activity in older adults: a systematic literature review and meta-analysis. *Journal of Rehabilitation Medicine*, *44*(9), 710–719. https://doi.org/10.2340/16501977-1025

Clegg, A., Young, J., Iliffe, S., Rikkert, M. O., & Rockwood, K. (2013). Frailty in elderly people. *The Lancet*, *381*(9868), 752–762. https://doi.org/10.1016/S0140-6736(12)62167-9

Collado-Mateo, D., Lavín-Pérez, A. M., Peñacoba, C., Del Coso, J., Leyton-Román, M., Luque-Casado, A., Gasque, P., Fernández-Del-Olmo, M. Á., & Amado-Alonso, D. (2021). Key Factors Associated with Adherence to Physical Exercise in Patients with Chronic

Diseases and Older Adults: An Umbrella Review. *International Journal of Environmental Research and Public Health*, *18*(4). https://doi.org/10.3390/ijerph18042023

Collard, R. M., Boter, H., Schoevers, R. A., & Oude Voshaar, R. C. (2012). Prevalence of frailty in community-dwelling older persons: a systematic review. *Journal of the American Geriatrics Society*, *60*(8), 1487–1492. https://doi.org/10.1111/j.1532-5415.2012.04054.x

Corazza, D. I., Sebastião, É., Pedroso, R. V., Andreatto, C. A. A., de Melo Coelho, F. G., Gobbi, S., Teodorov, E., & Santos-Galduróz, R. F. (2013). Influence of chronic exercise on serum cortisol levels in older adults. *European Review of Aging and Physical Activity : Official Journal of the European Group for Research into Elderly and Physical Activity*. https://doi.org/10.1007/s11556-013-0126-8

Cordes, T., Schoene, D., Kemmler, W., & Wollesen, B. (2021). Chair-Based Exercise Interventions for Nursing Home Residents: A Systematic Review. *Journal of the American Medical Directors Association*, *22*(4), 733–740. https://doi.org/10.1016/j.jamda.2020.09.042

Cox, K. L., Cyarto, E. V., Etherton-Beer, C., Ellis, K. A., Alfonso, H., Clare, L., Liew, D., Ames, D., Flicker, L., Almeida, O. P., LoGiudice, D., & Lautenschlager, N. T. (2017). A randomized controlled trial of physical activity with individual goal-setting and volunteer mentors to overcome sedentary lifestyle in older adults at risk of cognitive decline: the INDIGO trial protocol. *BMC Geriatrics*, *17*(1), 215. https://doi.org/10.1186/s12877-017-0617-y

Crimmins, E. M., & Beltrán-Sánchez, H. (2011). Mortality and morbidity trends: is there compression of morbidity? *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences*, *66*(1), 75–86. https://doi.org/10.1093/geronb/gbq088

Crimmins, E. M. (2004). Trends in the health of the elderly. *Annual Review of Public Health*, *25*, 79–98. https://doi.org/10.1146/annurev.publhealth.25.102802.124401

Crowley, K. (2011). Sleep and sleep disorders in older adults. *Neuropsychology Review*, *21*(1), 41–53. https://doi.org/10.1007/s11065-010-9154-6

Daskalopoulou, C., Stubbs, B., Kralj, C., Koukounari, A., Prince, M., & Prina, A. M. (2017). Physical activity and healthy ageing: A systematic review and meta-analysis of longitudinal cohort studies. *Ageing Research Reviews*, *38*, 6–17. https://doi.org/10.1016/j.arr.2017.06.003

Davies, C. A., Spence, J. C., Vandelanotte, C., Caperchione, C. M., & Mummery, W. K. (2012). Meta-analysis of internet-delivered interventions to increase physical activity levels. *The International Journal of Behavioral Nutrition and Physical Activity*, *9*, 52. https://doi.org/10.1186/1479-5868-9-52

Dawson, R., Oliveira, J. S., Kwok, W. S., Bratland, M., Rajendran, I. M., Srinivasan, A., Chu, C. Y., Pinheiro, M. B., Hassett, L., & Sherrington, C. (2023). Exercise Interventions Delivered Through Telehealth to Improve Physical Functioning for Older Adults with Frailty, Cognitive, or Mobility Disability: A Systematic Review and Meta-Analysis. *Telemedicine Journal and E-Health*. https://doi.org/10.1089/tmj.2023.0177

Da Silva, J. L., Agbangla, N. F., Le Page, C., Ghernout, W., & Andrieu, B. (2022). Effects of chronic physical exercise or multicomponent exercise programs on the mental health and cognition of older adults living in a nursing home: A systematic review of studies from the past 10 years. *Frontiers in Psychology*, *13*, 888851. https://doi.org/10.3389/fpsyg.2022.888851

Deady, M., Choi, I., Calvo, R. A., Glozier, N., Christensen, H., & Harvey, S. B. (2017). eHealth interventions for the prevention of depression and anxiety in the general population: a systematic review and meta-analysis. *BMC Psychiatry*, *17*(1), 310. https://doi.org/10.1186/s12888-017-1473-1

de Kloet, E. R. (2000). Stress in the brain. *European Journal of Pharmacology*, *405*(1–3), 187–198. https://doi.org/10.1016/s0014-2999(00)00552-5

de Labra, C., Guimaraes-Pinheiro, C., Maseda, A., Lorenzo, T., & Millán-Calenti, J. C. (2015). Effects of physical exercise interventions in frail older adults: a systematic review of randomized controlled trials. *BMC Geriatrics*, *15*, 154. https://doi.org/10.1186/s12877-015-0155-4

de Vries, N. M., van Ravensberg, C. D., Hobbelen, J. S. M., Olde Rikkert, M. G. M., Staal, J. B., & Nijhuis-van der Sanden, M. W. G. (2012). Effects of physical exercise therapy on mobility, physical functioning, physical activity and quality of life in community-dwelling older adults with impaired mobility, physical disability and/or multi-morbidity: a meta-analysis. *Ageing Research Reviews*, *11*(1), 136–149. https://doi.org/10.1016/j.arr.2011.11.002

de Witte, M., Pinho, A. da S., Stams, G.-J., Moonen, X., Bos, A. E. R., & van Hooren, S. (2022). Music therapy for stress reduction: a systematic review and meta-analysis. *Health Psychology Review*, *16*(1), 134–159. https://doi.org/10.1080/17437199.2020.1846580

Dickmeis, T. (2009). Glucocorticoids and the circadian clock. *The Journal of Endocrinology*, *200*(1), 3–22. https://doi.org/10.1677/JOE-08-0415

Diener, J., Rayling, S., Bezold, J., Krell-Roesch, J., Woll, A., & Wunsch, K. (2022). Effectiveness and Acceptability of e- and m-Health Interventions to Promote Physical Activity and Prevent Falls in Nursing Homes-A Systematic Review. *Frontiers in Physiology*, *13*, 894397. https://doi.org/10.3389/fphys.2022.894397

Dingle, G. A., Sharman, L. S., Bauer, Z., Beckman, E., Broughton, M., Bunzli, E., Davidson, R., Draper, G., Fairley, S., Farrell, C., Flynn, L. M., Gomersall, S., Hong, M., Larwood, J., Lee, C., Lee, J., Nitschinsk, L., Peluso, N., Reedman, S. E., … Wright, O. R. L. (2021). How Do Music Activities Affect Health and Well-Being? A Scoping Review of Studies Examining Psychosocial Mechanisms. *Frontiers in Psychology*, *12*, 713818. https://doi.org/10.3389/fpsyg.2021.713818

Di Lorito, C., Long, A., Byrne, A., Harwood, R. H., Gladman, J. R. F., Schneider, S., Logan, P., Bosco, A., & van der Wardt, V. (2021). Exercise interventions for older adults: A systematic review of meta-analyses. *Journal of Sport and Health Science*, *10*(1), 29–47. https://doi.org/10.1016/j.jshs.2020.06.003

Doody, P., Lord, J. M., Greig, C. A., & Whittaker, A. C. (2023). Frailty: pathophysiology, theoretical and operational definition(s), impact, prevalence, management and prevention, in an increasingly economically developed and ageing world. *Gerontology*, *69*(8), 927–945. https://doi.org/10.1159/000528561

Dos Santos, V. R., & Gobbo, L. A. (2021). Occupational and leisure-time physical activity decreases the odds of disability in older adults: Prospective study. *European Journal of Sport Science*, *21*(6), 927–934. https://doi.org/10.1080/17461391.2020.1790669

Duclos, M., Gouarne, C., & Bonnemaison, D. (2003). Acute and chronic effects of exercise on tissue sensitivity to glucocorticoids. *Journal of Applied Physiology: Respiratory,* *Environmental and Exercise Physiology*, *94*(3), 869–875. https://doi.org/10.1152/japplphysiol.00108.2002

Erickson, K. I., & Kramer, A. F. (2009). Aerobic exercise effects on cognitive and neural plasticity in older adults. *British Journal of Sports Medicine*, *43*(1), 22–24. https://doi.org/10.1136/bjsm.2008.052498

Espiritu, J. R. D. (2008). Aging-related sleep changes. *Clinics in Geriatric Medicine*, *24*(1), 1–14, v. https://doi.org/10.1016/j.cger.2007.08.007

Fakoya, O. A., McCorry, N. K., & Donnelly, M. (2020). Loneliness and social isolation interventions for older adults: a scoping review of reviews. *BMC Public Health*, *20*(1), 129. https://doi.org/10.1186/s12889-020-8251-6

Feng, Z., Lugtenberg, M., Franse, C., Fang, X., Hu, S., Jin, C., & Raat, H. (2017). Risk factors and protective factors associated with incident or increase of frailty among community-dwelling older adults: A systematic review of longitudinal studies. *Plos One*, *12*(6), e0178383. https://doi.org/10.1371/journal.pone.0178383

Ferrari, E., Cravello, L., Muzzoni, B., Casarotti, D., Paltro, M., Solerte, S. B., Fioravanti, M., Cuzzoni, G., Pontiggia, B., & Magri, F. (2001). Age-related changes of the hypothalamic-pituitary-adrenal axis: pathophysiological correlates. *European Journal of Endocrinology*, *144*(4), 319–329. https://doi.org/10.1530/eje.0.1440319

Fiatarone, M. A., O’Neill, E. F., Ryan, N. D., Clements, K. M., Solares, G. R., Nelson, M. E., Roberts, S. B., Kehayias, J. J., Lipsitz, L. A., & Evans, W. J. (1994). Exercise training and nutritional supplementation for physical frailty in very elderly people. *The New England*

Journal of Medicine, *330*(25), 1769–1775. https://doi.org/10.1056/NEJM199406233302501

Foster, C., Richards, J., Thorogood, M., & Hillsdon, M. (2013). Remote and web 2.0 interventions for promoting physical activity. *Cochrane Database of Systematic Reviews*, *9*(9), CD010395. https://doi.org/10.1002/14651858.CD010395.pub2

Fox, K. R., Stathi, A., McKenna, J., & Davis, M. G. (2007). Physical activity and mental well-being in older people participating in the Better Ageing Project. *European Journal of Applied Physiology*, *100*(5), 591–602. https://doi.org/10.1007/s00421-007-0392-0

Fried, Linda P. (2016). Interventions for human frailty: physical activity as a model. *Cold Spring Harbor Perspectives in Medicine*, *6*(6). https://doi.org/10.1101/cshperspect.a025916

Fried, L P, Tangen, C. M., Walston, J., Newman, A. B., Hirsch, C., Gottdiener, J., Seeman, T., Tracy, R., Kop, W. J., Burke, G., & McBurnie, M. A. (2001). Frailty in older adults: Evidence for a phenotype. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *56*(3), M146-56. https://doi.org/10.1093/gerona/56.3.m146

Gale, C. R., Westbury, L., & Cooper, C. (2018). Social isolation and loneliness as risk factors for the progression of frailty: the English Longitudinal Study of Ageing. *Age and Ageing*, *47*(3), 392–397. https://doi.org/10.1093/ageing/afx188

Garcia-Hermoso, A., López-Gil, J. F., Ramírez-Vélez, R., Alonso-Martínez, A. M., Izquierdo, M., & Ezzatvar, Y. (2023). Adherence to aerobic and muscle-strengthening activities guidelines: a systematic review and meta-analysis of 3.3 million participants across 32 countries. *British Journal of Sports Medicine*, *57*(4), 225–229. https://doi.org/10.1136/bjsports-2022-106189

Gill, T. M., Gahbauer, E. A., Allore, H. G., & Han, L. (2006). Transitions between frailty states among community-living older persons. *Archives of Internal Medicine*, *166*(4), 418–423. https://doi.org/10.1001/archinte.166.4.418

Gjerstad, J. K., Lightman, S. L., & Spiga, F. (2018). Role of glucocorticoid negative feedback in the regulation of HPA axis pulsatility. *Stress (Amsterdam, Netherlands)*, *21*(5), 403–416. https://doi.org/10.1080/10253890.2018.1470238

Gomes, M., Figueiredo, D., Teixeira, L., Poveda, V., Paúl, C., Santos-Silva, A., & Costa, E. (2017). Physical inactivity among older adults across Europe based on the SHARE database. *Age and Ageing*, *46*(1), 71–77. https://doi.org/10.1093/ageing/afw165

González-Rocha, A., Mendez-Sanchez, L., Ortíz-Rodríguez, M. A., & Denova-Gutiérrez, E. (2022). Effect Of Exercise on Muscle Mass, Fat Mass, Bone Mass, Muscular Strength and Physical Performance in Community Dwelling Older Adults: Systematic Review and Meta-Analysis. *Aging and Disease*, *13*(5), 1421–1435. https://doi.org/10.14336/AD.2022.0215

Gothe, N. P., Keswani, R. K., & McAuley, E. (2016). Yoga practice improves executive function by attenuating stress levels. *Biological Psychology*, *121*(Pt A), 109–116. https://doi.org/10.1016/j.biopsycho.2016.10.010

Gutman, G., & Shade, M. (2020). Digital Interventions to Promote Health and Well-Being of Older Adults. *Innovation in Aging*, *4*(Supplement_1), 755–755. https://doi.org/10.1093/geroni/igaa057.2721

Guzmán-García, A., Hughes, J. C., James, I. A., & Rochester, L. (2013). Dancing as a psychosocial intervention in care homes: a systematic review of the literature. *International Journal of Geriatric Psychiatry*, *28*(9), 914–924. https://doi.org/10.1002/gps.3913

Hackney, A. C. (2006a). Exercise as a stressor to the human neuroendocrine system. *Medicina (Kaunas, Lithuania)*, *42*(10), 788–797.

Hackney, A. C. (2006b). Stress and the neuroendocrine system: the role of exercise as a stressor and modifier of stress. *Expert Review of Endocrinology & Metabolism*, *1*(6), 783–792. https://doi.org/10.1586/17446651.1.6.783

Häkkinen, K., Pakarinen, A., Kraemer, W. J., Newton, R. U., & Alen, M. (2000). Basal concentrations and acute responses of serum hormones and strength development during heavy resistance training in middle-aged and elderly men and women. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *55*(2), B95-105. https://doi.org/10.1093/gerona/55.2.b95

Hayes, L. D., Grace, F. M., Sculthorpe, N., Herbert, P., Ratcliffe, J. W., Kilduff, L. P., & Baker, J. S. (2013). The effects of a formal exercise training programme on salivary hormone concentrations and body composition in previously sedentary aging men. *SpringerPlus*, *2*(1), 18. https://doi.org/10.1186/2193-1801-2-18

Heaney, J. L. J., Carroll, D., & Phillips, A. C. (2014). Physical activity, life events stress, cortisol, and DHEA: preliminary findings that physical activity may buffer against the negative effects of stress. *Journal of Aging and Physical Activity*, *22*(4), 465–473. https://doi.org/10.1123/japa.2012-0082

Heaney, J. L. J., Phillips, A. C., & Carroll, D. (2010). Ageing, depression, anxiety, social support and the diurnal rhythm and awakening response of salivary cortisol. *International Journal of Psychophysiology*, *78*(3), 201–208. https://doi.org/10.1016/j.ijpsycho.2010.07.009

Heaney, J. L. J., Phillips, A. C., & Carroll, D. (2012). Ageing, physical function, and the diurnal rhythms of cortisol and dehydroepiandrosterone. *Psychoneuroendocrinology*, *37*(3), 341–349. https://doi.org/10.1016/j.psyneuen.2011.07.001

Herman, J. P., McKlveen, J. M., Ghosal, S., Kopp, B., Wulsin, A., Makinson, R., Scheimann, J., & Myers, B. (2016). Regulation of the Hypothalamic-Pituitary-Adrenocortical Stress Response. *Comprehensive Physiology*, *6*(2), 603–621. https://doi.org/10.1002/cphy.c150015

Higueras-Fresnillo, S., Cabanas-Sánchez, V., García-Esquinas, E., Rodríguez-Artalejo, F., & Martinez-Gomez, D. (2018). Physical activity attenuates the impact of poor physical, mental, and social health on total and cardiovascular mortality in older adults: a population-based prospective cohort study. *Quality of Life Research*, *27*(12), 3293–3302. https://doi.org/10.1007/s11136-018-1974-5

Hinson, J. P., & Raven, P. W. (1999). DHEA deficiency syndrome: a new term for old age? *The Journal of Endocrinology*, *163*(1), 1–5. https://doi.org/10.1677/joe.0.1630001

Hwang, P. W.-N., & Braun, K. L. (2015). The effectiveness of dance interventions to improve older adults' health: A systematic literature review. *Alternative Therapies in Health and Medicine*, *21*(5), 64–70.

Ice, G. H., Katz-Stein, A., Himes, J., & Kane, R. L. (2004). Diurnal cycles of salivary cortisol in older adults. *Psychoneuroendocrinology*, *29*(3), 355–370. https://doi.org/10.1016/s0306-4530(03)00034-9

Irish, L. A., Kline, C. E., Gunn, H. E., Buysse, D. J., & Hall, M. H. (2015). The role of sleep hygiene in promoting public health: A review of empirical evidence. *Sleep Medicine Reviews*, *22*, 23–36. https://doi.org/10.1016/j.smrv.2014.10.001

Irwin, M. R. (2015). Why sleep is important for health: a psychoneuroimmunology perspective. *Annual Review of Psychology*, *66*, 143–172. https://doi.org/10.1146/annurev-psych-010213-115205

Izquierdo, M., Häkkinen, K., Antón, A., Garrues, M., Ibañez, J., Ruesta, M., & Gorostiaga, E. M. (2001). Maximal strength and power, endurance performance, and serum hormones in middle-aged and elderly men. *Medicine and Science in Sports and Exercise*, *33*(9), 1577–1587. https://doi.org/10.1097/00005768-200109000-00022

Jadczak, A. D., Makwana, N., Luscombe-Marsh, N., Visvanathan, R., & Schultz, T. J. (2018). Effectiveness of exercise interventions on physical function in community-dwelling frail older people: an umbrella review of systematic reviews. *JBI Database of Systematic Reviews and Implementation Reports*, *16*(3), 752–775. https://doi.org/10.11124/JBISRIR-2017-003551

Jakubowski, K., & Eerola, T. (2022). Music evokes fewer but more positive autobiographical memories than emotionally matched sound and word cues. *Journal of Applied Research in Memory and Cognition*, *11*(2), 272–288. https://doi.org/10.1016/j.jarmac.2021.09.002

Kalsbeek, A., Palm, I. F., La Fleur, S. E., Scheer, F. A. J. L., Perreau-Lenz, S., Ruiter, M., Kreier, F., Cailotto, C., & Buijs, R. M. (2006). SCN outputs and the hypothalamic balance of life. *Journal of Biological Rhythms*, *21*(6), 458–469. https://doi.org/10.1177/0748730406293854

Karlamangla, A. S., Friedman, E. M., Seeman, T. E., Stawksi, R. S., & Almeida, D. M. (2013). Daytime trajectories of cortisol: demographic and socioeconomic differences--findings from the National Study of Daily Experiences. *Psychoneuroendocrinology*, *38*(11), 2585–2597. https://doi.org/10.1016/j.psyneuen.2013.06.010

Karlamangla, A. S., Singer, B. H., McEwen, B. S., Rowe, J. W., & Seeman, T. E. (2002). Allostatic load as a predictor of functional decline. MacArthur studies of successful aging. *Journal of Clinical Epidemiology*, *55*(7), 696–710. https://doi.org/10.1016/s0895-4356(02)00399-2

Katz, S., Ford, A. B., Moskowitz, R. W., Jackson, B. A., & Jaffe, M. W. (1963). Studies of illness in the aged. the index of ADL: a standardized measure of biological and psychosocial function. *The Journal of the American Medical Association*, *185*, 914–919.

Khaw, K.-T., Wareham, N., Bingham, S., Welch, A., Luben, R., & Day, N. (2008). Combined impact of health behaviours and mortality in men and women: the EPIC-Norfolk prospective population study. *PLoS Medicine*, *5*(1), e12. https://doi.org/10.1371/journal.pmed.0050012

Klaperski, S., von Dawans, B., Heinrichs, M., & Fuchs, R. (2014). Effects of a 12-week endurance training program on the physiological response to psychosocial stress in men: a randomized controlled trial. *Journal of Behavioral Medicine*, *37*(6), 1118–1133. https://doi.org/10.1007/s10865-014-9562-9

Kojima, G. (2015). Prevalence of Frailty in Nursing Homes: A Systematic Review and Meta-Analysis. *Journal of the American Medical Directors Association*, *16*(11), 940–945. https://doi.org/10.1016/j.jamda.2015.06.025

Kraemer, W. J., Häkkinen, K., Newton, R. U., Nindl, B. C., Volek, J. S., McCormick, M., Gotshalk, L. A., Gordon, S. E., Fleck, S. J., Campbell, W. W., Putukian, M., & Evans, W. J. (1999). Effects of heavy-resistance training on hormonal response patterns in younger vs. older men. *Journal of Applied Physiology*, *87*(3), 982–992. https://doi.org/10.1152/jappl.1999.87.3.982

Kredlow, M. A., Capozzoli, M. C., Hearon, B. A., Calkins, A. W., & Otto, M. W. (2015). The effects of physical activity on sleep: a meta-analytic review. *Journal of Behavioral Medicine*, *38*(3), 427–449. https://doi.org/10.1007/s10865-015-9617-6

Kripke, D. F., Garfinkel, L., Wingard, D. L., Klauber, M. R., & Marler, M. R. (2002). Mortality associated with sleep duration and insomnia. *Archives of General Psychiatry*, *59*(2), 131–136. https://doi.org/10.1001/archpsyc.59.2.131

Kroboth, P. D., Salek, F. S., Pittenger, A. L., Fabian, T. J., & Frye, R. F. (1999). DHEA and DHEA-S: a review. *Journal of Clinical Pharmacology*, *39*(4), 327–348. https://doi.org/10.1177/00912709922007903

Kubzansky, L. D., Kawachi, I., & Sparrow, D. (1999). Socioeconomic status, hostility, and risk factor clustering in the Normative Aging Study: any help from the concept of allostatic load? *Annals of Behavioral Medicine*, *21*(4), 330–338. https://doi.org/10.1007/BF02895966

Landi, F., Abbatecola, A. M., Provinciali, M., Corsonello, A., Bustacchini, S., Manigrasso, L., Cherubini, A., Bernabei, R., & Lattanzio, F. (2010). Moving against frailty: does physical activity matter? *Biogerontology*, *11*(5), 537–545. https://doi.org/10.1007/s10522-010-9296-1

Lautenschlager, N. T., Cox, K. L., Flicker, L., Foster, J. K., van Bockxmeer, F. M., Xiao, J., Greenop, K. R., & Almeida, O. P. (2008). Effect of physical activity on cognitive function in older adults at risk for Alzheimer disease: a randomized trial. *The Journal of the American Medical Association*, *300*(9), 1027–1037. https://doi.org/10.1001/jama.300.9.1027

Lawton, M. P., & Brody, E. M. (1969). Assessment of older people: self-maintaining and instrumental activities of daily living. *The Gerontologist*, *9*(3), 179–186. https://doi.org/10.1093/geront/9.3_Part_1.179

Lee, P. G., Jackson, E. A., & Richardson, C. R. (2017). Exercise prescriptions in older adults. *American Family Physician*, *95*(7), 425–432.

Léger, D., Poursain, B., Neubauer, D., & Uchiyama, M. (2008). An international survey of sleeping problems in the general population. *Current Medical Research and Opinion*, *24*(1), 307–317. https://doi.org/10.1185/030079907x253771

Legrain, S., & Girard, L. (2003). Pharmacology and therapeutic effects of dehydroepiandrosterone in older subjects. *Drugs & Aging*, *20*(13), 949–967. https://doi.org/10.2165/00002512-200320130-00001

Lennartsson, A.-K., Kushnir, M. M., Bergquist, J., & Jonsdottir, I. H. (2012). DHEA and DHEA-S response to acute psychosocial stress in healthy men and women. *Biological Psychology*, *90*(2), 143–149. https://doi.org/10.1016/j.biopsycho.2012.03.003

Liu, C., Shiroy, D. M., Jones, L. Y., & Clark, D. O. (2014). Systematic review of functional training on muscle strength, physical functioning, and activities of daily living in older adults. *European Review of Aging and Physical Activity : Official Journal of the European*

Group for Research into Elderly and Physical Activity, *11*(2), 95–106. https://doi.org/10.1007/s11556-014-0144-1

Liu, X., Shen, P.-L., & Tsai, Y.-S. (2021). Dance intervention effects on physical function in healthy older adults: a systematic review and meta-analysis. *Aging Clinical and Experimental Research*, *33*(2), 253–263. https://doi.org/10.1007/s40520-019-01440-y

Loef, M., & Walach, H. (2012). The combined effects of healthy lifestyle behaviors on all cause mortality: a systematic review and meta-analysis. *Preventive Medicine*, *55*(3), 163–170. https://doi.org/10.1016/j.ypmed.2012.06.017

Luger, A., Deuster, P. A., Kyle, S. B., Gallucci, W. T., Montgomery, L. C., Gold, P. W., Loriaux, D. L., & Chrousos, G. P. (1987). Acute hypothalamic-pituitary-adrenal responses to the stress of treadmill exercise. Physiologic adaptations to physical training. *The New England Journal of Medicine*, *316*(21), 1309–1315. https://doi.org/10.1056/NEJM198705213162105

Lu, E. Y., Lee, P., Cai, S., So, W. W. Y., Ng, B. F. L., Jensen, M. P., Cheung, W. M., & Tsang, H. W. H. (2020). Qigong for the treatment of depressive symptoms: Preliminary evidence of neurobiological mechanisms. *International Journal of Geriatric Psychiatry*, *35*(11), 1393–1401. https://doi.org/10.1002/gps.5380

Lucertini, F., Ponzio, E., Di Palma, M., Galati, C., Federici, A., Barbadoro, P., D’Errico, M. M., Prospero, E., Ambrogini, P., Cuppini, R., Lattanzi, D., & Minelli, A. (2015). High Cardiorespiratory Fitness Is Negatively Associated with Daily Cortisol Output in Healthy Aging Men. *Plos One*, *10*(11), e0141970. https://doi.org/10.1371/journal.pone.0141970

Macera, C. A., Cavanaugh, A., & Bellettiere, J. (2017). State of the art review: physical activity and older adults. *American Journal of Lifestyle Medicine*, *11*(1), 42–57. https://doi.org/10.1177/1559827615571897

Macfarlane, D. P., Forbes, S., & Walker, B. R. (2008). Glucocorticoids and fatty acid metabolism in humans: fuelling fat redistribution in the metabolic syndrome. *The Journal of Endocrinology*, *197*(2), 189–204. https://doi.org/10.1677/JOE-08-0054

Mallon, L., Broman, J. E., & Hetta, J. (2002). Sleep complaints predict coronary artery disease mortality in males: a 12-year follow-up study of a middle-aged Swedish population. *Journal of Internal Medicine*, *251*(3), 207–216. https://doi.org/10.1046/j.1365-2796.2002.00941.x

Mander, B. A., Winer, J. R., & Walker, M. P. (2017). Sleep and human aging. *Neuron*, *94*(1), 19–36. https://doi.org/10.1016/j.neuron.2017.02.004

Mangani, I., Cesari, M., Kritchevsky, S. B., Maraldi, C., Carter, C. S., Atkinson, H. H., Penninx, B. W. H. J., Marchionni, N., & Pahor, M. (2006). Physical exercise and comorbidity. Results from the Fitness and Arthritis in Seniors Trial (FAST). *Aging Clinical and Experimental Research*, *18*(5), 374–380.

Maninger, N., Wolkowitz, O. M., Reus, V. I., Epel, E. S., & Mellon, S. H. (2009). Neurobiological and neuropsychiatric effects of dehydroepiandrosterone (DHEA) and DHEA sulfate (DHEAS). *Frontiers in Neuroendocrinology*, *30*(1), 65–91. https://doi.org/10.1016/j.yfrne.2008.11.002

Marceau, K., Shirtcliff, E. A., Hastings, P. D., Klimes-Dougan, B., Zahn-Waxler, C., Dorn, L. D., & Susman, E. J. (2014). Within-adolescent coupled changes in cortisol with DHEA and testosterone in response to three stressors during adolescence. *Psychoneuroendocrinology*, *41*, 33–45. https://doi.org/10.1016/j.psyneuen.2013.12.002

Marques, E. A., Wanderley, F., Machado, L., Sousa, F., Viana, J. L., Moreira-Gonçalves, D., Moreira, P., Mota, J., & Carvalho, J. (2011). Effects of resistance and aerobic exercise on physical function, bone mineral density, OPG and RANKL in older women. *Experimental Gerontology*, *46*(7), 524–532. https://doi.org/10.1016/j.exger.2011.02.005

May, M., Holmes, E., Rogers, W., & Poth, M. (1990). Protection from glucocorticoid induced thymic involution by dehydroepiandrosterone. *Life Sciences*, *46*(22), 1627–1631. https://doi.org/10.1016/0024-3205(90)90394-7

McEwen, Bruce S. (2007). Physiology and neurobiology of stress and adaptation: Central role of the brain. *Physiological Reviews*, *87*(3), 873–904. https://doi.org/10.1152/physrev.00041.2006

McEwen, B S, & Morrison, J. H. (2013). The brain on stress: vulnerability and plasticity of the prefrontal cortex over the life course. *Neuron*, *79*(1), 16–29. https://doi.org/10.1016/j.neuron.2013.06.028

McEwen, B S, & Seeman, T. (1999). Protective and damaging effects of mediators of stress. Elaborating and testing the concepts of allostasis and allostatic load. *Annals of the New York Academy of Sciences*, *896*, 30–47. https://doi.org/10.1111/j.1749-6632.1999.tb08103.x

McGarrigle, L., Boulton, E., & Todd, C. (2020). Map the apps: a rapid review of digital approaches to support the engagement of older adults in strength and balance exercises. *BMC Geriatrics*, *20*(1), 483. https://doi.org/10.1186/s12877-020-01880-6

McPhee, J. S., French, D. P., Jackson, D., Nazroo, J., Pendleton, N., & Degens, H. (2016). Physical activity in older age: perspectives for healthy ageing and frailty. *Biogerontology, 17*(3), 567–580. https://doi.org/10.1007/s10522-016-9641-0

Menon, V., & Levitin, D. J. (2005). The rewards of music listening: response and physiological connectivity of the mesolimbic system. *Neuroimage*, *28*(1), 175–184. https://doi.org/10.1016/j.neuroimage.2005.05.053

Minkler, M., Schauffler, H., & Clements-Nolle, K. (2000). Health promotion for older Americans in the 21st century. *American Journal of Health Promotion, 14*(6), 371–379. https://doi.org/10.4278/0890-1171-14.6.371

Montanini, V., Simoni, M., Chiossi, G., Baraghini, G. F., Velardo, A., Baraldi, E., & Marrama, P. (1988). Age-related changes in plasma dehydroepiandrosterone sulphate, cortisol, testosterone and free testosterone circadian rhythms in adult men. *Hormone Research*, *29*(1), 1–6. https://doi.org/10.1159/000180956

Morales, A. J., Nolan, J. J., Nelson, J. C., & Yen, S. S. (1994). Effects of replacement dose of dehydroepiandrosterone in men and women of advancing age. *The Journal of Clinical Endocrinology and Metabolism*, *78*(6), 1360–1367. https://doi.org/10.1210/jcem.78.6.7515387

Mora, J. C., & Valencia, W. M. (2018). Exercise and older adults. *Clinics in Geriatric Medicine*, *34*(1), 145–162. https://doi.org/10.1016/j.cger.2017.08.007

Morley, J. E., & Flaherty, J. H. (2002). It’s never too late: health promotion and illness prevention in older persons. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 57*(6), M338-42. https://doi.org/10.1093/gerona/57.6.m338

Muellmann, S., Forberger, S., Möllers, T., Bröring, E., Zeeb, H., & Pischke, C. R. (2018). Effectiveness of eHealth interventions for the promotion of physical activity in older adults: A systematic review. *Preventive Medicine*, *108*, 93–110. https://doi.org/10.1016/j.ypmed.2017.12.026

Munck, A., Guyre, P. M., & Holbrook, N. J. (1984). Physiological functions of glucocorticoids in stress and their relation to pharmacological actions. *Endocrine Reviews*, *5*(1), 25–44. https://doi.org/10.1210/edrv-5-1-25

Nascimento, M. de M., Gouveia, É. R., Marques, A., Gouveia, B. R., Marconcin, P., França, C., & Ihle, A. (2022). The Role of Physical Function in the Association between Physical Activity and Gait Speed in Older Adults: A Mediation Analysis. *International Journal of Environmental Research and Public Health*, *19*(19). https://doi.org/10.3390/ijerph191912581

Ng, B. H. P., & Tsang, H. W. H. (2009). Psychophysiological outcomes of health qigong for chronic conditions: a systematic review. *Psychophysiology*, *46*(2), 257–269. https://doi.org/10.1111/j.1469-8986.2008.00763.x

Ng, T. P., Feng, L., Nyunt, M. S. Z., Feng, L., Niti, M., Tan, B. Y., Chan, G., Khoo, S. A., Chan, S. M., Yap, P., & Yap, K. B. (2015). Nutritional, physical, cognitive, and combination interventions and frailty reversal among older adults: A randomized controlled trial. *The American Journal of Medicine*, *128*(11), 1225-1236.e1. https://doi.org/10.1016/j.amjmed.2015.06.017

Nicolaides, N. C., Charmandari, E., Chrousos, G. P., & Kino, T. (2014). Circadian endocrine rhythms: the hypothalamic-pituitary-adrenal axis and its actions. *Annals of the New York Academy of Sciences*, *1318*, 71–80. https://doi.org/10.1111/nyas.12464

Nollet, M., Wisden, W., & Franks, N. P. (2020). Sleep deprivation and stress: a reciprocal relationship. *Interface Focus*, *10*(3), 20190092. https://doi.org/10.1098/rsfs.2019.0092

Norman, G. J., Zabinski, M. F., Adams, M. A., Rosenberg, D. E., Yaroch, A. L., & Atienza, A. A. (2007). A review of eHealth interventions for physical activity and dietary behavior change. *American Journal of Preventive Medicine*, *33*(4), 336–345. https://doi.org/10.1016/j.amepre.2007.05.007

Nusselder, W. J., Looman, C. W. N., Franco, O. H., Peeters, A., Slingerland, A. S., & Mackenbach, J. P. (2008). The relation between non-occupational physical activity and years lived with and without disability. *Journal of Epidemiology and Community Health*, *62*(9), 823–828. https://doi.org/10.1136/jech.2007.067165

Nyman, S. R., & Victor, C. R. (2011). Older people's recruitment, sustained participation, and adherence to falls prevention interventions in institutional settings: a supplement to the Cochrane systematic review. *Age and Ageing*, *40*(4), 430–436. https://doi.org/10.1093/ageing/afr016

O'Neill, D., & Forman, D. E. (2020). The importance of physical function as a clinical outcome: Assessment and enhancement. *Clinical Cardiology*, *43*(2), 108–117. https://doi.org/10.1002/clc.23311

Ockenfels, M. C., Porter, L., Smyth, J., Kirschbaum, C., Hellhammer, D. H., & Stone, A. A. (1995). Effect of chronic stress associated with unemployment on salivary cortisol: overall cortisol levels, diurnal rhythm, and acute stress reactivity. *Psychosomatic Medicine*, *57*(5), 460–467. https://doi.org/10.1097/00006842-199509000-00008

Office for National Statistics. (2021, February 23). *Health state life expectancy, all ages, UK*. https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/healthandlifeexpectancies/datasets/healthstatelifeexpectancyallagesuk

Ono, D., & Yamanaka, A. (2017). Hypothalamic regulation of the sleep/wake cycle. *Neuroscience Research*, *118*, 74–81. https://doi.org/10.1016/j.neures.2017.03.013

Opp, M., Obál, F., & Krueger, J. M. (1989). Corticotropin-releasing factor attenuates interleukin 1-induced sleep and fever in rabbits. *The American Journal of Physiology*, *257*(3 Pt 2), R528-35. https://doi.org/10.1152/ajpregu.1989.257.3.R528

Opp, M. R. (1995). Corticotropin-releasing hormone involvement in stressor-induced alterations in sleep and in the regulation of waking. *Advances in Neuroimmunology*, *5*(2), 127–143. https://doi.org/10.1016/0960-5428(95)00004-l

Orentreich, N., Brind, J. L., Rizer, R. L., & Vogelman, J. H. (1984). Age changes and sex differences in serum dehydroepiandrosterone sulfate concentrations throughout adulthood. *The Journal of Clinical Endocrinology and Metabolism*, *59*(3), 551–555. https://doi.org/10.1210/jcem-59-3-551

Parker, K., Uddin, R., Ridgers, N. D., Brown, H., Veitch, J., Salmon, J., Timperio, A., Sahlqvist, S., Cassar, S., Toffoletti, K., Maddison, R., & Arundell, L. (2021). The Use of Digital Platforms for Adults' and Adolescents' Physical Activity During the COVID-19 Pandemic (Our Life at Home): Survey Study. *Journal of Medical Internet Research*, *23*(2), e23389. https://doi.org/10.2196/23389

Paterson, D. H., Jones, G. R., & Rice, C. L. (2007). Ageing and physical activity: evidence to develop exercise recommendations for older adults. *Canadian Journal of Public Health, 98 Suppl 2*, S69-108.

Paterson, D. H., & Warburton, D. E. (2010). Physical activity and functional limitations in older adults: a systematic review related to Canada's Physical Activity Guidelines. *The International Journal of Behavioral Nutrition and Physical Activity*, *7*, 38. https://doi.org/10.1186/1479-5868-7-38

Peel, N. M., McClure, R. J., & Bartlett, H. P. (2005). Behavioral determinants of healthy aging. *American Journal of Preventive Medicine*, *28*(3), 298–304. https://doi.org/10.1016/j.amepre.2004.12.002

Peterson, M. J., Giuliani, C., Morey, M. C., Pieper, C. F., Evenson, K. R., Mercer, V., Cohen, H. J., Visser, M., Brach, J. S., Kritchevsky, S. B., Goodpaster, B. H., Rubin, S., Satterfield, S., Newman, A. B., Simonsick, E. M., & Health, Aging and Body Composition Study Research Group. (2009). Physical activity as a preventative factor for frailty: the health, aging, and body composition study. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *64*(1), 61–68. https://doi.org/10.1093/gerona/gln001

Pettee Gabriel, K., Sternfeld, B., Colvin, A., Stewart, A., Strotmeyer, E. S., Cauley, J. A., Dugan, S., & Karvonen-Gutierrez, C. (2017). Physical activity trajectories during midlife and subsequent risk of physical functioning decline in late mid-life: The Study of Women's Health Across the Nation (SWAN). *Preventive Medicine*, *105*, 287–294. https://doi.org/10.1016/j.ypmed.2017.10.005

Phillips, A. C., Burns, V. E., & Lord, J. M. (2007). Stress and exercise: Getting the balance right for aging immunity. *Exercise and Sport Sciences Reviews, 35*(1), 35–39. https://doi.org/10.1097/jes.0b013e31802d7008

Phillips, A. C., Carroll, D., Gale, C. R., Lord, J. M., Arlt, W., & Batty, G. D. (2010a). Cortisol, DHEAS, their ratio and the metabolic syndrome: evidence from the Vietnam Experience Study. *European Journal of Endocrinology*, *162*(5), 919–923. https://doi.org/10.1530/EJE-09-1078

Phillips, A. C., Carroll, D., Gale, C. R., Lord, J. M., Arlt, W., & Batty, G. D. (2010b). Cortisol, DHEA sulphate, their ratio, and all-cause and cause-specific mortality in the Vietnam Experience Study. *European Journal of Endocrinology*, *163*(2), 285–292. https://doi.org/10.1530/EJE-10-0299

Ponzio, E., Sotte, L., D'Errico, M. M., Berti, S., Barbadoro, P., Prospero, E., & Minelli, A. (2015). Qi-gong training reduces basal and stress-elicited cortisol secretion in healthy older adults. *European Journal of Integrative Medicine*, *7*(3), 194–201. https://doi.org/10.1016/j.eujim.2015.01.002

Prakhinkit, S., Suppapitiporn, S., Tanaka, H., & Suksom, D. (2014). Effects of Buddhism walking meditation on depression, functional fitness, and endothelium-dependent vasodilation in depressed elderly. *Journal of Alternative and Complementary Medicine*, *20*(5), 411–416. https://doi.org/10.1089/acm.2013.0205

Priest, D. L., Karageorghis, C. I., & Sharp, N. C. C. (2004). The characteristics and effects of motivational music in exercise settings: the possible influence of gender, age, frequency of attendance, and time of attendance. *The Journal of Sports Medicine and Physical Fitness*, *44*(1), 77–86.

Qin, D.-D., Rizak, J., Feng, X.-L., Yang, S.-C., Lü, L.-B., Pan, L., Yin, Y., & Hu, X.-T. (2016). Prolonged secretion of cortisol as a possible mechanism underlying stress and depressive behaviour. *Scientific Reports*, *6*, 30187. https://doi.org/10.1038/srep30187

Ravaglia, G., Forti, P., Maioli, F., Pratelli, L., Vettori, C., Bastagli, L., Mariani, E., Facchini, A., & Cucinotta, D. (2001). Regular moderate intensity physical activity and blood concentrations of endogenous anabolic hormones and thyroid hormones in aging men. *Mechanisms of Ageing and Development*, *122*(2), 191–203. https://doi.org/10.1016/s0047-6374(00)00234-7

Riadi, I., Kervin, L., Dhillon, S., Teo, K., Churchill, R., Card, K. G., Sixsmith, A., Moreno, S., Fortuna, K. L., Torous, J., & Cosco, T. D. (2022). Digital interventions for depression and anxiety in older adults: a systematic review of randomised controlled trials. *The Lancet. Healthy Longevity*, *3*(8), e558–e571. https://doi.org/10.1016/S2666-7568(22)00121-0

Richards, J., Thorogood, M., Hillsdon, M., & Foster, C. (2013). Face-to-face versus remote and web 2.0 interventions for promoting physical activity. *Cochrane Database of Systematic Reviews*, *2013*(9), CD010393. https://doi.org/10.1002/14651858.CD010393.pub2

Rodrigues-Krause, J., Krause, M., & Reischak-Oliveira, A. (2019). Dancing for healthy aging: functional and metabolic perspectives. *Alternative Therapies in Health and Medicine*, *25*(1), 44–63.

Rodriguez-Larrad, A., Arrieta, H., Rezola-Pardo, C., Esain, I., Mendia-Oria, P., & Irazusta, J. (2021). Loss of benefits after cessation of exercise interventions in nursing home residents: randomized controlled trial follow-up. *Geriatric Nursing (New York, N.Y.)*, *42*(3), 621–627. https://doi.org/10.1016/j.gerinurse.2021.03.009

Rodriguez-Mañas, L., & Fried, L. P. (2015). Frailty in the clinical scenario. *The Lancet*, *385*(9968), e7–e9. https://doi.org/10.1016/S0140-6736(14)61595-6

Ronquillo, Y., Meyers, A., & Korvek, S. J. (2023). Digital Health. In *StatPearls*. StatPearls Publishing. https://doi.org/10.1007/978-3-319-61446-5

Rosenfeld, R. S., Hellman, L., Roffwarg, H., Weitzman, E. D., Fukushima, D. K., & Gallagher, T. F. (1971). Dehydroisoandrosterone is secreted episodically and synchronously with cortisol by normal man. *The Journal of Clinical Endocrinology and Metabolism*, *33*(1), 87–92. https://doi.org/10.1210/jcem-33-1-87

Roser, M., Ortiz-Ospina, E., & Ritchie, H. (2013). Life Expectancy. *Our World in Data*. https://ourworldindata.org/life-expectancy

Ryan, R., Booth, S., Spathis, A., Mollart, S., & Clow, A. (2016). Use of salivary diurnal cortisol as an outcome measure in randomised controlled trials: a systematic review. *Annals of Behavioral Medicine*, *50*(2), 210–236. https://doi.org/10.1007/s12160-015-9753-9

Sackley, C., Levin, S., Cardoso, K., & Hoppitt, T. (2006). Observations of activity levels and social interaction in a residential care setting. *International Journal of Therapy and Rehabilitation*, *13*(8), 370–373. https://doi.org/10.12968/ijtr.2006.13.8.370

Saczawa, M. E., Graber, J. A., Brooks-Gunn, J., & Warren, M. P. (2013). Methodological considerations in use of the cortisol/DHEA(S) ratio in adolescent populations. *Psychoneuroendocrinology*, *38*(11), 2815–2819. https://doi.org/10.1016/j.psyneuen.2013.06.024

Sapolsky, R. M., Romero, L. M., & Munck, A. U. (2000). How do glucocorticoids influence stress responses? Integrating permissive, suppressive, stimulatory, and preparative actions. *Endocrine Reviews*, *21*(1), 55–89. https://doi.org/10.1210/edrv.21.1.0389

Seeman, T. E., Singer, B. H., Rowe, J. W., Horwitz, R. I., & McEwen, B. S. (1997). Price of adaptation--allostatic load and its health consequences. MacArthur studies of successful aging. *Archives of Internal Medicine, 157*(19), 2259–2268. https://doi.org/10.1001/archinte.157.19.2259

Seifert, A., Cotten, S. R., & Xie, B. (2021). A Double Burden of Exclusion? Digital and Social Exclusion of Older Adults in Times of COVID-19. *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences*, *76*(3), e99–e103. https://doi.org/10.1093/geronb/gbaa098

Shamliyan, T., Talley, K. M. C., Ramakrishnan, R., & Kane, R. L. (2013). Association of frailty with survival: a systematic literature review. *Ageing Research Reviews*, *12*(2), 719–736. https://doi.org/10.1016/j.arr.2012.03.001

Sillanpää, E., Häkkinen, A., Laaksonen, D. E., Karavirta, L., Kraemer, W. J., & Häkkinen, K. (2010). Serum basal hormone concentrations, nutrition and physical fitness during strength and/or endurance training in 39-64-year-old women. *International Journal of Sports Medicine*, *31*(2), 110–117. https://doi.org/10.1055/s-0029-1242811

Silverman, H. G., & Mazzeo, R. S. (1996). Hormonal responses to maximal and submaximal exercise in trained and untrained men of various ages. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *51*(1), B30-7. https://doi.org/10.1093/gerona/51a.1.b30

Singh, B., Olds, T., Curtis, R., Dumuid, D., Virgara, R., Watson, A., Szeto, K., O’Connor, E., Ferguson, T., Eglitis, E., Miatke, A., Simpson, C. E., & Maher, C. (2023). Effectiveness of physical activity interventions for improving depression, anxiety and distress: an overview of systematic reviews. *British Journal of Sports Medicine*, *57*(18), 1203–1209. https://doi.org/10.1136/bjsports-2022-106195

Sjösten, N., & Kivelä, S.-L. (2006). The effects of physical exercise on depressive symptoms among the aged: a systematic review. *International Journal of Geriatric Psychiatry*, *21*(5), 410–418. https://doi.org/10.1002/gps.1494

Smith, A. (2014). *Older Adults and Technology Use*.

Snowden, M., Steinman, L., Mochan, K., Grodstein, F., Prohaska, T. R., Thurman, D. J., Brown, D. R., Laditka, J. N., Soares, J., Zweiback, D. J., Little, D., & Anderson, L. A. (2011). Effect of exercise on cognitive performance in community-dwelling older adults: review of intervention trials and recommendations for public health practice and research. *Journal of the American Geriatrics Society*, *59*(4), 704–716. https://doi.org/10.1111/j.1532-5415.2011.03323.x

Solis-Navarro, L., Gismero, A., Fernández-Jané, C., Torres-Castro, R., Solá-Madurell, M., Bergé, C., Pérez, L. M., Ars, J., Martín-Borràs, C., Vilaró, J., & Sitjà-Rabert, M. (2022). Effectiveness of home-based exercise delivered by digital health in older adults: a systematic review and meta-analysis. *Age and Ageing*, *51*(11). https://doi.org/10.1093/ageing/afac243

Son, J. S., Nimrod, G., West, S. T., Janke, M. C., Liechty, T., & Naar, J. J. (2020). Promoting Older Adults’ Physical Activity and Social Well-Being during COVID-19. *Leisure Sciences*, 1–8. https://doi.org/10.1080/01490400.2020.1774015

Sooktho, S., Songserm, N., Woradet, S., & Suksatan, W. (2022). A Meta-analysis of Dance Programs on Physical Performance: An Appropriate Health Promotion for Healthy Older Adults. *Annals of Geriatric Medicine and Research*. https://doi.org/10.4235/agmr.22.0066

Sothmann, M. S., Buckworth, J., Claytor, R. P., Cox, R. H., White-Welkley, J. E., & Dishman, R. K. (1996). Exercise training and the cross-stressor adaptation hypothesis. *Exercise and Sport Sciences Reviews*, *24*, 267–287.

Sourial, N., Bergman, H., Karunananthan, S., Wolfson, C., Payette, H., Gutierrez-Robledo, L. M., Béland, F., Fletcher, J. D., & Guralnik, J. (2013). Implementing frailty into clinical practice: a cautionary tale. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *68*(12), 1505–1511. https://doi.org/10.1093/gerona/glt053

Sparrow, D., Gottlieb, D. J., Demolles, D., & Fielding, R. A. (2011). Increases in muscle strength and balance using a resistance training program administered via a telecommunications system in older adults. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *66*(11), 1251–1257. https://doi.org/10.1093/gerona/glr138

Späth-Schwalbe, E., Gofferje, M., Kern, W., Born, J., & Fehm, H. L. (1991). Sleep disruption alters nocturnal ACTH and cortisol secretory patterns. *Biological Psychiatry*, *29*(6), 575–584. https://doi.org/10.1016/0006-3223(91)90093-2

Stalder, T., Kirschbaum, C., Kudielka, B. M., Adam, E. K., Pruessner, J. C., Wüst, S., Dockray, S., Smyth, N., Evans, P., Hellhammer, D. H., Miller, R., Wetherell, M. A., Lupien, S. J., & Clow, A. (2016). Assessment of the cortisol awakening response: Expert consensus guidelines. *Psychoneuroendocrinology*, *63*, 414–432. https://doi.org/10.1016/j.psyneuen.2015.10.010

Steiger, A. (2002). Sleep and the hypothalamo-pituitary-adrenocortical system. *Sleep Medicine Reviews*, *6*(2), 125–138. https://doi.org/10.1053/smrv.2001.0159

Sternberg, S. A., Wershof Schwartz, A., Karunananthan, S., Bergman, H., & Mark Clarfield, A. (2011). The identification of frailty: a systematic literature review. *Journal of the American Geriatrics Society*, *59*(11), 2129–2138. https://doi.org/10.1111/j.1532-5415.2011.03597.x

Strawbridge, W. J., Deleger, S., Roberts, R. E., & Kaplan, G. A. (2002). Physical activity reduces the risk of subsequent depression for older adults. *American Journal of Epidemiology*, *156*(4), 328–334. https://doi.org/10.1093/aje/kwf047

Swales, B., Ryde, G. C., & Whittaker, A. C. (2022). A randomized controlled feasibility trial evaluating a resistance training intervention with frail older adults in residential care: the keeping active in residential elderly trial. *Journal of Aging and Physical Activity*, *30*(3), 364–388. https://doi.org/10.1123/japa.2021-0130

Tarazona-Santabalbina, F. J., Gómez-Cabrera, M. C., Pérez-Ros, P., Martínez-Arnau, F. M., Cabo, H., Tsaparas, K., Salvador-Pascual, A., Rodriguez-Mañas, L., & Viña, J. (2016). A Multicomponent Exercise Intervention that Reverses Frailty and Improves Cognition, Emotion, and Social Networking in the Community-Dwelling Frail Elderly: A Randomized Clinical Trial. *Journal of the American Medical Directors Association*, *17*(5), 426–433. https://doi.org/10.1016/j.jamda.2016.01.019

Tissandier, O., Péres, G., Fiet, J., & Piette, F. (2001). Testosterone, dehydroepiandrosterone, insulin-like growth factor 1, and insulin in sedentary and physically trained aged men. *European Journal of Applied Physiology*, *85*(1–2), 177–184. https://doi.org/10.1007/s004210100420

Tsang, H. W. H., & Fung, K. M. T. (2008). A review on neurobiological and psychological mechanisms underlying the anti-depressive effect of qigong exercise. *Journal of Health Psychology*, *13*(7), 857–863. https://doi.org/10.1177/1359105308095057

Tsang, H. W. H., Tsang, W. W. N., Jones, A. Y. M., Fung, K. M. T., Chan, A. H. L., Chan, E. P., & Au, D. W. H. (2013). Psycho-physical and neurophysiological effects of qigong on depressed elders with chronic illness. *Aging & Mental Health*, *17*(3), 336–348. https://doi.org/10.1080/13607863.2012.732035

Tsigos, C., & Chrousos, G. P. (2002). Hypothalamic-pituitary-adrenal axis, neuroendocrine factors and stress. *Journal of Psychosomatic Research*, *53*(4), 865–871. https://doi.org/10.1016/s0022-3999(02)00429-4

Uchida, S., Shioda, K., Morita, Y., Kubota, C., Ganeko, M., & Takeda, N. (2012). Exercise effects on sleep physiology. *Frontiers in Neurology, 3*, 48. https://doi.org/10.3389/fneur.2012.00048

Valenzuela, T., Okubo, Y., Woodbury, A., Lord, S. R., & Delbaere, K. (2018). Adherence to Technology-Based Exercise Programs in Older Adults: A Systematic Review. *Journal of Geriatric Physical Therapy (2001), 41*(1), 49–61. https://doi.org/10.1519/JPT.0000000000000095

Vanderlinden, J., Boen, F., & van Uffelen, J. G. Z. (2020). Effects of physical activity programs on sleep outcomes in older adults: a systematic review. *The International Journal of Behavioral Nutrition and Physical Activity*, *17*(1), 11. https://doi.org/10.1186/s12966-020-0913-3

Van Cauter, E., Leproult, R., & Kupfer, D. J. (1996). Effects of gender and age on the levels and circadian rhythmicity of plasma cortisol. *The Journal of Clinical Endocrinology and Metabolism*, *81*(7), 2468–2473. https://doi.org/10.1210/jcem.81.7.8675562

van den Beld, A. W., Kaufman, J.-M., Zillikens, M. C., Lamberts, S. W. J., Egan, J. M., & van der Lely, A. J. (2018). The physiology of endocrine systems with ageing. *The Lancet. Diabetes & Endocrinology*, *6*(8), 647–658. https://doi.org/10.1016/S2213-8587(18)30026-3

von Haaren, B., Ottenbacher, J., Muenz, J., Neumann, R., Boes, K., & Ebner-Priemer, U. (2016). Does a 20-week aerobic exercise training programme increase our capabilities to buffer real-life stressors? A randomized, controlled trial using ambulatory assessment. *European Journal of Applied Physiology*, *116*(2), 383–394. https://doi.org/10.1007/s00421-015-3284-8

Vordos, Z., Kouidi, E., Mavrovouniotis, F., Metaxas, T., Dimitros, E., Kaltsatou, A., & Deligiannis, A. (2017). Impact of traditional Greek dancing on jumping ability, muscular strength and lower limb endurance in cardiac rehabilitation programmes. *European Journal of Cardiovascular Nursing : Journal of the Working Group on Cardiovascular Nursing of the European Society of Cardiology*, *16*(2), 150–156. https://doi.org/10.1177/1474515116636980

Wang, D. X. M., Yao, J., Zirek, Y., Reijnierse, E. M., & Maier, A. B. (2020). Muscle mass, strength, and physical performance predicting activities of daily living: a meta-analysis. *Journal of Cachexia, Sarcopenia and Muscle*, *11*(1), 3–25. https://doi.org/10.1002/jcsm.12502

Wang, F., & Boros, S. (2019). The effect of physical activity on sleep quality: a systematic review. *European Journal of Physiotherapy*, 1–8. https://doi.org/10.1080/21679169.2019.1623314

Warburton, D. E. R., Nicol, C. W., & Bredin, S. S. D. (2006). Health benefits of physical activity: the evidence. *Canadian Medical Association Journal*, *174*(6), 801–809. https://doi.org/10.1503/cmaj.051351

Weitzman, E. D., Zimmerman, J. C., Czeisler, C. A., & Ronda, J. (1983). Cortisol secretion is inhibited during sleep in normal man. *The Journal of Clinical Endocrinology and Metabolism*, *56*(2), 352–358. https://doi.org/10.1210/jcem-56-2-352

Westhorp, G. (2014, September 3). *Realist impact evaluation: an introduction*. https://odi.org/en/publications/realist-impact-evaluation-an-introduction/

Whetzel, C. A., & Klein, L. C. (2010). Measuring DHEA-S in saliva: time of day differences and positive correlations between two different types of collection methods. *BMC Research Notes*, *3*, 204. https://doi.org/10.1186/1756-0500-3-204

Windle, G., Hughes, D., Linck, P., Russell, I., & Woods, B. (2010). Is exercise effective in promoting mental well-being in older age? A systematic review. *Aging & Mental Health*, *14*(6), 652–669. https://doi.org/10.1080/13607861003713232

World Health Organization. (2022, October 1). *Ageing and health*. https://www.who.int/news-room/fact-sheets/detail/ageing-and-health

Wright, B. E., Porter, J. R., Browne, E. S., & Svec, F. (1992). Antiglucocorticoid action of dehydroepiandrosterone in young obese Zucker rats. *International Journal of Obesity and Related Metabolic Disorders*, *16*(8), 579–583.

Xue, Q.-L. (2011). The frailty syndrome: definition and natural history. *Clinics in Geriatric Medicine*, *27*(1), 1–15. https://doi.org/10.1016/j.cger.2010.08.009

Yates, L. B., Djoussé, L., Kurth, T., Buring, J. E., & Gaziano, J. M. (2008). Exceptional longevity in men: modifiable factors associated with survival and function to age 90 years. *Archives of Internal Medicine*, *168*(3), 284–290. https://doi.org/10.1001/archinternmed.2007.77

Zschucke, E., Renneberg, B., Dimeo, F., Wüstenberg, T., & Ströhle, A. (2015). The stress-buffering effect of acute exercise: Evidence for HPA axis negative feedback. *Psychoneuroendocrinology*, *51*, 414–425. https://doi.org/10.1016/j.psyneuen.2014.10.019

Chapter 2

Aardal-Eriksson, E., Karlberg, B. E., & Holm, A. C. (1998). Salivary cortisol--an alternative to serum cortisol determinations in dynamic function tests. *Clinical Chemistry and Laboratory Medicine*, *36*(4), 215–222. https://doi.org/10.1515/CCLM.1998.037

Abbasi, A., Duthie, E. H., Sheldahl, L., Wilson, C., Sasse, E., Rudman, I., & Mattson, D. E. (1998). Association of dehydroepiandrosterone sulfate, body composition, and physical fitness in independent community-dwelling older men and women. *Journal of the American Geriatrics Society*, *46*(3), 263–273. https://doi.org/10.1111/j.1532-5415.1998.tb01036.x

Adam, E. K., & Kumari, M. (2009). Assessing salivary cortisol in large-scale, epidemiological research. *Psychoneuroendocrinology*, *34*(10), 1423–1436. https://doi.org/10.1016/j.psyneuen.2009.06.011

Ahn, N., & Kim, K. (2018). The effects of resistance elastic bands exercises on salivary IgA and salivary cortisol levels in elderly women. *Biomedical Research*, *29*(5), 889–894. https://doi.org/10.4066/biomedicalresearch.29-17-2726

Ahn, R.-S., Lee, Y.-J., Choi, J.-Y., Kwon, H.-B., & Chun, S.-I. (2007). Salivary cortisol and DHEA levels in the Korean population: age-related differences, diurnal rhythm, and correlations with serum levels. *Yonsei Medical Journal*, *48*(3), 379–388. https://doi.org/10.3349/ymj.2007.48.3.379

Al-Turk, W., & Al-Dujaili, E. A. S. (2016). Effect of age, gender and exercise on salivary dehydroepiandrosterone circadian rhythm profile in human volunteers. *Steroids*, *106*, 19–25. https://doi.org/10.1016/j.steroids.2015.12.001

Aldred, S., Rohalu, M., Edwards, K., & Burns, V. (2009). Altered DHEA and DHEAS response to exercise in healthy older adults. *Journal of Aging and Physical Activity*, *17*(1), 77–88. https://doi.org/10.1123/japa.17.1.77

American College of Sports Medicine. (2013). *ACSM's guidelines for exercise testing and prescription*. https://books.google.be/books?hl=nl&lr=&id=hhosAwAAQBAJ&oi=fnd&pg=PP1&dq=+~elderly+OR+%22older+people%22+OR+%22older+adults%22+OR+~aged+OR+~exercise+OR+%22physical+activity%22+OR+%22~sedentary%22+OR+~fitness+OR+yoga+OR+%22taj+ji%22+OR+%22tai+chi%22+OR+cortisol+OR+DHEA+OR+DHEAS+OR+dehydroepiandrosterone+OR+%22dehydroepiandrosterone+sulfate%22&ots=lkB5_E-ZOC&sig=CqabmC-98ULaIS8ThIeoKpLPhqU

Anderson, T., & Wideman, L. (2017). Exercise and the cortisol awakening response: A systematic review. *Sports Medicine - Open*, *3*(1), 37. https://doi.org/10.1186/s40798-017-0102-3

Aronson, L. (2020). Healthy aging across the stages of old age. *Clinics in Geriatric Medicine*, *36*(4), 549–558. https://doi.org/10.1016/j.cger.2020.06.001

Banitalebi, E., Faramarzi, M., Bagheri, L., & Kazemi, A. R. (2018). Comparison of performing 12 weeks' resistance training before, after and/or in between aerobic exercise on the hormonal status of aged women: a randomized controlled trial. *Hormone Molecular Biology and Clinical Investigation*, *35*(3), 20180020. https://doi.org/10.1515/hmbci-2018-0020

Barnett, K., Mercer, S. W., Norbury, M., Watt, G., Wyke, S., & Guthrie, B. (2012). Epidemiology of multimorbidity and implications for health care, research, and medical education: a cross-sectional study. *The Lancet*, *380*(9836), 37–43. https://doi.org/10.1016/S0140-6736(12)60240-2

Belvederi Murri, M., Pariante, C., Mondelli, V., Masotti, M., Atti, A. R., Mellacqua, Z., Antonioli, M., Ghio, L., Menchetti, M., Zanetidou, S., Innamorati, M., & Amore, M. (2014). HPA axis and aging in depression: systematic review and meta-analysis. *Psychoneuroendocrinology*, *41*, 46–62. https://doi.org/10.1016/j.psyneuen.2013.12.004

Berr, C., Lafont, S., Debuire, B., Dartigues, J. F., & Baulieu, E. E. (1996). Relationships of dehydroepiandrosterone sulfate in the elderly with functional, psychological, and mental status, and short-term mortality: a French community-based study. *Proceedings of the National Academy of Sciences of the United States of America*, *93*(23), 13410–13415. https://doi.org/10.1073/pnas.93.23.13410

Bonnefoy, M., Kostka, T., Patricot, M. C., Berthouze, S. E., Mathian, B., & Lacour, J. R. (1998). Physical activity and dehydroepiandrosterone sulphate, insulin-like growth factor I and testosterone in healthy active elderly people. *Age and Ageing*, *27*(6), 745–751. https://doi.org/10.1093/ageing/27.6.745

Bonnefoy, M., Patricot, M. C., Lacour, J. R., Rahmani, A., Berthouze, S., & Kostka, T. (2002). [Relation between physical activity, muscle function and IGF-1, testosterone and DHEAS concentrations in the elderly]. *La Revue de Medecine Interne*, *23*(10), 819–827. https://doi.org/10.1016/s0248-8663(02)00689-6

Boon, M. H., & Thomson, H. (2021). The effect direction plot revisited: Application of the 2019 Cochrane Handbook guidance on alternative synthesis methods. *Research Synthesis Methods*, *12*(1), 29–33. https://doi.org/10.1002/jrsm.1458

Borenstein, M., Hedges, L. V., Higgins, J. P. T., & Rothstein, H. R. (2009). *Introduction to Meta-Analysis*. John Wiley & Sons, Ltd. https://doi.org/10.1002/9780470743386

Borst, S. E., Vincent, K. R., Lowenthal, D. T., & Braith, R. W. (2002). Effects of resistance training on insulin-like growth factor and its binding proteins in men and women aged 60 to 85. *Journal of the American Geriatrics Society*, *50*(5), 884–888. https://doi.org/10.1046/j.1532-5415.2002.50215.x

Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., Carty, C., Chaput, J.-P., Chastin, S., Chou, R., Dempsey, P. C., DiPietro, L., Ekelund, U., Firth, J., Friedenreich, C. M., Garcia, L., Gichu, M., Jago, R., Katzmarzyk, P. T., … Willumsen, J. F. (2020). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British Journal of Sports Medicine*, *54*(24), 1451–1462. https://doi.org/10.1136/bjsports-2020-102955

Buoso, E., Lanni, C., Molteni, E., Rousset, F., Corsini, E., & Racchi, M. (2011). Opposing effects of cortisol and dehydroepiandrosterone on the expression of the receptor for Activated C Kinase 1: implications in immunosenescence. *Experimental Gerontology, 46*(11), 877–883. https://doi.org/10.1016/j.exger.2011.07.007

Burke, J. F., Sussman, J. B., Kent, D. M., & Hayward, R. A. (2015). Three simple rules to ensure reasonably credible subgroup analyses. *BMJ (Clinical Research Ed.)*, *351*, h5651. https://doi.org/10.1136/bmj.h5651

Butcher, S. K., Killampalli, V., Lascelles, D., Wang, K., Alpar, E. K., & Lord, J. M. (2005). Raised cortisol:DHEAS ratios in the elderly after injury: potential impact upon neutrophil function and immunity. *Aging Cell*, *4*(6), 319–324. https://doi.org/10.1111/j.1474-9726.2005.00178.x

Caiozzo, V. J., Davis, J. A., Ellis, J. F., Azus, J. L., Vandagriff, R., Prietto, C. A., & McMaster, W. C. (1982). A comparison of gas exchange indices used to detect the anaerobic threshold. *Journal of Applied Physiology: Respiratory, Environmental and Exercise Physiology*, *53*(5), 1184–1189. https://doi.org/10.1152/jappl.1982.53.5.1184

Campo, R. A., Light, K. C., O'Connor, K., Nakamura, Y., Lipschitz, D., LaStayo, P. C., Pappas, L. M., Boucher, K. M., Irwin, M. R., Hill, H. R., Martins, T. B., Agarwal, N., & Kinney, A. Y. (2015). Blood pressure, salivary cortisol, and inflammatory cytokine outcomes in senior female cancer survivors enrolled in a tai chi chih randomized controlled trial. *Journal of Cancer Survivorship : Research and Practice*, *9*(1), 115–125. https://doi.org/10.1007/s11764-014-0395-x

Campo, R. A., O'Connor, K., Light, K. C., Nakamura, Y., Lipschitz, D. L., LaStayo, P. C., Pappas, L., Boucher, K., Irwin, M. R., Agarwal, N., & Kinney, A. Y. (2013). Feasibility and acceptability of a Tai Chi Chih randomized controlled trial in senior female cancer survivors. *Integrative Cancer Therapies*, *12*(6), 464–474. https://doi.org/10.1177/1534735413485418

Chaturvedi, A., Nayak, G., Nayak, A. G., & Rao, A. (2016). Comparative assessment of the effects of hatha yoga and physical exercise on biochemical functions in perimenopausal women. *Journal of Clinical and Diagnostic Research : JCDR*, *10*(8), KC01-4. https://doi.org/10.7860/JCDR/2016/18891.8389

Chehab, O., Ouertani, M., Chaieb, K., Haouala, F., & Mahdouani, K. (2007). Hormonal status of cortisol and dehydroepiandrosterone sulfate in an elderly Tunisian population. *Comptes Rendus Biologies*, *330*(10), 755–763. https://doi.org/10.1016/j.crvi.2007.08.004

Corazza, D. I., Sebastião, É., Pedroso, R. V., Andreatto, C. A. A., de Melo Coelho, F. G., Gobbi, S., Teodorov, E., & Santos-Galduróz, R. F. (2013). Influence of chronic exercise on serum cortisol levels in older adults. *European Review of Aging and Physical Activity : Official Journal of the European Group for Research into Elderly and Physical Activity*. https://doi.org/10.1007/s11556-013-0126-8

Coste, J., Strauch, G., Letrait, M., & Bertagna, X. (1994). Reliability of hormonal levels for assessing the hypothalamic-pituitary-adrenocortical system in clinical pharmacology. *British Journal of Clinical Pharmacology*, *38*(5), 474–479. https://doi.org/10.1111/j.1365-2125.1994.tb04386.x

Crimmins, E. M., & Beltrán-Sánchez, H. (2011). Mortality and morbidity trends: is there compression of morbidity? *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences*, *66*(1), 75–86. https://doi.org/10.1093/geronb/gbq088

Crimmins, E. M. (2004). Trends in the health of the elderly. *Annual Review of Public Health*, *25*, 79–98. https://doi.org/10.1146/annurev.publhealth.25.102802.124401

Daskalopoulou, C., Stubbs, B., Kralj, C., Koukounari, A., Prince, M., & Prina, A. M. (2017). Physical activity and healthy ageing: A systematic review and meta-analysis of longitudinal cohort studies. *Ageing Research Reviews*, *38*, 6–17. https://doi.org/10.1016/j.arr.2017.06.003

de Gonzalo-Calvo, D., Fernández-García, B., de Luxán-Delgado, B., Rodríguez-González, S., García-Macia, M., Suárez, F. M., Solano, J. J., Rodríguez-Colunga, M. J., & Coto-Montes, A. (2012). Long-term training induces a healthy inflammatory and endocrine emergent biomarker profile in elderly men. *Age*, *34*(3), 761–771. https://doi.org/10.1007/s11357-011-9266-9

Deuschle, M., Gotthardt, U., Schweiger, U., Weber, B., Körner, A., Schmider, J., Standhardt, H., Lammers, C. H., & Heuser, I. (1997). With aging in humans the activity of the hypothalamus-pituitary-adrenal system increases and its diurnal amplitude flattens. *Life Sciences*, *61*(22), 2239–2246. https://doi.org/10.1016/S0024-3205(97)00926-0

Dickerson, S. S., & Kemeny, M. E. (2004). Acute stressors and cortisol responses: a theoretical integration and synthesis of laboratory research. *Psychological Bulletin*, *130*(3), 355–391. https://doi.org/10.1037/0033-2909.130.3.355

Dos Santos, V. R., & Gobbo, L. A. (2021). Occupational and leisure-time physical activity decreases the odds of disability in older adults: Prospective study. *European Journal of Sport Science*, *21*(6), 927–934. https://doi.org/10.1080/17461391.2020.1790669

Duclos, M., & Tabarin, A. (2016). Exercise and the Hypothalamo-Pituitary-Adrenal Axis. *Frontiers of Hormone Research*, *47*, 12–26. https://doi.org/10.1159/000445149

Egger, M., Smith, G., Schneider, M., & Minder, C. (1997). Bias in meta-analysis detected by a simple, graphical test. *BMJ (Clinical Research Ed.)*, *315*(7109), 629–634. https://doi.org/10.1136/bmj.315.7109.629

Ekkekakis, P., Parfitt, G., & Petruzzello, S. J. (2011). The pleasure and displeasure people feel when they exercise at different intensities: decennial update and progress towards a tripartite rationale for exercise intensity prescription. *Sports Medicine (Auckland, N.Z.)*, *41*(8), 641–671. https://doi.org/10.2165/11590680-000000000-00000

Ferrari, E., Cravello, L., Muzzoni, B., Casarotti, D., Paltro, M., Solerte, S. B., Fioravanti, M., Cuzzoni, G., Pontiggia, B., & Magri, F. (2001). Age-related changes of the hypothalamic-pituitary-adrenal axis: pathophysiological correlates. *European Journal of Endocrinology*, *144*(4), 319–329. https://doi.org/10.1530/eje.0.1440319

Fragala, M. S., Kraemer, W. J., Denegar, C. R., Maresh, C. M., Mastro, A. M., & Volek, J. S. (2011). Neuroendocrine-immune interactions and responses to exercise. *Sports Medicine (Auckland, N.Z.)*, *41*(8), 621–639. https://doi.org/10.2165/11590430-000000000-00000

Furtado, G. E., Carvalho, H. M., Loureiro, M., Patrício, M., Uba-Chupel, M., Colado, J. C., Hogervorst, E., Ferreira, J. P., & Teixeira, A. M. (2020). Chair-based exercise programs in institutionalized older women: Salivary steroid hormones, disabilities and frailty changes. *Experimental Gerontology*, *130*, 110790. https://doi.org/10.1016/j.exger.2019.110790

Furtado, G. E., Letieri, R. V., Silva-Caldo, A., Trombeta, J. C. S., Monteiro, C., Rodrigues, R. N., Vieira-Pedrosa, A., Barros, M. P., Cavaglieri, C. R., Hogervorst, E., Teixeira, A. M., &

Ferreira, J. P. (2021). Combined Chair-Based Exercises Improve Functional Fitness, Mental Well-Being, Salivary Steroid Balance, and Anti-microbial Activity in Pre-frail Older Women. *Frontiers in Psychology*, *12*, 564490. https://doi.org/10.3389/fpsyg.2021.564490

Furtado, G. E., Uba-Chupel, M., Carvalho, H. M., Souza, N. R., Ferreira, J. P., & Teixeira, A. M. (2016). Effects of a chair-yoga exercises on stress hormone levels, daily life activities, falls and physical fitness in institutionalized older adults. *Complementary Therapies in Clinical Practice*, *24*, 123–129. https://doi.org/10.1016/j.ctcp.2016.05.012

Garber, C. E., Blissmer, B., Deschenes, M. R., Franklin, B. A., Lamonte, M. J., Lee, I.-M., Nieman, D. C., Swain, D. P., & American College of Sports Medicine. (2011). American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Medicine and Science in Sports and Exercise*, *43*(7), 1334–1359. https://doi.org/10.1249/MSS.0b013e318213fefb

Gatti, R., & De Palo, E. F. (2011). An update: salivary hormones and physical exercise. *Scandinavian Journal of Medicine & Science in Sports*, *21*(2), 157–169. https://doi.org/10.1111/j.1600-0838.2010.01252.x

Gozansky, W. S., Lynn, J. S., Laudenslager, M. L., & Kohrt, W. M. (2005). Salivary cortisol determined by enzyme immunoassay is preferable to serum total cortisol for assessment of dynamic hypothalamic--pituitary--adrenal axis activity. *Clinical Endocrinology*, *63*(3), 336–341. https://doi.org/10.1111/j.1365-2265.2005.02349.x

Guyatt, G. H., Oxman, A. D., Vist, G. E., Kunz, R., Falck-Ytter, Y., Alonso-Coello, P., Schünemann, H. J., & GRADE Working Group. (2008). GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. *BMJ (Clinical Research Ed.)*, *336*(7650), 924–926. https://doi.org/10.1136/bmj.39489.470347.AD

Hackney, Anthony C, & Hackney, Z. C. (2005). The exercise-hypogonadal male condition and endurance exercise training. *Current Trends in Endocrinology*, *1*, 101–106.

Hackney, Anthony C. (2006). Exercise as a stressor to the human neuroendocrine system. *Medicina (Kaunas, Lithuania)*, *42*(10), 788–797.

Hackney, A C, & Viru, A. (1999). Twenty-four-hour cortisol response to multiple daily exercise sessions of moderate and high intensity. *Clinical Physiology (Oxford, England)*, *19*(2), 178–182. https://doi.org/10.1046/j.1365-2281.1999.00157.x

Häkkinen, A., Pakarinen, A., Hannonen, P., Kautiainen, H., Nyman, K., Kraemer, W. J., & Häkkinen, K. (2005). Effects of prolonged combined strength and endurance training on physical fitness, body composition and serum hormones in women with rheumatoid arthritis and in healthy controls. *Clinical and Experimental Rheumatology*, *23*(4), 505–512.

Häkkinen, K, Pakarinen, A., Kraemer, W. J., Newton, R. U., & Alen, M. (2000). Basal concentrations and acute responses of serum hormones and strength development during heavy resistance training in middle-aged and elderly men and women. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *55*(2), B95-105. https://doi.org/10.1093/gerona/55.2.b95

Häkkinen, Keijo, Kraemer, W. J., Pakarinen, A., Triplett-McBride, T., McBride, J. M., Häkkinen, A., Alen, M., McGuigan, M. R., Bronks, R., & Newton, R. U. (2002). Effects of heavy resistance/power training on maximal strength, muscle morphology, and hormonal response patterns in 60-75-year-old men and women. *Canadian Journal of Applied*

Physiology = Revue Canadienne de Physiologie Appliquee, *27*(3), 213–231. https://doi.org/10.1139/h02-013

Hawley, J. A., Hargreaves, M., Joyner, M. J., & Zierath, J. R. (2014). Integrative biology of exercise. *Cell*, *159*(4), 738–749. https://doi.org/10.1016/j.cell.2014.10.029

Hayes, L. D., Grace, F. M., Sculthorpe, N., Herbert, P., Ratcliffe, J. W., Kilduff, L. P., & Baker, J. S. (2013). The effects of a formal exercise training programme on salivary hormone concentrations and body composition in previously sedentary aging men. *SpringerPlus*, *2*(1), 18. https://doi.org/10.1186/2193-1801-2-18

Ha, M.-S., & Son, W.-M. (2018). Combined exercise is a modality for improving insulin resistance and aging-related hormone biomarkers in elderly Korean women. *Experimental Gerontology*, *114*, 13–18. https://doi.org/10.1016/j.exger.2018.10.012

Heaney, J. L. J., Carroll, D., & Phillips, A. C. (2013). DHEA, DHEA-S and cortisol responses to acute exercise in older adults in relation to exercise training status and sex. *Age*, *35*(2), 395–405. https://doi.org/10.1007/s11357-011-9345-y

Heaney, J. L. J., Carroll, D., & Phillips, A. C. (2014). Physical activity, life events stress, cortisol, and DHEA: preliminary findings that physical activity may buffer against the negative effects of stress. *Journal of Aging and Physical Activity*, *22*(4), 465–473. https://doi.org/10.1123/japa.2012-0082

Heaney, J. L. J., Phillips, A. C., & Carroll, D. (2010). Ageing, depression, anxiety, social support and the diurnal rhythm and awakening response of salivary cortisol. *International Journal of Psychophysiology*, *78*(3), 201–208. https://doi.org/10.1016/j.ijpsycho.2010.07.009

Heaney, J. L. J., Phillips, A. C., & Carroll, D. (2012a). Aging, health behaviors, and the diurnal rhythm and awakening response of salivary cortisol. *Experimental Aging Research*, *38*(3), 295–314. https://doi.org/10.1080/0361073X.2012.672134

Heaney, J. L. J., Phillips, A. C., & Carroll, D. (2012b). Ageing, physical function, and the diurnal rhythms of cortisol and dehydroepiandrosterone. *Psychoneuroendocrinology*, *37*(3), 341–349. https://doi.org/10.1016/j.psyneuen.2011.07.001

Hellhammer, J., Fries, E., Schweisthal, O. W., Schlotz, W., Stone, A. A., & Hagemann, D. (2007). Several daily measurements are necessary to reliably assess the cortisol rise after awakening: state- and trait components. *Psychoneuroendocrinology*, *32*(1), 80–86. https://doi.org/10.1016/j.psyneuen.2006.10.005

Hersey, W. C., Graves, J. E., Pollock, M. L., Gingerich, R., Shireman, R. B., Heath, G. W., Spierto, F., McCole, S. D., & Hagberg, J. M. (1994). Endurance exercise training improves body composition and plasma insulin responses in 70- to 79-year-old men and women. *Metabolism: Clinical and Experimental*, *43*(7), 847–854. https://doi.org/10.1016/0026-0495(94)90265-8

Higgins, J. P. T., Altman, D. G., Gøtzsche, P. C., Jüni, P., Moher, D., Oxman, A. D., Savovic, J., Schulz, K. F., Weeks, L., Sterne, J. A. C., Cochrane Bias Methods Group, & Cochrane Statistical Methods Group. (2011). The Cochrane Collaboration’s tool for assessing risk of bias in randomised trials. *BMJ (Clinical Research Ed.)*, *343*, d5928. https://doi.org/10.1136/bmj.d5928

Hill, E. E., Zack, E., Battaglini, C., Viru, M., Viru, A., & Hackney, A. C. (2008). Exercise and circulating cortisol levels: the intensity threshold effect. *Journal of Endocrinological Investigation*, *31*(7), 587–591. https://doi.org/10.1007/BF03345606

Ho, R. T. H., Fong, T. C. T., Chan, W. C., Kwan, J. S. K., Chiu, P. K. C., Yau, J. C. Y., & Lam, L. C. W. (2020). Psychophysiological effects of dance movement therapy and physical exercise on older adults with mild dementia: A randomized controlled trial. *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences*, *75*(3), 560–570. https://doi.org/10.1093/geronb/gby145

Ho, R. T. H., Fong, T. C. T., Cheung, I. K. M., Yip, P. S. F., & Luk, M.-Y. (2016). Effects of a Short-Term Dance Movement Therapy Program on Symptoms and Stress in Patients With Breast Cancer Undergoing Radiotherapy: A Randomized, Controlled, Single-Blind Trial. *Journal of Pain and Symptom Management*, *51*(5), 824–831. https://doi.org/10.1016/j.jpainsymman.2015.12.332

Ibáñez, J., Gorostiaga, E. M., Alonso, A. M., Forga, L., Argüelles, I., Larrión, J. L., & Izquierdo, M. (2008). Lower muscle strength gains in older men with type 2 diabetes after resistance training. *Journal of Diabetes and Its Complications*, *22*(2), 112–118. https://doi.org/10.1016/j.jdiacomp.2007.06.008

Ice, G. H., Katz-Stein, A., Himes, J., & Kane, R. L. (2004). Diurnal cycles of salivary cortisol in older adults. *Psychoneuroendocrinology*, *29*(3), 355–370. https://doi.org/10.1016/s0306-4530(03)00034-9

Im, J. Y., Bang, H. S., & Seo, D. Y. (2019). The effects of 12 weeks of a combined exercise program on physical function and hormonal status in elderly korean women. *International Journal of Environmental Research and Public Health*, *16*(21). https://doi.org/10.3390/ijerph16214196

Izquierdo, M., Häkkinen, K., Antón, A., Garrues, M., Ibañez, J., Ruesta, M., & Gorostiaga, E. M. (2001). Maximal strength and power, endurance performance, and serum hormones in middle-aged and elderly men. *Medicine and Science in Sports and Exercise*, *33*(9), 1577–1587. https://doi.org/10.1097/00005768-200109000-00022

Joseph, J. J., & Golden, S. H. (2017). Cortisol dysregulation: the bidirectional link between stress, depression, and type 2 diabetes mellitus. *Annals of the New York Academy of Sciences*, *1391*(1), 20–34. https://doi.org/10.1111/nyas.13217

Juster, R.-P., McEwen, B. S., & Lupien, S. J. (2010). Allostatic load biomarkers of chronic stress and impact on health and cognition. *Neuroscience and Biobehavioral Reviews*, *35*(1), 2–16. https://doi.org/10.1016/j.neubiorev.2009.10.002

Karlamangla, A. S., Friedman, E. M., Seeman, T. E., Stawksi, R. S., & Almeida, D. M. (2013). Daytime trajectories of cortisol: demographic and socioeconomic differences--findings from the National Study of Daily Experiences. *Psychoneuroendocrinology*, *38*(11), 2585–2597. https://doi.org/10.1016/j.psyneuen.2013.06.010

Karlamangla, A. S., Singer, B. H., McEwen, B. S., Rowe, J. W., & Seeman, T. E. (2002). Allostatic load as a predictor of functional decline. MacArthur studies of successful aging. *Journal of Clinical Epidemiology*, *55*(7), 696–710. https://doi.org/10.1016/s0895-4356(02)00399-2

Kennedy, I. (2016). *How to do Research: Today's Tips and Tools* (1st ed.). Kennedy House Publishing. https://www.amazon.com/how-research-todays-tips-tools-ebook/dp/b01i5jjdxc

Khoury, J. E., Gonzalez, A., Levitan, R. D., Pruessner, J. C., Chopra, K., Basile, V. S., Masellis, M., Goodwill, A., & Atkinson, L. (2015). Summary cortisol reactivity indicators: Interrelations and meaning. *Neurobiology of Stress*, *2*, 34–43. https://doi.org/10.1016/j.ynstr.2015.04.002

Kim, J., Park, H.-Y., & Lim, K. (2018). Effects of 12 weeks of combined exercise on heart rate variability and dynamic pulmonary function in obese and elderly korean women. *Iranian Journal of Public Health*, *47*(Suppl 1), 74–81.

Klaperski, S., von Dawans, B., Heinrichs, M., & Fuchs, R. (2014). Effects of a 12-week endurance training program on the physiological response to psychosocial stress in men: a randomized controlled trial. *Journal of Behavioral Medicine*, *37*(6), 1118–1133. https://doi.org/10.1007/s10865-014-9562-9

Koltyn, K. F. (2001). The association between physical activity and quality of life in older women. *Women's Health Issues*, *11*(6), 471–480. https://doi.org/10.1016/S1049-3867(01)00128-1

Kraemer, H. C., Giese-Davis, J., Yutsis, M., O'Hara, R., Neri, E., Gallagher-Thompson, D., Taylor, C. B., & Spiegel, D. (2006). Design decisions to optimize reliability of daytime cortisol slopes in an older population. *The American Journal of Geriatric Psychiatry*, *14*(4), 325–333. https://doi.org/10.1097/01.JGP.0000201816.26786.5b

Kraemer, W J, Häkkinen, K., Newton, R. U., Nindl, B. C., Volek, J. S., McCormick, M., Gotshalk, L. A., Gordon, S. E., Fleck, S. J., Campbell, W. W., Putukian, M., & Evans, W. J. (1999). Effects of heavy-resistance training on hormonal response patterns in younger vs. older men. *Journal of Applied Physiology*, *87*(3), 982–992. https://doi.org/10.1152/jappl.1999.87.3.982

Kraemer, William J, Ratamess, N. A., Hymer, W. C., Nindl, B. C., & Fragala, M. S. (2020). Growth Hormone(s), Testosterone, Insulin-Like Growth Factors, and Cortisol: Roles and Integration for Cellular Development and Growth With Exercise. *Frontiers in Endocrinology*, *11*, 33. https://doi.org/10.3389/fendo.2020.00033

Kraemer, William J, & Ratamess, N. A. (2005). Hormonal responses and adaptations to resistance exercise and training. *Sports Medicine (Auckland, N.Z.)*, *35*(4), 339–361. https://doi.org/10.2165/00007256-200535040-00004

Kubzansky, L. D., Kawachi, I., & Sparrow, D. (1999). Socioeconomic status, hostility, and risk factor clustering in the Normative Aging Study: any help from the concept of allostatic load? *Annals of Behavioral Medicine*, *21*(4), 330–338. https://doi.org/10.1007/BF02895966

Kudielka, B. M., Buske-Kirschbaum, A., Hellhammer, D. H., & Kirschbaum, C. (2004). HPA axis responses to laboratory psychosocial stress in healthy elderly adults, younger adults, and children: impact of age and gender. *Psychoneuroendocrinology*, *29*(1), 83–98. https://doi.org/10.1016/s0306-4530(02)00146-4

Kumari, M., Badrick, E., Sacker, A., Kirschbaum, C., Marmot, M., & Chandola, T. (2010). Identifying patterns in cortisol secretion in an older population. Findings from the Whitehall II study. *Psychoneuroendocrinology*, *35*(7), 1091–1099. https://doi.org/10.1016/j.psyneuen.2010.01.010

Lally, P., van Jaarsveld, C. H. M., Potts, H. W. W., & Wardle, J. (2010). How are habits formed: Modelling habit formation in the real world. *European Journal of Social Psychology*, *40*(6), 998–1009. https://doi.org/10.1002/ejsp.674

Laughlin, G. A., & Barrett-Connor, E. (2000). Sexual dimorphism in the influence of advanced aging on adrenal hormone levels: the Rancho Bernardo Study. *The Journal of Clinical Endocrinology and Metabolism*, *85*(10), 3561–3568. https://doi.org/10.1210/jcem.85.10.6861

Leal-Cerro, A., Gippini, A., Amaya, M. J., Lage, M., Mato, J. A., Dieguez, C., & Casanueva, F. F. (2003). Mechanisms underlying the neuroendocrine response to physical exercise. *Journal of Endocrinological Investigation*, *26*(9), 879–885. https://doi.org/10.1007/BF03345239

Lu, E. Y., Lee, P., Cai, S., So, W. W. Y., Ng, B. F. L., Jensen, M. P., Cheung, W. M., & Tsang, H. W. H. (2020). Qigong for the treatment of depressive symptoms: Preliminary evidence of neurobiological mechanisms. *International Journal of Geriatric Psychiatry*, *35*(11), 1393–1401. https://doi.org/10.1002/gps.5380

Lucertini, F., Ponzio, E., Di Palma, M., Galati, C., Federici, A., Barbadoro, P., D'Errico, M. M., Prospero, E., Ambrogini, P., Cuppini, R., Lattanzi, D., & Minelli, A. (2015). High Cardiorespiratory Fitness Is Negatively Associated with Daily Cortisol Output in Healthy Aging Men. *Plos One*, *10*(11), e0141970. https://doi.org/10.1371/journal.pone.0141970

Luger, A., Deuster, P. A., Kyle, S. B., Gallucci, W. T., Montgomery, L. C., Gold, P. W., Loriaux, D. L., & Chrousos, G. P. (1987). Acute hypothalamic-pituitary-adrenal responses to the stress of treadmill exercise. Physiologic adaptations to physical training. *The New England Journal of Medicine*, *316*(21), 1309–1315. https://doi.org/10.1056/NEJM198705213162105

Macera, C. A., Cavanaugh, A., & Bellettiere, J. (2017). State of the art review: physical activity and older adults. *American Journal of Lifestyle Medicine*, *11*(1), 42–57. https://doi.org/10.1177/1559827615571897

Mazat, L., Lafont, S., Berr, C., Debuire, B., Tessier, J. F., Dartigues, J. F., & Baulieu, E. E. (2001). Prospective measurements of dehydroepiandrosterone sulfate in a cohort of elderly subjects: relationship to gender, subjective health, smoking habits, and 10-year mortality.

Proceedings of the National Academy of Sciences of the United States of America, *98*(14), 8145–8150. https://doi.org/10.1073/pnas.121177998

Ma, L.-L., Wang, Y.-Y., Yang, Z.-H., Huang, D., Weng, H., & Zeng, X.-T. (2020). Methodological quality (risk of bias) assessment tools for primary and secondary medical studies: what are they and which is better? *Military Medical Research*, *7*(1), 7. https://doi.org/10.1186/s40779-020-00238-8

McEwen, Bruce S. (2003). Interacting mediators of allostasis and allostatic load: towards an understanding of resilience in aging. *Metabolism: Clinical and Experimental*, *52*(10 Suppl 2), 10–16. https://doi.org/10.1016/s0026-0495(03)00295-6

McEwen, B S, & Morrison, J. H. (2013). The brain on stress: vulnerability and plasticity of the prefrontal cortex over the life course. *Neuron*, *79*(1), 16–29. https://doi.org/10.1016/j.neuron.2013.06.028

McEwen, B S, & Stellar, E. (1993). Stress and the individual. Mechanisms leading to disease. *Archives of Internal Medicine*, *153*(18), 2093–2101. https://doi.org/10.1001/archinte.153.18.2093

McGuinness, L. A., & Higgins, J. P. T. (2021). Risk-of-bias VISualization (robvis): An R package and Shiny web app for visualizing risk-of-bias assessments. *Research Synthesis Methods*, *12*(1), 55–61. https://doi.org/10.1002/jrsm.1411

McMurray, R. G., & Hackney, A. C. (2000). Endocrine response to exercise and training. In W. E. Garret & D. T. Kirkendall (Eds.), *Exercise in sport science* (pp. 135–161). Lippincott Williams & Wilkins.

Moraes, H., Deslandes, A., Maciel-Pinheiro, P. de T., Corrêa, H., & Laks, J. (2016). Cortisol, DHEA, and depression in the elderly: the influence of physical capacity. *Arquivos de Neuro-Psiquiatria*, *74*(6), 456–461. https://doi.org/10.1590/0004-282X20160059

Mura, G., Cossu, G., Migliaccio, G. M., Atzori, C., Nardi, A. E., Machado, S., & Carta, M. G. (2014). Quality of life, cortisol blood levels and exercise in older adults: results of a randomized controlled trial. *Clinical Practice and Epidemiology in Mental Health : CP & EMH*, *10*, 67–72. https://doi.org/10.2174/1745017901410010067

Najafi, P., & Moghadasi, M. (2017). The effect of yoga training on enhancement of Adrenocorticotropic hormone (ACTH) and cortisol levels in female patients with multiple sclerosis. *Complementary Therapies in Clinical Practice*, *26*, 21–25. https://doi.org/10.1016/j.ctcp.2016.11.006

Nater, U. M., Hoppmann, C. A., & Scott, S. B. (2013). Diurnal profiles of salivary cortisol and alpha-amylase change across the adult lifespan: evidence from repeated daily life assessments. *Psychoneuroendocrinology*, *38*(12), 3167–3171. https://doi.org/10.1016/j.psyneuen.2013.09.008

Nelson, M. E., Rejeski, W. J., Blair, S. N., Duncan, P. W., Judge, J. O., King, A. C., Macera, C. A., Castaneda-Sceppa, C., American College of Sports Medicine, & American Heart Association. (2007). Physical activity and public health in older adults: recommendation from the American College of Sports Medicine and the American Heart Association. *Circulation*, *116*(9), 1094–1105. https://doi.org/10.1161/CIRCULATIONAHA.107.185650

Ockenfels, M. C., Porter, L., Smyth, J., Kirschbaum, C., Hellhammer, D. H., & Stone, A. A. (1995). Effect of chronic stress associated with unemployment on salivary cortisol: overall cortisol levels, diurnal rhythm, and acute stress reactivity. *Psychosomatic Medicine*, *57*(5), 460–467. https://doi.org/10.1097/00006842-199509000-00008

Orentreich, N., Brind, J. L., Rizer, R. L., & Vogelman, J. H. (1984). Age changes and sex differences in serum dehydroepiandrosterone sulfate concentrations throughout adulthood. *The Journal of Clinical Endocrinology and Metabolism*, *59*(3), 551–555. https://doi.org/10.1210/jcem-59-3-551

Orentreich, N., Brind, J. L., Vogelman, J. H., Andres, R., & Baldwin, H. (1992). Long-term longitudinal measurements of plasma dehydroepiandrosterone sulfate in normal men. *The Journal of Clinical Endocrinology and Metabolism*, *75*(4), 1002–1004. https://doi.org/10.1210/jcem.75.4.1400863

Ouzzani, M., Hammady, H., Fedorowicz, Z., & Elmagarmid, A. (2016). Rayyan-a web and mobile app for systematic reviews. *Systematic Reviews*, *5*(1), 210. https://doi.org/10.1186/s13643-016-0384-4

Page, M., McKenzie, J., Bossuyt, P., Boutron, I., Hoffmann, T., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ (Clinical Research Ed.)*, *372*, n71. https://doi.org/10.1136/bmj.n71

Parfitt, G., Rose, E. A., & Burgess, W. M. (2006). The psychological and physiological responses of sedentary individuals to prescribed and preferred intensity exercise. *British Journal of Health Psychology*, *11*(Pt 1), 39–53. https://doi.org/10.1348/135910705X43606

Pauly, T., Michalowski, V. I., Nater, U. M., Gerstorf, D., Ashe, M. C., Madden, K. M., & Hoppmann, C. A. (2019). Everyday associations between older adults' physical activity, negative affect, and cortisol. *Health Psychology*, *38*(6), 494–501. https://doi.org/10.1037/hea0000743

Penedo, F. J., & Dahn, J. R. (2005). Exercise and well-being: a review of mental and physical health benefits associated with physical activity. *Current Opinion in Psychiatry*, *18*(2), 189–193. https://doi.org/10.1097/00001504-200503000-00013

Peterson, M. J., Giuliani, C., Morey, M. C., Pieper, C. F., Evenson, K. R., Mercer, V., Cohen, H. J., Visser, M., Brach, J. S., Kritchevsky, S. B., Goodpaster, B. H., Rubin, S., Satterfield, S., Newman, A. B., Simonsick, E. M., & Health, Aging and Body Composition Study Research Group. (2009). Physical activity as a preventative factor for frailty: the health, aging, and body composition study. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *64*(1), 61–68. https://doi.org/10.1093/gerona/gln001

Phillips, A. C., Burns, V. E., & Lord, J. M. (2007). Stress and exercise: Getting the balance right for aging immunity. *Exercise and Sport Sciences Reviews*, *35*(1), 35–39. https://doi.org/10.1097/jes.0b013e31802d7008

Phillips, A. C., Carroll, D., Gale, C. R., Lord, J. M., Arlt, W., & Batty, G. D. (2010a). Cortisol, DHEAS, their ratio and the metabolic syndrome: evidence from the Vietnam Experience Study. *European Journal of Endocrinology*, *162*(5), 919–923. https://doi.org/10.1530/EJE-09-1078

Phillips, A. C., Carroll, D., Gale, C. R., Lord, J. M., Arlt, W., & Batty, G. D. (2010b). Cortisol, DHEA sulphate, their ratio, and all-cause and cause-specific mortality in the

Vietnam Experience Study. *European Journal of Endocrinology*, *163*(2), 285–292. https://doi.org/10.1530/EJE-10-0299

Pluchino, N., Drakopoulos, P., Bianchi-Demicheli, F., Wenger, J. M., Petignat, P., & Genazzani, A. R. (2015). Neurobiology of DHEA and effects on sexuality, mood and cognition. *The Journal of Steroid Biochemistry and Molecular Biology*, *145*, 273–280. https://doi.org/10.1016/j.jsbmb.2014.04.012

Ponzio, E., Sotte, L., D'Errico, M. M., Berti, S., Barbadoro, P., Prospero, E., & Minelli, A. (2015). Qi-gong training reduces basal and stress-elicited cortisol secretion in healthy older adults. *European Journal of Integrative Medicine*, *7*(3), 194–201. https://doi.org/10.1016/j.eujim.2015.01.002

Prakhinkit, S., Suppapitiporn, S., Tanaka, H., & Suksom, D. (2014). Effects of Buddhism walking meditation on depression, functional fitness, and endothelium-dependent vasodilation in depressed elderly. *Journal of Alternative and Complementary Medicine*, *20*(5), 411–416. https://doi.org/10.1089/acm.2013.0205

Pruessner, J. C., Wolf, O. T., Hellhammer, D. H., Buske-Kirschbaum, A., von Auer, K., Jobst, S., Kaspers, F., & Kirschbaum, C. (1997). Free cortisol levels after awakening: a reliable biological marker for the assessment of adrenocortical activity. *Life Sciences*, *61*(26), 2539–2549. https://doi.org/10.1016/S0024-3205(97)01008-4

Ravaglia, G., Forti, P., Maioli, F., Pratelli, L., Vettori, C., Bastagli, L., Mariani, E., Facchini, A., & Cucinotta, D. (2001). Regular moderate intensity physical activity and blood concentrations of endogenous anabolic hormones and thyroid hormones in aging men. *Mechanisms of Ageing and Development*, *122*(2), 191–203. https://doi.org/10.1016/s0047-6374(00)00234-7

Richardson, W. S., Wilson, M. C., Nishikawa, J., & Hayward, R. S. (1995). The well-built clinical question: a key to evidence-based decisions. *ACP Journal Club*, *123*(3), A12-3. https://doi.org/10.7326/ACPJC-1995-123-3-A12

Rieping, T., Furtado, G. E., Letieri, R. V., Chupel, M. U., Colado, J. C., Hogervorst, E., Filaire, E., Teixeira, A. M. M. B., & Ferreira, J. P. (2019). Effects of Different Chair-Based Exercises on Salivary Biomarkers and Functional Autonomy in Institutionalized Older Women. *Research Quarterly for Exercise and Sport*, *90*(1), 36–45. https://doi.org/10.1080/02701367.2018.1563272

Rimmele, U., Seiler, R., Marti, B., Wirtz, P. H., Ehlert, U., & Heinrichs, M. (2009). The level of physical activity affects adrenal and cardiovascular reactivity to psychosocial stress. *Psychoneuroendocrinology*, *34*(2), 190–198. https://doi.org/10.1016/j.psyneuen.2008.08.023

Rimmele, U., Zellweger, B. C., Marti, B., Seiler, R., Mohiyeddini, C., Ehlert, U., & Heinrichs, M. (2007). Trained men show lower cortisol, heart rate and psychological responses to psychosocial stress compared with untrained men. *Psychoneuroendocrinology*, *32*(6), 627–635. https://doi.org/10.1016/j.psyneuen.2007.04.005

Roser, M., Ortiz-Ospina, E., & Ritchie, H. (2013). Life Expectancy. *Our World in Data*. https://ourworldindata.org/life-expectancy

Ryan, R., Booth, S., Spathis, A., Mollart, S., & Clow, A. (2016). Use of salivary diurnal cortisol as an outcome measure in randomised controlled trials: a systematic review. *Annals of Behavioral Medicine*, *50*(2), 210–236. https://doi.org/10.1007/s12160-015-9753-9

Sato, K., Iemitsu, M., Matsutani, K., Kurihara, T., Hamaoka, T., & Fujita, S. (2014). Resistance training restores muscle sex steroid hormone steroidogenesis in older men. *The FASEB Journal*, *28*(4), 1891–1897. https://doi.org/10.1096/fj.13-245480

Saxbe, D. E. (2008). A field (researcher's) guide to cortisol: tracking HPA axis functioning in everyday life. *Health Psychology Review*, *2*(2), 163–190. https://doi.org/10.1080/17437190802530812

Schulkin, J. (2003). Allostasis: a neural behavioral perspective. *Hormones and Behavior*, *43*(1), 21–27; discussion 28. https://doi.org/10.1016/s0018-506x(02)00035-1

Schünemann, H., Brożek, J., Guyatt, G., & Oxman, A. (2013). *GRADE handbook for grading quality of evidence and strength of recommendations.* The GRADE Working Group. http://guidelinedevelopment.org/handbook

Seeman, T. E., Singer, B. H., Rowe, J. W., Horwitz, R. I., & McEwen, B. S. (1997). Price of adaptation--allostatic load and its health consequences. MacArthur studies of successful aging. *Archives of Internal Medicine*, *157*(19), 2259–2268. https://doi.org/10.1001/archinte.157.19.2259

Segerstrom, S. C., Boggero, I. A., Smith, G. T., & Sephton, S. E. (2014). Variability and reliability of diurnal cortisol in younger and older adults: implications for design decisions. *Psychoneuroendocrinology*, *49*, 299–309. https://doi.org/10.1016/j.psyneuen.2014.07.022

Sellami, M., Bragazzi, N. L., Slimani, M., Hayes, L., Jabbour, G., De Giorgio, A., & Dugué, B. (2019). The Effect of Exercise on Glucoregulatory Hormones: A Countermeasure to Human Aging: Insights from a Comprehensive Review of the Literature. *International*

Journal of Environmental Research and Public Health, *16*(10). https://doi.org/10.3390/ijerph16101709

Sillanpää, E., Häkkinen, A., Laaksonen, D. E., Karavirta, L., Kraemer, W. J., & Häkkinen, K. (2010). Serum basal hormone concentrations, nutrition and physical fitness during strength and/or endurance training in 39-64-year-old women. *International Journal of Sports Medicine*, *31*(2), 110–117. https://doi.org/10.1055/s-0029-1242811

Sin, M.-K., Ibarra, B., Tae, T., & Murphy, P. J. M. (2015). Effect of a randomized controlled trial walking program on walking, stress, depressive symptoms and cardiovascular biomarkers in elderly korean immigrants. *Journal of Korean Biological Nursing Science*, *17*(2), 89–96. https://doi.org/10.7586/jkbns.2015.17.2.89

Son, W.-M., Pekas, E. J., & Park, S.-Y. (2020). Twelve weeks of resistance band exercise training improves age-associated hormonal decline, blood pressure, and body composition in postmenopausal women with stage 1 hypertension: a randomized clinical trial. *Menopause*, *27*(2), 199–207. https://doi.org/10.1097/GME.0000000000001444

Stalder, T., Kirschbaum, C., Kudielka, B. M., Adam, E. K., Pruessner, J. C., Wüst, S., Dockray, S., Smyth, N., Evans, P., Hellhammer, D. H., Miller, R., Wetherell, M. A., Lupien, S. J., & Clow, A. (2016). Assessment of the cortisol awakening response: Expert consensus guidelines. *Psychoneuroendocrinology*, *63*, 414–432. https://doi.org/10.1016/j.psyneuen.2015.10.010

Sterling, P. (2004). Principles of allostasis: optimal design, predictive regulation, pathophysiology, and rational therapeutics. In J. Schulkin (Ed.), *Allostasis, homeostasis, and the costs of physiological adaptation* (pp. 17–64). Cambridge University Press. https://doi.org/10.1017/CBO9781316257081.004

Sterne, J. A., & Smith, G. (2001). Sifting the evidence-what's wrong with significance tests? *BMJ (Clinical Research Ed.)*, *322*(7280), 226–231. https://doi.org/10.1093/ptj/81.8.1464

Sterne, J. A. C., Sutton, A. J., Ioannidis, J. P. A., Terrin, N., Jones, D. R., Lau, J., Carpenter, J., Rücker, G., Harbord, R. M., Schmid, C. H., Tetzlaff, J., Deeks, J. J., Peters, J., Macaskill, P., Schwarzer, G., Duval, S., Altman, D. G., Moher, D., & Higgins, J. P. T. (2011). Recommendations for examining and interpreting funnel plot asymmetry in meta-analyses of randomised controlled trials. *BMJ (Clinical Research Ed.)*, *343*, d4002. https://doi.org/10.1136/bmj.d4002

Ströhle, A., Höfler, M., Pfister, H., Müller, A.-G., Hoyer, J., Wittchen, H.-U., & Lieb, R. (2007). Physical activity and prevalence and incidence of mental disorders in adolescents and young adults. *Psychological Medicine*, *37*(11), 1657–1666. https://doi.org/10.1017/S003329170700089X

Strüder, H. K., Hollmann, W., Platen, P., Rost, R., Weicker, H., & Weber, K. (1998). Hypothalamic-pituitary-adrenal and -gonadal axis function after exercise in sedentary and endurance trained elderly males. *European Journal of Applied Physiology and Occupational Physiology*, *77*(3), 285–288. https://doi.org/10.1007/s004210050334

Tada, A. (2018). Psychological effects of exercise on community-dwelling older adults. *Clinical Interventions in Aging*, *13*, 271–276. https://doi.org/10.2147/CIA.S152939

The Cochrane Collaboration. (2020). *Review Manager (RevMan)* (5.4) [Computer software]. The Cochrane Collaboration.

Tissandier, O., Péres, G., Fiet, J., & Piette, F. (2001). Testosterone, dehydroepiandrosterone, insulin-like growth factor 1, and insulin in sedentary and physically trained aged men.

European Journal of Applied Physiology, *85*(1–2), 177–184. https://doi.org/10.1007/s004210100420

Traustadóttir, T., Bosch, P. R., & Matt, K. S. (2003). Gender differences in cardiovascular and hypothalamic-pituitary-adrenal axis responses to psychological stress in healthy older adult men and women. *Stress (Amsterdam, Netherlands)*, *6*(2), 133–140. https://doi.org/10.1080/1025389031000111302

Tsang, H. W. H., Mok, C. K., Au Yeung, Y. T., & Chan, S. Y. C. (2003). The effect of Qigong on general and psychosocial health of elderly with chronic physical illnesses: a randomized clinical trial. *International Journal of Geriatric Psychiatry*, *18*(5), 441–449. https://doi.org/10.1002/gps.861

Tsang, H. W. H., Tsang, W. W. N., Jones, A. Y. M., Fung, K. M. T., Chan, A. H. L., Chan, E. P., & Au, D. W. H. (2013). Psycho-physical and neurophysiological effects of qigong on depressed elders with chronic illness. *Aging & Mental Health*, *17*(3), 336–348. https://doi.org/10.1080/13607863.2012.732035

Unger, J. B., Johnson, C. A., & Marks, G. (1997). Functional decline in the elderly: evidence for direct and stress-buffering protective effects of social interactions and physical activity. *Annals of Behavioral Medicine*, *19*(2), 152–160. https://doi.org/10.1007/BF02883332

Valkeinen, H., Häkkinen, K., Pakarinen, A., Hannonen, P., Häkkinen, A., Airaksinen, O., Niemitukia, L., Kraemer, W. J., & Alén, M. (2005). Muscle hypertrophy, strength development, and serum hormones during strength training in elderly women with fibromyalgia. *Scandinavian Journal of Rheumatology*, *34*(4), 309–314. https://doi.org/10.1080/03009740510018697

VanBruggen, M. D., Hackney, A. C., McMurray, R. G., & Ondrak, K. S. (2011). The relationship between serum and salivary cortisol levels in response to different intensities of exercise. *International Journal of Sports Physiology and Performance*, *6*(3), 396–407. https://doi.org/10.1123/ijspp.6.3.396

Van Cauter, E., Leproult, R., & Kupfer, D. J. (1996). Effects of gender and age on the levels and circadian rhythmicity of plasma cortisol. *The Journal of Clinical Endocrinology and Metabolism*, *81*(7), 2468–2473. https://doi.org/10.1210/jcem.81.7.8675562

van den Beld, A. W., Kaufman, J.-M., Zillikens, M. C., Lamberts, S. W. J., Egan, J. M., & van der Lely, A. J. (2018). The physiology of endocrine systems with ageing. *The Lancet. Diabetes & Endocrinology*, *6*(8), 647–658. https://doi.org/10.1016/S2213-8587(18)30026-3

Vardell, E., & Malloy, M. (2013). Joanna Briggs Institute: an evidence-based practice database. *Medical Reference Services Quarterly*, *32*(4), 434–442. https://doi.org/10.1080/02763869.2013.837734

Venturelli, M., Sollima, A., Cè, E., Limonta, E., Bisconti, A. V., Brasioli, A., Muti, E., & Esposito, F. (2016). Effectiveness of Exercise- and Cognitive-Based Treatments on Salivary Cortisol Levels and Sundowning Syndrome Symptoms in Patients with Alzheimer’s Disease. *Journal of Alzheimer’s Disease*, *53*(4), 1631–1640. https://doi.org/10.3233/JAD-160392

Vining, R. F., McGinley, R. A., Maksvytis, J. J., & Ho, K. Y. (1983). Salivary cortisol: a better measure of adrenal cortical function than serum cortisol. *Annals of Clinical Biochemistry*, *20 (Pt 6)*, 329–335. https://doi.org/10.1177/000456328302000601

Vrinceanu, T., Esmail, A., Berryman, N., Predovan, D., Vu, T. T. M., Villalpando, J. M., Pruessner, J. C., & Bherer, L. (2019). Dance your stress away: comparing the effect of dance/movement training to aerobic exercise training on the cortisol awakening response in healthy older adults. *Stress (Amsterdam, Netherlands)*, *22*(6), 687–695. https://doi.org/10.1080/10253890.2019.1617690

Wasserstein, R. L., Schirm, A. L., & Lazar, N. A. (2019). Moving to a World Beyond “$p < 0.05$”. *The American Statistician*, *73*(sup1), 1–19. https://doi.org/10.1080/00031305.2019.1583913

Wegner, M., Amatriain-Fernández, S., Kaulitzky, A., Murillo-Rodriguez, E., Machado, S., & Budde, H. (2020). Systematic Review of Meta-Analyses: Exercise Effects on Depression in Children and Adolescents. *Frontiers in Psychiatry*, *11*, 81. https://doi.org/10.3389/fpsyt.2020.00081

Whetzel, C. A., & Klein, L. C. (2010). Measuring DHEA-S in saliva: time of day differences and positive correlations between two different types of collection methods. *BMC Research Notes*, *3*, 204. https://doi.org/10.1186/1756-0500-3-204

Yamada, M., Nishiguchi, S., Fukutani, N., Aoyama, T., & Arai, H. (2015). Mail-Based Intervention for Sarcopenia Prevention Increased Anabolic Hormone and Skeletal Muscle Mass in Community-Dwelling Japanese Older Adults: The INE (Intervention by Nutrition and Exercise) Study. *Journal of the American Medical Directors Association*, *16*(8), 654–660. https://doi.org/10.1016/j.jamda.2015.02.017

Zhao, Z.-Y., Lu, F.-H., Xie, Y., Fu, Y.-R., Bogdan, A., & Touitou, Y. (2003). Cortisol secretion in the elderly. Influence of age, sex and cardiovascular disease in a Chinese population. *Steroids*, *68*(6), 551–555. https://doi.org/10.1016/S0039-128X(03)00083-7

Zschucke, E., Renneberg, B., Dimeo, F., Wüstenberg, T., & Ströhle, A. (2015). The stress-buffering effect of acute exercise: Evidence for HPA axis negative feedback. *Psychoneuroendocrinology*, *51*, 414–425. https://doi.org/10.1016/j.psyneuen.2014.10.019

Zumoff, B., Strain, G. W., Miller, L. K., & Rosner, W. (1995). Twenty-four-hour mean plasma testosterone concentration declines with age in normal premenopausal women. *The Journal of Clinical Endocrinology and Metabolism*, *80*(4), 1429–1430. https://doi.org/10.1210/jcem.80.4.7714119

Chapter 3

Adam, E. K., Hawkley, L. C., Kudielka, B. M., & Cacioppo, J. T. (2006). Day-to-day dynamics of experience--cortisol associations in a population-based sample of older adults. *Proceedings of the National Academy of Sciences of the United States of America*, *103*(45), 17058–17063. https://doi.org/10.1073/pnas.0605053103

Adam, E. K., & Kumari, M. (2009). Assessing salivary cortisol in large-scale, epidemiological research. *Psychoneuroendocrinology*, *34*(10), 1423–1436. https://doi.org/10.1016/j.psyneuen.2009.06.011

Al-Sharman, A., Khalil, H., El-Salem, K., Aldughmi, M., & Aburub, A. (2019). The effects of aerobic exercise on sleep quality measures and sleep-related biomarkers in individuals with Multiple Sclerosis: A pilot randomised controlled trial. *NeuroRehabilitation*, *45*(1), 107–115. https://doi.org/10.3233/NRE-192748

Al-Turk, W., & Al-Dujaili, E. A. S. (2016). Effect of age, gender and exercise on salivary dehydroepiandrosterone circadian rhythm profile in human volunteers. *Steroids*, *106*, 19–25. https://doi.org/10.1016/j.steroids.2015.12.001

Andersen, B. L., Thornton, L. M., Shapiro, C. L., Farrar, W. B., Mundy, B. L., Yang, H.-C., & Carson, W. E. (2010). Biobehavioral, immune, and health benefits following recurrence for psychological intervention participants. *Clinical Cancer Research*, *16*(12), 3270–3278. https://doi.org/10.1158/1078-0432.CCR-10-0278

Anderson, T., & Wideman, L. (2017). Exercise and the cortisol awakening response: A systematic review. *Sports Medicine - Open*, *3*(1), 37. https://doi.org/10.1186/s40798-017-0102-3

Antoni, M. H., Lehman, J. M., Kilbourn, K. M., Boyers, A. E., Culver, J. L., Alferi, S. M., Yount, S. E., McGregor, B. A., Arena, P. L., Harris, S. D., Price, A. A., & Carver, C. S. (2001). Cognitive-behavioral stress management intervention decreases the prevalence of depression and enhances benefit finding among women under treatment for early-stage breast cancer. *Health Psychology*, *20*(1), 20–32. https://doi.org/10.1037//0278-6133.20.1.20

Arikawa, A. Y., Thomas, W., Patel, S. R., & Kurzer, M. S. (2013). No effect of exercise on urinary 6-sulfatoxymelatonin and catecholamines in young women participating in a 16-week randomized controlled trial. *Cancer Epidemiology, Biomarkers & Prevention*, *22*(9), 1634–1636. https://doi.org/10.1158/1055-9965.EPI-13-0583

Banasik, J., Williams, H., Haberman, M., Blank, S. E., & Bendel, R. (2011). Effect of Iyengar yoga practice on fatigue and diurnal salivary cortisol concentration in breast cancer survivors. *Journal of the American Academy of Nurse Practitioners*, *23*(3), 135–142. https://doi.org/10.1111/j.1745-7599.2010.00573.x

Beserra, A. H. N., Kameda, P., Deslandes, A. C., Schuch, F. B., Laks, J., & Moraes, H. S. de. (2018). Can physical exercise modulate cortisol level in subjects with depression? A systematic review and meta-analysis. *Trends in Psychiatry and Psychotherapy*, *40*(4), 360–368. https://doi.org/10.1590/2237-6089-2017-0155

Boon, M. H., & Thomson, H. (2021). The effect direction plot revisited: Application of the 2019 Cochrane Handbook guidance on alternative synthesis methods. *Research Synthesis Methods*, *12*(1), 29–33. https://doi.org/10.1002/jrsm.1458

Bowden, D., Gaudry, C., An, S. C., & Gruzelier, J. (2012). A comparative randomised controlled trial of the effects of brain wave vibration training, iyengar yoga, and mindfulness on mood, well-being, and salivary cortisol. *Evidence-Based Complementary and Alternative Medicine*, *2012*, 234713. https://doi.org/10.1155/2012/234713

Bower, J. E., Ganz, P. A., Dickerson, S. S., Petersen, L., Aziz, N., & Fahey, J. L. (2005). Diurnal cortisol rhythm and fatigue in breast cancer survivors. *Psychoneuroendocrinology*, *30*(1), 92–100. https://doi.org/10.1016/j.psyneuen.2004.06.003

Brown, J. C., Huedo-Medina, T. B., Pescatello, L. S., Pescatello, S. M., Ferrer, R. A., & Johnson, B. T. (2011). Efficacy of exercise interventions in modulating cancer-related fatigue among adult cancer survivors: a meta-analysis. *Cancer Epidemiology, Biomarkers & Prevention*, *20*(1), 123–133. https://doi.org/10.1158/1055-9965.EPI-10-0988

Brupbacher, G., Gerger, H., Zander-Schellenberg, T., Straus, D., Porschke, H., Gerber, M., von Känel, R., & Schmidt-Trucksäss, A. (2021). The effects of exercise on sleep in unipolar depression: A systematic review and network meta-analysis. *Sleep Medicine Reviews*, *59*, 101452. https://doi.org/10.1016/j.smrv.2021.101452

Buckley, T. M., & Schatzberg, A. F. (2005a). Aging and the role of the HPA axis and rhythm in sleep and memory-consolidation. *The American Journal of Geriatric Psychiatry, 13*(5), 344–352. https://doi.org/10.1176/appi.ajgp.13.5.344

Buckley, T. M., & Schatzberg, A. F. (2005b). On the interactions of the hypothalamic-pituitary-adrenal (HPA) axis and sleep: normal HPA axis activity and circadian rhythm, exemplary sleep disorders. *The Journal of Clinical Endocrinology and Metabolism*, *90*(5), 3106–3114. https://doi.org/10.1210/jc.2004-1056

Burke, J. F., Sussman, J. B., Kent, D. M., & Hayward, R. A. (2015). Three simple rules to ensure reasonably credible subgroup analyses. *BMJ (Clinical Research Ed.), 351*, h5651. https://doi.org/10.1136/bmj.h5651

Byar, K. L., Berger, A. M., Bakken, S. L., & Cetak, M. A. (2006). Impact of adjuvant breast cancer chemotherapy on fatigue, other symptoms, and quality of life. *Oncology Nursing Forum, 33*(1), E18-26. https://doi.org/10.1188/06.ONF.E18-E26

Chandwani, K. D., Thornton, B., Perkins, G. H., Arun, B., Raghuram, N. V., Nagendra, H. R., Wei, Q., & Cohen, L. (2010). Yoga improves quality of life and benefit finding in women undergoing radiotherapy for breast cancer. *Journal of the Society for Integrative Oncology*, *8*(2), 43–55.

Chen, Z., Meng, Z., Milbury, K., Bei, W., Zhang, Y., Thornton, B., Liao, Z., Wei, Q., Chen, J., Guo, X., Liu, L., McQuade, J., Kirschbaum, C., & Cohen, L. (2013). Qigong improves quality of life in women undergoing radiotherapy for breast cancer: results of a randomized controlled trial. *Cancer, 119*(9), 1690–1698. https://doi.org/10.1002/cncr.27904

Coste, J., Strauch, G., Letrait, M., & Bertagna, X. (1994). Reliability of hormonal levels for assessing the hypothalamic-pituitary-adrenocortical system in clinical pharmacology. *British Journal of Clinical Pharmacology*, *38*(5), 474–479. https://doi.org/10.1111/j.1365-2125.1994.tb04386.x

Danhauer, S. C., Mihalko, S. L., Russell, G. B., Campbell, C. R., Felder, L., Daley, K., & Levine, E. A. (2009). Restorative yoga for women with breast cancer: findings from a randomized pilot study. *Psycho-Oncology*, *18*(4), 360–368. https://doi.org/10.1002/pon.1503

de Bruin, E. I., Formsma, A. R., Frijstein, G., & Bögels, S. M. (2017). Mindful2work: effects of combined physical exercise, yoga, and mindfulness meditations for stress relieve in employees. A proof of concept study. *Mindfulness*, *8*(1), 204–217. https://doi.org/10.1007/s12671-016-0593-x

Dickerson, S. S., & Kemeny, M. E. (2004). Acute stressors and cortisol responses: a theoretical integration and synthesis of laboratory research. *Psychological Bulletin*, *130*(3), 355–391. https://doi.org/10.1037/0033-2909.130.3.355

Duclos, M., & Tabarin, A. (2016). Exercise and the Hypothalamo-Pituitary-Adrenal Axis. *Frontiers of Hormone Research*, *47*, 12–26. https://doi.org/10.1159/000445149

Egger, M., Smith, G., Schneider, M., & Minder, C. (1997). Bias in meta-analysis detected by a simple, graphical test. *BMJ (Clinical Research Ed.)*, *315*(7109), 629–634. https://doi.org/10.1136/bmj.315.7109.629

Egger, M., Zellweger-Zähner, T., Schneider, M., Junker, C., Lengeler, C., & Antes, G. (1997). Language bias in randomised controlled trials published in English and German. *The Lancet, 350*(9074), 326–329. https://doi.org/10.1016/S0140-6736(97)02419-7

Fouladbakhsh, J. M., Davis, J. E., & Yarandi, H. N. (2014). A pilot study of the feasibility and outcomes of yoga for lung cancer survivors. *Oncology Nursing Forum*, *41*(2), 162–174. https://doi.org/10.1188/14.ONF.162-174

Fragala, M. S., Kraemer, W. J., Denegar, C. R., Maresh, C. M., Mastro, A. M., & Volek, J. S. (2011). Neuroendocrine-immune interactions and responses to exercise. *Sports Medicine (Auckland, N.Z.), 41*(8), 621–639. https://doi.org/10.2165/11590430-000000000-00000

Friedmann, B., & Kindermann, W. (1989). Energy metabolism and regulatory hormones in women and men during endurance exercise. *European Journal of Applied Physiology and Occupational Physiology*, *59*(1–2), 1–9. https://doi.org/10.1007/BF02396572

Garrido, M., Castaño, M. Y., Biehl-Printes, C., Gomez, M. A., Branco, J. C., Tomas-Carus, P., & Rodriguez, A. B. (2017). Effects of a respiratory functional training program on pain and sleep quality in patients with fibromyalgia: A pilot study. *Complementary Therapies in Clinical Practice*, *28*, 116–121. https://doi.org/10.1016/j.ctcp.2017.05.013

Gillies, G. E., & McArthur, S. (2010). Estrogen actions in the brain and the basis for differential action in men and women: a case for sex-specific medicines. *Pharmacological Reviews*, *62*(2), 155–198. https://doi.org/10.1124/pr.109.002071

Glenton, C., Santesso, N., Rosenbaum, S., Nilsen, E. S., Rader, T., Ciapponi, A., & Dilkes, H. (2010). Presenting the results of Cochrane Systematic Reviews to a consumer audience: a qualitative study. *Medical Decision Making, 30*(5), 566–577. https://doi.org/10.1177/0272989X10375853

Grahn Kronhed, A.-C., Enthoven, P., Spångeus, A., & Willerton, C. (2020). Mindfulness and Modified Medical Yoga as Intervention in Older Women with Osteoporotic Vertebral Fracture. *Journal of Alternative and Complementary Medicine*, *26*(7), 610–619. https://doi.org/10.1089/acm.2019.0450

Grandner, M. A. (2017). Sleep, health, and society. *Sleep Medicine Clinics*, *12*(1), 1–22. https://doi.org/10.1016/j.jsmc.2016.10.012

Guyatt, G. H., Oxman, A. D., Montori, V., Vist, G., Kunz, R., Brozek, J., Alonso-Coello, P., Djulbegovic, B., Atkins, D., Falck-Ytter, Y., Williams, J. W., Meerpohl, J., Norris, S. L., Akl, E. A., & Schünemann, H. J. (2011). GRADE guidelines: 5. Rating the quality of evidence--publication bias. *Journal of Clinical Epidemiology, 64*(12), 1277–1282. https://doi.org/10.1016/j.jclinepi.2011.01.011

Guyatt, G. H., Oxman, A. D., Vist, G. E., Kunz, R., Falck-Ytter, Y., Alonso-Coello, P., Schünemann, H. J., & GRADE Working Group. (2008). GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. *BMJ (Clinical Research Ed.), 336*(7650), 924–926. https://doi.org/10.1136/bmj.39489.470347.AD

Haddaway, N. R., Collins, A. M., Coughlin, D., & Kirk, S. (2015). The role of google scholar in evidence reviews and its applicability to grey literature searching. *Plos One*, *10*(9), e0138237. https://doi.org/10.1371/journal.pone.0138237

Halpern, J., Cohen, M., Kennedy, G., Reece, J., Cahan, C., & Baharav, A. (2014). Yoga for improving sleep quality and quality of life for older adults. *Alternative Therapies in Health and Medicine*, *20*(3), 37–46.

Hanson, B. L., & Ruthig, J. C. (2012). The Unique Role of Sleep Quality in Older Adults' Psychological Well-Being. *Journal of Applied Gerontology : The Official Journal of the Southern Gerontological Society*, *31*(5), 587–607. https://doi.org/10.1177/0733464810392226

Heaney, J. L. J., Phillips, A. C., & Carroll, D. (2012). Aging, health behaviors, and the diurnal rhythm and awakening response of salivary cortisol. *Experimental Aging Research*, *38*(3), 295–314. https://doi.org/10.1080/0361073X.2012.672134

Hellhammer, J., Fries, E., Schweisthal, O. W., Schlotz, W., Stone, A. A., & Hagemann, D. (2007). Several daily measurements are necessary to reliably assess the cortisol rise after awakening: state- and trait components. *Psychoneuroendocrinology*, *32*(1), 80–86. https://doi.org/10.1016/j.psyneuen.2006.10.005

Higgins, J. P. T., Altman, D. G., Gøtzsche, P. C., Jüni, P., Moher, D., Oxman, A. D., Savovic, J., Schulz, K. F., Weeks, L., Sterne, J. A. C., Cochrane Bias Methods Group, & Cochrane Statistical Methods Group. (2011). The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ (Clinical Research Ed.)*, *343*, d5928. https://doi.org/10.1136/bmj.d5928

Hilcove, K., Marceau, C., Thekdi, P., Larkey, L., Brewer, M. A., & Jones, K. (2021). Holistic Nursing in Practice: Mindfulness-Based Yoga as an Intervention to Manage Stress and Burnout. *Journal of Holistic Nursing : Official Journal of the American Holistic Nurses' Association*, *39*(1), 29–42. https://doi.org/10.1177/0898010120921587

Ho, R. T. H., Fong, T. C. T., Cheung, I. K. M., Yip, P. S. F., & Luk, M.-Y. (2016). Effects of a Short-Term Dance Movement Therapy Program on Symptoms and Stress in Patients With Breast Cancer Undergoing Radiotherapy: A Randomized, Controlled, Single-Blind Trial. *Journal of Pain and Symptom Management*, *51*(5), 824–831. https://doi.org/10.1016/j.jpainsymman.2015.12.332

Ho, R. T. H., Fong, T. C. T., & Yip, P. S. F. (2018). Perceived stress moderates the effects of a randomized trial of dance movement therapy on diurnal cortisol slopes in breast cancer patients. *Psychoneuroendocrinology*, *87*, 119–126. https://doi.org/10.1016/j.psyneuen.2017.10.012

Imboden, C., Gerber, M., Beck, J., Eckert, A., Lejri, I., Pühse, U., Holsboer-Trachsler, E., & Hatzinger, M. (2021). Aerobic Exercise and Stretching as Add-On to Inpatient Treatment for Depression Have No Differential Effects on Stress-Axis Activity, Serum-BDNF, TNF-Alpha and Objective Sleep Measures. *Brain Sciences*, *11*(4). https://doi.org/10.3390/brainsci11040411

Innes, K. E., & Selfe, T. K. (2012). The Effects of a Gentle Yoga Program on Sleep, Mood, and Blood Pressure in Older Women with Restless Legs Syndrome (RLS): A Preliminary Randomized Controlled Trial. *Evidence-Based Complementary and Alternative Medicine*, *2012*, 294058. https://doi.org/10.1155/2012/294058

Irwin, M. R. (2015). Why sleep is important for health: a psychoneuroimmunology perspective. *Annual Review of Psychology*, *66*, 143–172. https://doi.org/10.1146/annurev-psych-010213-115205

Jemal, A., Siegel, R., Ward, E., Murray, T., Xu, J., & Thun, M. J. (2007). Cancer statistics, 2007. *CA: A Cancer Journal for Clinicians*, *57*(1), 43–66. https://doi.org/10.3322/canjclin.57.1.43

Juster, R.-P., McEwen, B. S., & Lupien, S. J. (2010). Allostatic load biomarkers of chronic stress and impact on health and cognition. *Neuroscience and Biobehavioral Reviews*, *35*(1), 2–16. https://doi.org/10.1016/j.neubiorev.2009.10.002

Kim, T. W., Jeong, J.-H., & Hong, S.-C. (2015). The impact of sleep and circadian disturbance on hormones and metabolism. *International Journal of Endocrinology, 2015*, 591729. https://doi.org/10.1155/2015/591729

Kirschbaum, C., & Hellhammer, D. H. (1989). Salivary cortisol in psychobiological research: an overview. *Neuropsychobiology, 22*(3), 150–169. https://doi.org/10.1159/000118611

Kirschbaum, C., Kudielka, B. M., Gaab, J., Schommer, N. C., & Hellhammer, D. H. (1999). Impact of gender, menstrual cycle phase, and oral contraceptives on the activity of the hypothalamus-pituitary-adrenal axis. *Psychosomatic Medicine*, *61*(2), 154–162. https://doi.org/10.1097/00006842-199903000-00006

Kirschbaum, C., Wüst, S., Faig, H. G., & Hellhammer, D. H. (1992). Heritability of cortisol responses to human corticotropin-releasing hormone, ergometry, and psychological stress in humans. *The Journal of Clinical Endocrinology and Metabolism*, *75*(6), 1526–1530. https://doi.org/10.1210/jcem.75.6.1464659

Kraemer, R. R., Blair, S., Kraemer, G. R., & Castracane, V. D. (1989). Effects of treadmill running on plasma beta-endorphin, corticotropin, and cortisol levels in male and female

10K runners. *European Journal of Applied Physiology and Occupational Physiology*, *58*(8), 845–851. https://doi.org/10.1007/BF02332217

Kredlow, M. A., Capozzoli, M. C., Hearon, B. A., Calkins, A. W., & Otto, M. W. (2015). The effects of physical activity on sleep: a meta-analytic review. *Journal of Behavioral Medicine*, *38*(3), 427–449. https://doi.org/10.1007/s10865-015-9617-6

Kripke, D. F., Garfinkel, L., Wingard, D. L., Klauber, M. R., & Marler, M. R. (2002). Mortality associated with sleep duration and insomnia. *Archives of General Psychiatry*, *59*(2), 131–136. https://doi.org/10.1001/archpsyc.59.2.131

Kudielka, Brigitte M, & Kirschbaum, C. (2005). Sex differences in HPA axis responses to stress: a review. *Biological Psychology*, *69*(1), 113–132. https://doi.org/10.1016/j.biopsycho.2004.11.009

Kudielka, B M, Buske-Kirschbaum, A., Hellhammer, D. H., & Kirschbaum, C. (2004). HPA axis responses to laboratory psychosocial stress in healthy elderly adults, younger adults, and children: impact of age and gender. *Psychoneuroendocrinology*, *29*(1), 83–98. https://doi.org/10.1016/s0306-4530(02)00146-4

Kumari, M., Shipley, M., Stafford, M., & Kivimaki, M. (2011). Association of diurnal patterns in salivary cortisol with all-cause and cardiovascular mortality: findings from the Whitehall II study. *The Journal of Clinical Endocrinology and Metabolism*, *96*(5), 1478–1485. https://doi.org/10.1210/jc.2010-2137

Kunz-Ebrecht, S. R., Kirschbaum, C., Marmot, M., & Steptoe, A. (2004). Differences in cortisol awakening response on work days and weekends in women and men from the

Whitehall II cohort. *Psychoneuroendocrinology*, *29*(4), 516–528. https://doi.org/10.1016/s0306-4530(03)00072-6

Lederman, O., Ward, P. B., Firth, J., Maloney, C., Carney, R., Vancampfort, D., Stubbs, B., Kalucy, M., & Rosenbaum, S. (2019). Does exercise improve sleep quality in individuals with mental illness? A systematic review and meta-analysis. *Journal of Psychiatric Research*, *109*, 96–106. https://doi.org/10.1016/j.jpsychires.2018.11.004

Léger, D., Poursain, B., Neubauer, D., & Uchiyama, M. (2008). An international survey of sleeping problems in the general population. *Current Medical Research and Opinion*, *24*(1), 307–317. https://doi.org/10.1185/030079907x253771

Leone, M., Lalande, D., Thériault, L., Kalinova, É., & Fortin, A. (2018). Effects of an exercise program on the physiological, biological and psychological profiles in patients with mood disorders: a pilot study. *International Journal of Psychiatry in Clinical Practice*, *22*(4), 268–273. https://doi.org/10.1080/13651501.2018.1425458

Lupien, S. J., Maheu, F., Tu, M., Fiocco, A., & Schramek, T. E. (2007). The effects of stress and stress hormones on human cognition: Implications for the field of brain and cognition. *Brain and Cognition*, *65*(3), 209–237. https://doi.org/10.1016/j.bandc.2007.02.007

Mallon, L., Broman, J. E., & Hetta, J. (2002). Sleep complaints predict coronary artery disease mortality in males: a 12-year follow-up study of a middle-aged Swedish population. *Journal of Internal Medicine*, *251*(3), 207–216. https://doi.org/10.1046/j.1365-2796.2002.00941.x

McGuinness, L. A., & Higgins, J. P. T. (2021). Risk-of-bias VISualization (robvis): An R package and Shiny web app for visualizing risk-of-bias assessments. *Research Synthesis Methods*, *12*(1), 55–61. https://doi.org/10.1002/jrsm.1411

Miller, K. D., Siegel, R. L., Lin, C. C., Mariotto, A. B., Kramer, J. L., Rowland, J. H., Stein, K. D., Alteri, R., & Jemal, A. (2016). Cancer treatment and survivorship statistics, 2016. *CA: A Cancer Journal for Clinicians*, *66*(4), 271–289. https://doi.org/10.3322/caac.21349

Noal, S., Levy, C., Hardouin, A., Rieux, C., Heutte, N., Ségura, C., Collet, F., Allouache, D., Switsers, O., Delcambre, C., Delozier, T., Henry-Amar, M., & Joly, F. (2011). One-year longitudinal study of fatigue, cognitive functions, and quality of life after adjuvant radiotherapy for breast cancer. *International Journal of Radiation Oncology, Biology, Physics*, *81*(3), 795–803. https://doi.org/10.1016/j.ijrobp.2010.06.037

Nollet, M., Wisden, W., & Franks, N. P. (2020). Sleep deprivation and stress: a reciprocal relationship. *Interface Focus*, *10*(3), 20190092. https://doi.org/10.1098/rsfs.2019.0092

Ockenfels, M. C., Porter, L., Smyth, J., Kirschbaum, C., Hellhammer, D. H., & Stone, A. A. (1995). Effect of chronic stress associated with unemployment on salivary cortisol: overall cortisol levels, diurnal rhythm, and acute stress reactivity. *Psychosomatic Medicine*, *57*(5), 460–467. https://doi.org/10.1097/00006842-199509000-00008

Oldehinkel, A. J., & Bouma, E. M. C. (2011). Sensitivity to the depressogenic effect of stress and HPA axis reactivity in adolescence: a review of gender differences. *Neuroscience and Biobehavioral Reviews*, *35*(8), 1757–1770. https://doi.org/10.1016/j.neubiorev.2010.10.013

Ono, D., & Yamanaka, A. (2017). Hypothalamic regulation of the sleep/wake cycle. *Neuroscience Research*, *118*, 74–81. https://doi.org/10.1016/j.neures.2017.03.013

Organization, W. H. (2015). *World Report on Ageing and Health* (1st ed., p. 230). World Health Organization. https://apps.who.int/iris/handle/10665/186463

Ouzzani, M., Hammady, H., Fedorowicz, Z., & Elmagarmid, A. (2016). Rayyan-a web and mobile app for systematic reviews. *Systematic Reviews*, *5*(1), 210. https://doi.org/10.1186/s13643-016-0384-4

Page, M., McKenzie, J., Bossuyt, P., Boutron, I., Hoffmann, T., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ (Clinical Research Ed.)*, *372*, n71. https://doi.org/10.1136/bmj.n71

Passos, G. S., Poyares, D., Santana, M. G., Teixeira, A. A. de S., Lira, F. S., Youngstedt, S. D., dos Santos, R. V. T., Tufik, S., & de Mello, M. T. (2014). Exercise improves immune function, antidepressive response, and sleep quality in patients with chronic primary insomnia. *BioMed Research International*, *2014*, 498961. https://doi.org/10.1155/2014/498961

Pawlyk, A. C., Morrison, A. R., Ross, R. J., & Brennan, F. X. (2008). Stress-induced changes in sleep in rodents: models and mechanisms. *Neuroscience and Biobehavioral Reviews*, *32*(1), 99–117. https://doi.org/10.1016/j.neubiorev.2007.06.001

Payne, J. D., & Nadel, L. (2004). Sleep, dreams, and memory consolidation: the role of the stress hormone cortisol. *Learning & Memory*, *11*(6), 671–678. https://doi.org/10.1101/lm.77104

Payne, J. K., Held, J., Thorpe, J., & Shaw, H. (2008). Effect of exercise on biomarkers, fatigue, sleep disturbances, and depressive symptoms in older women with breast cancer receiving hormonal therapy. *Oncology Nursing Forum*, *35*(4), 635–642. https://doi.org/10.1188/08.ONF.635-642

Penedo, F. J., & Dahn, J. R. (2005). Exercise and well-being: a review of mental and physical health benefits associated with physical activity. *Current Opinion in Psychiatry*, *18*(2), 189–193. https://doi.org/10.1097/00001504-200503000-00013

Phillips, A. C., Carroll, D., Gale, C. R., Lord, J. M., Arlt, W., & Batty, G. D. (2010). Cortisol, DHEA sulphate, their ratio, and all-cause and cause-specific mortality in the Vietnam Experience Study. *European Journal of Endocrinology*, *163*(2), 285–292. https://doi.org/10.1530/EJE-10-0299

Pruessner, J. C., Wolf, O. T., Hellhammer, D. H., Buske-Kirschbaum, A., von Auer, K., Jobst, S., Kaspers, F., & Kirschbaum, C. (1997). Free cortisol levels after awakening: a reliable biological marker for the assessment of adrenocortical activity. *Life Sciences*, *61*(26), 2539–2549. https://doi.org/10.1016/S0024-3205(97)01008-4

Ratcliff, C. G., Milbury, K., Chandwani, K. D., Chaoul, A., Perkins, G., Nagarathna, R., Haddad, R., Nagendra, H. R., Raghuram, N. V., Spelman, A., Arun, B., Wei, Q., & Cohen, L. (2016). Examining mediators and moderators of yoga for women with breast cancer undergoing radiotherapy. *Integrative Cancer Therapies*, *15*(3), 250–262. https://doi.org/10.1177/1534735415624141

Reid, H., Ridout, A. J., Tomaz, S. A., Kelly, P., Jones, N., & Physical Activity Risk Consensus group. (2022). Benefits outweigh the risks: a consensus statement on the risks of physical activity for people living with long-term conditions. *British Journal of Sports Medicine*, *56*(8), 427–438. https://doi.org/10.1136/bjsports-2021-104281

Reid, K. J., Baron, K. G., Lu, B., Naylor, E., Wolfe, L., & Zee, P. C. (2010). Aerobic exercise improves self-reported sleep and quality of life in older adults with insomnia. *Sleep Medicine*, *11*(9), 934–940. https://doi.org/10.1016/j.sleep.2010.04.014

Richardson, W. S., Wilson, M. C., Nishikawa, J., & Hayward, R. S. (1995). The well-built clinical question: a key to evidence-based decisions. *ACP Journal Club*, *123*(3), A12-3. https://doi.org/10.7326/ACPJC-1995-123-3-A12

Rohatgi, A. (2021). *WebPlotDigitizer* (4.5) [Computer software]. https://automeris.io/WebPlotDigitizer

Roscoe, J. A., Morrow, G. R., Hickok, J. T., Bushunow, P., Matteson, S., Rakita, D., & Andrews, P. L. R. (2002). Temporal interrelationships among fatigue, circadian rhythm and depression in breast cancer patients undergoing chemotherapy treatment. *Supportive Care in Cancer*, *10*(4), 329–336. https://doi.org/10.1007/s00520-001-0317-0

Ryan, R., Booth, S., Spathis, A., Mollart, S., & Clow, A. (2016). Use of salivary diurnal cortisol as an outcome measure in randomised controlled trials: a systematic review. *Annals of Behavioral Medicine*, *50*(2), 210–236. https://doi.org/10.1007/s12160-015-9753-9

Schmidt, M. E., Semik, J., Habermann, N., Wiskemann, J., Ulrich, C. M., & Steindorf, K. (2016). Cancer-related fatigue shows a stable association with diurnal cortisol dysregulation in breast cancer patients. *Brain, Behavior, and Immunity*, *52*, 98–105. https://doi.org/10.1016/j.bbi.2015.10.005

Schneider, S., Moyer, A., Knapp-Oliver, S., Sohl, S., Cannella, D., & Targhetta, V. (2010). Pre-intervention distress moderates the efficacy of psychosocial treatment for cancer patients: a meta-analysis. *Journal of Behavioral Medicine*, *33*(1), 1–14. https://doi.org/10.1007/s10865-009-9227-2

Schulz, P., Kirschbaum, C., Prüßner, J., & Hellhammer, D. (1998). Increased free cortisol secretion after awakening in chronically stressed individuals due to work overload. *Stress Medicine*, *14*(2), 91–97. https://doi.org/10.1002/(SICI)1099-1700(199804)14:2<91::AID-SMI765>3.0.CO;2-S

Schünemann, H., Brożek, J., Guyatt, G., & Oxman, A. (2013). *GRADE handbook for grading quality of evidence and strength of recommendations.* The GRADE Working Group. http://guidelinedevelopment.org/handbook

Sephton, Lush, Dedert, Floyd, Rebholz, Dhabhar, F. S., Spiegel, D., & Salmon, P. (2013). Diurnal cortisol rhythm as a predictor of lung cancer survival. *Brain, Behavior, and Immunity*, *30 Suppl*, S163-70. https://doi.org/10.1016/j.bbi.2012.07.019

Sephton, Sapolsky, Kraemer, & Spiegel, D. (2000). Diurnal cortisol rhythm as a predictor of breast cancer survival. *Journal of the National Cancer Institute*, *92*(12), 994–1000. https://doi.org/10.1093/jnci/92.12.994

Simon, G. E., & VonKorff, M. (1997). Prevalence, burden, and treatment of insomnia in primary care. *The American Journal of Psychiatry*, *154*(10), 1417–1423. https://doi.org/10.1176/ajp.154.10.1417

Sjövall, K., Strömbeck, G., Löfgren, A., Bendahl, P. O., & Gunnars, B. (2010). Adjuvant radiotherapy of women with breast cancer - information, support and side-effects.

European Journal of Oncology Nursing : The Official Journal of European Oncology Nursing Society, *14*(2), 147–153. https://doi.org/10.1016/j.ejon.2009.09.002

Smyth, J. M., Ockenfels, M. C., Gorin, A. A., Catley, D., Porter, L. S., Kirschbaum, C., Hellhammer, D. H., & Stone, A. A. (1997). Individual differences in the diurnal cycle of cortisol. *Psychoneuroendocrinology*, *22*(2), 89–105. https://doi.org/10.1016/s0306-4530(96)00039-x

Spiegel, K., Leproult, R., & Van Cauter, E. (1999). Impact of sleep debt on metabolic and endocrine function. *The Lancet*, *354*(9188), 1435–1439. https://doi.org/10.1016/S0140-6736(99)01376-8

Stalder, T., Kirschbaum, C., Kudielka, B. M., Adam, E. K., Pruessner, J. C., Wüst, S., Dockray, S., Smyth, N., Evans, P., Hellhammer, D. H., Miller, R., Wetherell, M. A., Lupien, S. J., & Clow, A. (2016). Assessment of the cortisol awakening response: Expert consensus guidelines. *Psychoneuroendocrinology*, *63*, 414–432. https://doi.org/10.1016/j.psyneuen.2015.10.010

Steiger, A. (2002). Sleep and the hypothalamo-pituitary-adrenocortical system. *Sleep Medicine Reviews*, *6*(2), 125–138. https://doi.org/10.1053/smrv.2001.0159

Steptoe, A., Cropley, M., Griffith, J., & Kirschbaum, C. (2000). Job strain and anger expression predict early morning elevations in salivary cortisol. *Psychosomatic Medicine*, *62*(2), 286–292. https://doi.org/10.1097/00006842-200003000-00022

Sterne, J. A. C., Sutton, A. J., Ioannidis, J. P. A., Terrin, N., Jones, D. R., Lau, J., Carpenter, J., Rücker, G., Harbord, R. M., Schmid, C. H., Tetzlaff, J., Deeks, J. J., Peters, J., Macaskill, P., Schwarzer, G., Duval, S., Altman, D. G., Moher, D., & Higgins, J. P. T.

(2011). Recommendations for examining and interpreting funnel plot asymmetry in meta-analyses of randomised controlled trials. *BMJ (Clinical Research Ed.)*, *343*, d4002. https://doi.org/10.1136/bmj.d4002

Tell, D., Mathews, H. L., & Janusek, L. W. (2014). Day-to-day dynamics of associations between sleep, napping, fatigue, and the cortisol diurnal rhythm in women diagnosed as having breast cancer. *Psychosomatic Medicine*, *76*(7), 519–528. https://doi.org/10.1097/PSY.0000000000000097

The Cochrane Collaboration. (2020). *Review Manager (RevMan)* (5.4) [Computer software]. The Cochrane Collaboration.

Uchida, S., Shioda, K., Morita, Y., Kubota, C., Ganeko, M., & Takeda, N. (2012). Exercise effects on sleep physiology. *Frontiers in Neurology*, *3*, 48. https://doi.org/10.3389/fneur.2012.00048

Vanderlinden, J., Boen, F., & van Uffelen, J. G. Z. (2020). Effects of physical activity programs on sleep outcomes in older adults: a systematic review. *The International Journal of Behavioral Nutrition and Physical Activity*, *17*(1), 11. https://doi.org/10.1186/s12966-020-0913-3

Van Cauter, E., Leproult, R., & Plat, L. (2000). Age-related changes in slow wave sleep and REM sleep and relationship with growth hormone and cortisol levels in healthy men. *The Journal of the American Medical Association*, *284*(7), 861–868. https://doi.org/10.1001/jama.284.7.861

Vera, F. M., Manzaneque, J. M., Maldonado, E. F., Carranque, G. A., Rodriguez, F. M., Blanca, M. J., & Morell, M. (2009). Subjective Sleep Quality and hormonal modulation in long-term yoga practitioners. *Biological Psychology*, *81*(3), 164–168. https://doi.org/10.1016/j.biopsycho.2009.03.008

Wang, F., & Boros, S. (2019). The effect of physical activity on sleep quality: a systematic review. *European Journal of Physiotherapy*, 1–8. https://doi.org/10.1080/21679169.2019.1623314

Wright, K. P., Drake, A. L., Frey, D. J., Fleshner, M., Desouza, C. A., Gronfier, C., & Czeisler, C. A. (2015). Influence of sleep deprivation and circadian misalignment on cortisol, inflammatory markers, and cytokine balance. *Brain, Behavior, and Immunity*, *47*, 24–34. https://doi.org/10.1016/j.bbi.2015.01.004

Zaccari, B., Callahan, M. L., Storzbach, D., McFarlane, N., Hudson, R., & Loftis, J. M. (2020). Yoga for veterans with PTSD: Cognitive functioning, mental health, and salivary cortisol. *Psychological Trauma : Theory, Research, Practice and Policy*, *12*(8), 913–917. https://doi.org/10.1037/tra0000909

Chapter 4

Alzheimer's Society. (2022, July 19). *Facts for the media*. https://www.alzheimers.org.uk/about-us/news-and-media/facts-media

Arrieta, H., Rezola-Pardo, C., Zarrazquin, I., Echeverria, I., Yanguas, J. J., Iturburu, M., Gil, S. M., Rodriguez-Larrad, A., & Irazusta, J. (2018). A multicomponent exercise program improves physical function in long-term nursing home residents: A randomized controlled trial. *Experimental Gerontology*, *103*, 94–100. https://doi.org/10.1016/j.exger.2018.01.008

Bao, J., Chua, K.-C., Prina, M., & Prince, M. (2019). Multimorbidity and care dependence in older adults: a longitudinal analysis of findings from the 10/66 study. *BMC Public Health*, *19*(1), 585. https://doi.org/10.1186/s12889-019-6961-4

Bherer, L., Erickson, K. I., & Liu-Ambrose, T. (2013). A review of the effects of physical activity and exercise on cognitive and brain functions in older adults. *Journal of Aging Research*, *2013*, 657508. https://doi.org/10.1155/2013/657508

Brustio, P. R., Liubicich, M. E., Chiabrero, M., & Rabaglietti, E. (2018). Dancing in the golden age: a study on physical function, quality of life, and social engagement. *Geriatric Nursing (New York, N.Y.)*, *39*(6), 635–639. https://doi.org/10.1016/j.gerinurse.2018.04.013

Byng, R., Norman, I., & Redfern, S. (2005). Using Realistic Evaluation to Evaluate a Practice-level Intervention to Improve Primary Healthcare for Patients with Long-term Mental Illness. *Evaluation*, *11*(1), 69–93. https://doi.org/10.1177/1356389005053198

Chehab, O., Ouertani, M., Chaieb, K., Haouala, F., & Mahdouani, K. (2007). Hormonal status of cortisol and dehydroepiandrosterone sulfate in an elderly Tunisian population. *Comptes Rendus Biologies*, *330*(10), 755–763. https://doi.org/10.1016/j.crvi.2007.08.004

Chou, C.-H., Hwang, C.-L., & Wu, Y.-T. (2012). Effect of exercise on physical function, daily living activities, and quality of life in the frail older adults: a meta-analysis. *Archives of Physical Medicine and Rehabilitation*, *93*(2), 237–244. https://doi.org/10.1016/j.apmr.2011.08.042

Clegg, A., Young, J., Iliffe, S., Rikkert, M. O., & Rockwood, K. (2013). Frailty in elderly people. *The Lancet*, *381*(9868), 752–762. https://doi.org/10.1016/S0140-6736(12)62167-9

Cohen, S., Kamarck, T., & Mermelstein, R. (1983). A global measure of perceived stress. *Journal of Health and Social Behavior*, *24*(4), 385–396. https://doi.org/10.2307/2136404

Cordes, T., Schoene, D., Kemmler, W., & Wollesen, B. (2021). Chair-Based Exercise Interventions for Nursing Home Residents: A Systematic Review. *Journal of the American Medical Directors Association*, *22*(4), 733–740. https://doi.org/10.1016/j.jamda.2020.09.042

Da Silva, J. L., Agbangla, N. F., Le Page, C., Ghernout, W., & Andrieu, B. (2022). Effects of chronic physical exercise or multicomponent exercise programs on the mental health and cognition of older adults living in a nursing home: A systematic review of studies from the past 10 years. *Frontiers in Psychology*, *13*, 888851. https://doi.org/10.3389/fpsyg.2022.888851

De Nys, L., Ofosu, E. F., Ryde, G. C., Connelly, J., & Whittaker, A. C. (2022). Physical Activity Influences Cortisol and Dehydroepiandrosterone (Sulfate) Levels in Older Adults: A Systematic Review and Meta-Analysis. *Journal of Aging and Physical Activity*, 1–22. https://doi.org/10.1123/japa.2021-0501

de Souto Barreto, P., Morley, J. E., Chodzko-Zajko, W., H Pitkala, K., Weening-Djiksterhuis, E., Rodriguez-Mañas, L., Barbagallo, M., Rosendahl, E., Sinclair, A., Landi, F., Izquierdo, M., Vellas, B., Rolland, Y., & International Association of Gerontology and Geriatrics – Global Aging Research Network (IAGG-GARN) and the IAGG European Region Clinical Section. (2016). Recommendations on Physical Activity and Exercise for Older Adults Living in Long-Term Care Facilities: A Taskforce Report. *Journal of the American Medical Directors Association*, *17*(5), 381–392. https://doi.org/10.1016/j.jamda.2016.01.021

Diener, J., Rayling, S., Bezold, J., Krell-Roesch, J., Woll, A., & Wunsch, K. (2022). Effectiveness and Acceptability of e- and m-Health Interventions to Promote Physical Activity and Prevent Falls in Nursing Homes-A Systematic Review. *Frontiers in Physiology*, *13*, 894397. https://doi.org/10.3389/fphys.2022.894397

Djukanovic, I., Carlsson, J., & Årestedt, K. (2017). Is the Hospital Anxiety and Depression Scale (HADS) a valid measure in a general population 65-80 years old? A psychometric evaluation study. *Health and Quality of Life Outcomes*, *15*(1), 193. https://doi.org/10.1186/s12955-017-0759-9

Eldridge, S. M., Chan, C. L., Campbell, M. J., Bond, C. M., Hopewell, S., Thabane, L., Lancaster, G. A., & PAFS consensus group. (2016). CONSORT 2010 statement: extension to randomised pilot and feasibility trials. *BMJ (Clinical Research Ed.)*, *355*, i5239. https://doi.org/10.1136/bmj.i5239

EuroQol Group. (1990). EuroQol--a new facility for the measurement of health-related quality of life. *Health Policy (Amsterdam, Netherlands)*, *16*(3), 199–208.

Foà, C., Guarnieri, M. C., Bastoni, G., Benini, B., Giunti, O. M., Mazzotti, M., Rossi, C., Savoia, A., Sarli, L., & Artioli, G. (2020). Job satisfaction, work engagement and stress/burnout of elderly care staff: a qualitative research. *Acta Bio-Medica : Atenei Parmensis*, *91*(12-S), e2020014. https://doi.org/10.23750/abm.v91i12-S.10918

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). “Mini-mental state”. A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, *12*(3), 189–198. https://doi.org/10.1016/0022-3956(75)90026-6

Fried, L. P., Tangen, C. M., Walston, J., Newman, A. B., Hirsch, C., Gottdiener, J., Seeman, T., Tracy, R., Kop, W. J., Burke, G., & McBurnie, M. A. (2001). Frailty in older adults: Evidence for a phenotype. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *56*(3), M146-56. https://doi.org/10.1093/gerona/56.3.m146

Gordon, A. L., Franklin, M., Bradshaw, L., Logan, P., Elliott, R., & Gladman, J. R. F. (2014). Health status of UK care home residents: a cohort study. *Age and Ageing*, *43*(1), 97–103. https://doi.org/10.1093/ageing/aft077

Guzmán-García, A., Hughes, J. C., James, I. A., & Rochester, L. (2013). Dancing as a psychosocial intervention in care homes: a systematic review of the literature. *International Journal of Geriatric Psychiatry*, *28*(9), 914–924. https://doi.org/10.1002/gps.3913

Heaney, J. L. J., Carroll, D., & Phillips, A. C. (2014). Physical activity, life events stress, cortisol, and DHEA: preliminary findings that physical activity may buffer against the negative effects of stress. *Journal of Aging and Physical Activity*, *22*(4), 465–473. https://doi.org/10.1123/japa.2012-0082

Henskens, M., Nauta, I. M., Drost, K. T., & Scherder, E. J. (2018). The effects of movement stimulation on activities of daily living performance and quality of life in nursing home residents with dementia: a randomized controlled trial. *Clinical Interventions in Aging*, *13*, 805–817. https://doi.org/10.2147/CIA.S160031

Hill, N. L., Kolanowski, A., & Kürüm, E. (2010). Agreeableness and activity engagement in nursing home residents with dementia. *Journal of Gerontological Nursing*, *36*(9), 45–52. https://doi.org/10.3928/00989134-20100330-10

Hirakawa, Y., Chiang, C., Uemura, M. Y., & Aoyama, A. (2019). Job Satisfaction Among Japanese Home-Visit Care Workers. *Home Health Care Management & Practice*, *31*(1), 3–8. https://doi.org/10.1177/1084822318803861

Hwang, P. W.-N., & Braun, K. L. (2015). The effectiveness of dance interventions to improve older adults' health: A systematic literature review. *Alternative Therapies in Health and Medicine*, *21*(5), 64–70.

Jenkins, C., Smythe, A., Galant-Miecznikowska, M., Bentham, P., & Oyebode, J. (2016). Overcoming challenges of conducting research in nursing homes. *Nursing Older People*, *28*(5), 16–23. https://doi.org/10.7748/nop.28.5.16.s24

Kempen, G. I. J. M., Yardley, L., van Haastregt, J. C. M., Zijlstra, G. A. R., Beyer, N., Hauer, K., & Todd, C. (2008). The Short FES-I: a shortened version of the falls efficacy scale-international to assess fear of falling. *Age and Ageing*, *37*(1), 45–50. https://doi.org/10.1093/ageing/afm157

Lachenbruch, P. A., & Cohen, J. (1989). Statistical Power Analysis for the Behavioral Sciences (2nd ed.). *Journal of the American Statistical Association*, *84*(408), 1096. https://doi.org/10.2307/2290095

Lazarus, N. R., & Harridge, S. D. R. (2018). The inherent human aging process and the facilitating role of exercise. *Frontiers in Physiology*, *9*, 1135. https://doi.org/10.3389/fphys.2018.01135

Lindsay-Smith, G., Eime, R., O'Sullivan, G., Harvey, J., & van Uffelen, J. G. Z. (2019). A mixed-methods case study exploring the impact of participation in community activity groups for older adults on physical activity, health and wellbeing. *BMC Geriatrics*, *19*(1), 243. https://doi.org/10.1186/s12877-019-1245-5

Low, L. F., Carroll, S., Merom, D., Baker, J. R., Kochan, N., Moran, F., & Brodaty, H. (2016). We think you can dance! A pilot randomised controlled trial of dance for nursing home residents with moderate to severe dementia. *Complementary Therapies in Medicine*, *29*, 42–44. https://doi.org/10.1016/j.ctim.2016.09.005

Manzano, A. (2016). The craft of interviewing in realist evaluation. *Evaluation*, *22*(3), 342–360. https://doi.org/10.1177/1356389016638615

Marengoni, A., Angleman, S., Melis, R., Mangialasche, F., Karp, A., Garmen, A., Meinow, B., & Fratiglioni, L. (2011). Aging with multimorbidity: a systematic review of the literature. *Ageing Research Reviews*, *10*(4), 430–439. https://doi.org/10.1016/j.arr.2011.03.003

Maula, A., LaFond, N., Orton, E., Iliffe, S., Audsley, S., Vedhara, K., & Kendrick, D. (2019). Use it or lose it: a qualitative study of the maintenance of physical activity in older adults. *BMC Geriatrics*, *19*(1), 349. https://doi.org/10.1186/s12877-019-1366-x

Moore, G. F., Audrey, S., Barker, M., Bond, L., Bonell, C., Hardeman, W., Moore, L., O'Cathain, A., Tinati, T., Wight, D., & Baird, J. (2015). Process evaluation of complex interventions: Medical Research Council guidance. *BMJ (Clinical Research Ed.)*, *350*, h1258. https://doi.org/10.1136/bmj.h1258

Moyle, W., Skinner, J., Rowe, G., & Gork, C. (2003). Views of job satisfaction and dissatisfaction in Australian long-term care. *Journal of Clinical Nursing*, *12*(2), 168–176. https://doi.org/10.1046/j.1365-2702.2003.00732.x

Nelson, E., Wasson, J., Kirk, J., Keller, A., Clark, D., Dietrich, A., Stewart, A., & Zubkoff, M. (1987). Assessment of function in routine clinical practice: description of the COOP Chart method and preliminary findings. *Journal of Chronic Diseases*, *40 Suppl 1*, 55S-69S. https://doi.org/10.1016/s0021-9681(87)80033-4

Neto, F. (2014). Psychometric analysis of the short-form UCLA Loneliness Scale (ULS-6) in older adults. *European Journal of Ageing*, *11*(4), 313–319. https://doi.org/10.1007/s10433-014-0312-1

Nyman, S. R., & Victor, C. R. (2011). Older people's recruitment, sustained participation, and adherence to falls prevention interventions in institutional settings: a supplement to the Cochrane systematic review. *Age and Ageing*, *40*(4), 430–436. https://doi.org/10.1093/ageing/afr016

OECD. (2021). *Health at a glance 2021: OECD indicators*. OECD Publishing. https://doi.org/10.1787/ae3016b9-en

Office for National Statistics. (2014, August). *Changes in the Older Resident Care Home Population between 2001 and 2011*. https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/ageing/articles/changesintheolderresidentcarehomepopulationbetween2001and2011/2014-08-01

Ofosu, Esther Frema, de Nys, L., Connelly, J., Ryde, G. C., & Whittaker, A. C. (2023). Dimensions of Physical Activity Are Important in Managing Anxiety in Older Adults: A Systematic Review and Meta-Analysis. *Journal of Aging and Physical Activity*, 1–14. https://doi.org/10.1123/japa.2022-0098

Ofosu, E F, De Nys, L., Connelly, J., Ryde, G. C., & Whittaker, A. C. (2023). A realist evaluation of the feasibility of a randomised controlled trial of a digital music and movement intervention for older people living in care homes. *BMC Geriatrics*, *23*(1), 125. https://doi.org/10.1186/s12877-023-03794-5

Ohayon, M. M., Paskow, M., Roach, A., Filer, C., Hillygus, D. S., Chen, M. C., Langer, G., Hirshkowitz, M., & National Sleep Foundation Sleep Satisfaction Consensus Panel. (2019). The national sleep foundation's sleep satisfaction tool. *Sleep Health*, *5*(1), 5–11. https://doi.org/10.1016/j.sleh.2018.10.003

Pawson, R., & Manzano-Santaella, A. (2012). A realist diagnostic workshop. *Evaluation*, *18*(2), 176–191. https://doi.org/10.1177/1356389012440912

Podsiadlo, D., & Richardson, S. (1991). The timed "Up & Go": A test of basic functional mobility for frail elderly persons. *Journal of the American Geriatrics Society*, *39*(2), 142–148. https://doi.org/10.1111/j.1532-5415.1991.tb01616.x

Rodriguez-Larrad, A., Arrieta, H., Rezola-Pardo, C., Esain, I., Mendia-Oria, P., & Irazusta, J. (2021). Loss of benefits after cessation of exercise interventions in nursing home residents: randomized controlled trial follow-up. *Geriatric Nursing (New York, N.Y.)*, *42*(3), 621–627. https://doi.org/10.1016/j.gerinurse.2021.03.009

Sackley, C., Levin, S., Cardoso, K., & Hoppitt, T. (2006). Observations of activity levels and social interaction in a residential care setting. *International Journal of Therapy and Rehabilitation*, *13*(8), 370–373. https://doi.org/10.12968/ijtr.2006.13.8.370

Salive, M. E. (2013). Multimorbidity in older adults. *Epidemiologic Reviews*, *35*, 75–83. https://doi.org/10.1093/epirev/mxs009

Salter, K. L., & Kothari, A. (2014). Using realist evaluation to open the black box of knowledge translation: a state-of-the-art review. *Implementation Science, 9,* 115. https://doi.org/10.1186/s13012-014-0115-y

Sellami, M., Bragazzi, N. L., Slimani, M., Hayes, L., Jabbour, G., De Giorgio, A., & Dugué, B. (2019). The Effect of Exercise on Glucoregulatory Hormones: A Countermeasure to Human Aging: Insights from a Comprehensive Review of the Literature. *International Journal of Environmental Research and Public Health*, *16*(10). https://doi.org/10.3390/ijerph16101709

Spittaels, H., De Bourdeaudhuij, I., & Vandelanotte, C. (2007). Evaluation of a website-delivered computer-tailored intervention for increasing physical activity in the general population. *Preventive Medicine*, *44*(3), 209–217. https://doi.org/10.1016/j.ypmed.2006.11.010

Strawbridge, W. J., Deleger, S., Roberts, R. E., & Kaplan, G. A. (2002). Physical activity reduces the risk of subsequent depression for older adults. *American Journal of Epidemiology*, *156*(4), 328–334. https://doi.org/10.1093/aje/kwf047

Swales, B., Ryde, G. C., & Whittaker, A. C. (2022). A randomized controlled feasibility trial evaluating a resistance training intervention with frail older adults in residential care: the keeping active in residential elderly trial. *Journal of Aging and Physical Activity*, *30*(3), 364–388. https://doi.org/10.1123/japa.2021-0130

Thurm, F., Scharpf, A., Liebermann, N., Kolassa, S., Elbert, T., Lüchtenberg, D., Woll, A., & Kolassa, I.-T. (2011). Improvement of Cognitive Function after Physical Movement Training in Institutionalized Very Frail Older Adults with Dementia. *GeroPsych*, *24*(4), 197–208. https://doi.org/10.1024/1662-9647/a000048

Treacy, D., & Hassett, L. (2018). The short physical performance battery. *Journal of Physiotherapy*, *64*(1), 61. https://doi.org/10.1016/j.jphys.2017.04.002

Ulbrecht, G., Wagner, D., & Gräßel, E. (2012). Exergames and their acceptance among nursing home residents. *Activities, Adaptation & Aging*, *36*(2), 93–106. https://doi.org/10.1080/01924788.2012.673155

Valenzuela, P. L., Morales, J. S., Pareja-Galeano, H., Izquierdo, M., Emanuele, E., de la Villa, P., & Lucia, A. (2018). Physical strategies to prevent disuse-induced functional decline in the elderly. *Ageing Research Reviews, 47,* 80–88. https://doi.org/10.1016/j.arr.2018.07.003

Valenzuela, T., Okubo, Y., Woodbury, A., Lord, S. R., & Delbaere, K. (2018). Adherence to Technology-Based Exercise Programs in Older Adults: A Systematic Review. *Journal of Geriatric Physical Therapy (2001)*, *41*(1), 49–61. https://doi.org/10.1519/JPT.0000000000000095

Westhorp, G. (2014, September 3). *Realist impact evaluation: an introduction*. https://odi.org/en/publications/realist-impact-evaluation-an-introduction/

Wilson, M.-M. G., Thomas, D. R., Rubenstein, L. Z., Chibnall, J. T., Anderson, S., Baxi, A., Diebold, M. R., & Morley, J. E. (2005). Appetite assessment: simple appetite questionnaire predicts weight loss in community-dwelling adults and nursing home residents. *The American Journal of Clinical Nutrition*, *82*(5), 1074–1081. https://doi.org/10.1093/ajcn/82.5.1074

Windle, G., Hughes, D., Linck, P., Russell, I., & Woods, B. (2010). Is exercise effective in promoting mental well-being in older age? A systematic review. *Aging & Mental Health, 14*(6), 652–669. https://doi.org/10.1080/13607861003713232

Wong, G., Westhorp, G., Manzano, A., Greenhalgh, J., Jagosh, J., & Greenhalgh, T. (2016). RAMESES II reporting standards for realist evaluations. *BMC Medicine*, *14*(1), 96. https://doi.org/10.1186/s12916-016-0643-1

Yardley, L., Bishop, F. L., Beyer, N., Hauer, K., Kempen, G. I. J. M., Piot-Ziegler, C., Todd, C. J., Cuttelod, T., Horne, M., Lanta, K., & Holt, A. R. (2006). Older people's views of falls-prevention interventions in six European countries. *The Gerontologist*, *46*(5), 650–660. https://doi.org/10.1093/geront/46.5.650

Yardley, L., Donovan-Hall, M., Francis, K., & Todd, C. (2007). Attitudes and beliefs that predict older people's intention to undertake strength and balance training. *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences*, *62*(2), P119-25. https://doi.org/10.1093/geronb/62.2.p119

Zigmond, A. S., & Snaith, R. P. (1983). The hospital anxiety and depression scale. *Acta Psychiatrica Scandinavica*, *67*(6), 361–370. https://doi.org/10.1111/j.1600-0447.1983.tb09716.x

Chapter 5

Alipour, F., Sajadi, H., Forouzan, A., Nabavi, H., & Khedmati, E. (2009). The Role of Social Support in the Anxiety and Depression of Elderly. *Iranian Journal of Ageing*.

Anderson, T., & Wideman, L. (2017). Exercise and the cortisol awakening response: A systematic review. *Sports Medicine - Open*, *3*(1), 37. https://doi.org/10.1186/s40798-017-0102-3

Barbour, K. A., Edenfield, T. M., & Blumenthal, J. A. (2007). Exercise as a treatment for depression and other psychiatric disorders: a review. *Journal of Cardiopulmonary*

Rehabilitation and Prevention, *27*(6), 359–367. https://doi.org/10.1097/01.HCR.0000300262.69645.95

Bieniek, J., Wilczyński, K., & Szewieczek, J. (2016). Fried frailty phenotype assessment components as applied to geriatric inpatients. *Clinical Interventions in Aging*, *11*, 453–459. https://doi.org/10.2147/CIA.S101369

Blumenthal, J. A., Babyak, M. A., Doraiswamy, P. M., Watkins, L., Hoffman, B. M., Barbour, K. A., Herman, S., Craighead, W. E., Brosse, A. L., Waugh, R., Hinderliter, A., & Sherwood, A. (2007). Exercise and pharmacotherapy in the treatment of major depressive disorder. *Psychosomatic Medicine*, *69*(7), 587–596. https://doi.org/10.1097/PSY.0b013e318148c19a

Bohannon, R. W. (2008). Hand-grip dynamometry predicts future outcomes in aging adults. *Journal of Geriatric Physical Therapy (2001)*, *31*(1), 3–10. https://doi.org/10.1519/00139143-200831010-00002

Bouchard, C., Shephard, R. J., & Brubaker, P. H. (1994). Physical activity, fitness, and health. *Medicine & Science in Sports & Exercise*, *26*(1), 119. https://doi.org/10.1249/00005768-199401000-00024

Boyd, M. A. (2007). *Psychiatric Nursing: Contemporary Practice (Point (Lippincott Williams & Wilkins))* (4th ed., p. 976). Lippincott Williams & Wilkins.

British Psychological Society. (2010). *Audit tool for Mental Capacity Assessments* (p. 28).

Bromberg-Martin, E. S., Matsumoto, M., & Hikosaka, O. (2010). Dopamine in motivational control: rewarding, aversive, and alerting. *Neuron*, *68*(5), 815–834. https://doi.org/10.1016/j.neuron.2010.11.022

Browne, R. H. (1995). On the use of a pilot sample for sample size determination. *Statistics in Medicine*, *14*(17), 1933–1940. https://doi.org/10.1002/sim.4780141709

Buford, T. W., & Willoughby, D. S. (2008). Impact of DHEA(S) and cortisol on immune function in aging: a brief review. *Applied Physiology, Nutrition, and Metabolism*, *33*(3), 429–433. https://doi.org/10.1139/H08-013

Butcher, S. K., Killampalli, V., Lascelles, D., Wang, K., Alpar, E. K., & Lord, J. M. (2005). Raised cortisol:DHEAS ratios in the elderly after injury: potential impact upon neutrophil function and immunity. *Aging Cell*, *4*(6), 319–324. https://doi.org/10.1111/j.1474-9726.2005.00178.x

Buyl, R., Beogo, I., Fobelets, M., Deletroz, C., Van Landuyt, P., Dequanter, S., Gorus, E., Bourbonnais, A., Giguère, A., Lechasseur, K., & Gagnon, M.-P. (2020). e-Health interventions for healthy aging: a systematic review. *Systematic Reviews*, *9*(1), 128. https://doi.org/10.1186/s13643-020-01385-8

Caiozzo, V. J., Davis, J. A., Ellis, J. F., Azus, J. L., Vandagriff, R., Prietto, C. A., & McMaster, W. C. (1982). A comparison of gas exchange indices used to detect the anaerobic threshold. *Journal of Applied Physiology: Respiratory, Environmental and Exercise Physiology*, *53*(5), 1184–1189. https://doi.org/10.1152/jappl.1982.53.5.1184

Caspar, S., Phinney, A., Spenceley, S., & Ratner, P. (2020). Creating Cultures of Care: Exploring the Social Organization of Care Delivery in Long-Term Care Homes. *Journal of Long-Term Care*, *0*(2020), 13. https://doi.org/10.31389/jltc.17

Chan, J. K. Y., Klainin-Yobas, P., Chi, Y., Gan, J. K. E., Chow, G., & Wu, X. V. (2021). The effectiveness of e-interventions on fall, neuromuscular functions and quality of life in community-dwelling older adults: A systematic review and meta-analysis. *International Journal of Nursing Studies*, *113*, 103784. https://doi.org/10.1016/j.ijnurstu.2020.103784

Clair, A. A. (1996). Therapeutic uses of music with older adults. In *Music in physical exercise*. (pp. 151–167). Health professions.

Cohen, S., Kamarck, T., & Mermelstein, R. (1983). A global measure of perceived stress. *Journal of Health and Social Behavior*, *24*(4), 385–396. https://doi.org/10.2307/2136404

Coste, J., Strauch, G., Letrait, M., & Bertagna, X. (1994). Reliability of hormonal levels for assessing the hypothalamic-pituitary-adrenocortical system in clinical pharmacology. *British Journal of Clinical Pharmacology*, *38*(5), 474–479. https://doi.org/10.1111/j.1365-2125.1994.tb04386.x

Cruz-Jentoft, A. J., Baeyens, J. P., Bauer, J. M., Boirie, Y., Cederholm, T., Landi, F., Martin, F. C., Michel, J.-P., Rolland, Y., Schneider, S. M., Topinková, E., Vandewoude, M., Zamboni, M., & European Working Group on Sarcopenia in Older People. (2010). Sarcopenia: European consensus on definition and diagnosis: Report of the European Working Group on Sarcopenia in Older People. *Age and Ageing*, *39*(4), 412–423. https://doi.org/10.1093/ageing/afq034

Daskalopoulou, C., Stubbs, B., Kralj, C., Koukounari, A., Prince, M., & Prina, A. M. (2017). Physical activity and healthy ageing: A systematic review and meta-analysis of longitudinal cohort studies. *Ageing Research Reviews*, *38*, 6–17. https://doi.org/10.1016/j.arr.2017.06.003

Davies, C. A., Spence, J. C., Vandelanotte, C., Caperchione, C. M., & Mummery, W. K. (2012). Meta-analysis of internet-delivered interventions to increase physical activity levels. *The International Journal of Behavioral Nutrition and Physical Activity*, *9*, 52. https://doi.org/10.1186/1479-5868-9-52

Devereux-Fitzgerald, A., Powell, R., Dewhurst, A., & French, D. P. (2016). The acceptability of physical activity interventions to older adults: A systematic review and meta-synthesis. *Social Science & Medicine*, *158*, 14–23. https://doi.org/10.1016/j.socscimed.2016.04.006

De Nys, L., Anderson, K., Ofosu, E. F., Ryde, G. C., Connelly, J., & Whittaker, A. C. (2022). The effects of physical activity on cortisol and sleep: A systematic review and meta-analysis. *Psychoneuroendocrinology*, *143*, 105843. https://doi.org/10.1016/j.psyneuen.2022.105843

De Nys, L., Ofosu, E. F., Ryde, G. C., Connelly, J., & Whittaker, A. C. (2022). Physical Activity Influences Cortisol and Dehydroepiandrosterone (Sulfate) Levels in Older Adults: A Systematic Review and Meta-Analysis. *Journal of Aging and Physical Activity*, 1–22. https://doi.org/10.1123/japa.2021-0501

de Vries, N. M., van Ravensberg, C. D., Hobbelen, J. S. M., Olde Rikkert, M. G. M., Staal, J. B., & Nijhuis-van der Sanden, M. W. G. (2012). Effects of physical exercise therapy on mobility, physical functioning, physical activity and quality of life in community-dwelling older adults with impaired mobility, physical disability and/or multi-morbidity: a meta-analysis. *Ageing Research Reviews*, *11*(1), 136–149. https://doi.org/10.1016/j.arr.2011.11.002

Dingle, G. A., Sharman, L. S., Bauer, Z., Beckman, E., Broughton, M., Bunzli, E., Davidson, R., Draper, G., Fairley, S., Farrell, C., Flynn, L. M., Gomersall, S., Hong, M., Larwood, J., Lee, C., Lee, J., Nitschinsk, L., Peluso, N., Reedman, S. E., … Wright, O. R. L. (2021). How Do Music Activities Affect Health and Well-Being? A Scoping Review of Studies

Examining Psychosocial Mechanisms. *Frontiers in Psychology*, *12*, 713818. https://doi.org/10.3389/fpsyg.2021.713818

Djukanovic, I., Carlsson, J., & Årestedt, K. (2017). Is the Hospital Anxiety and Depression Scale (HADS) a valid measure in a general population 65-80 years old? A psychometric evaluation study. *Health and Quality of Life Outcomes*, *15*(1), 193. https://doi.org/10.1186/s12955-017-0759-9

Duclos, M., & Tabarin, A. (2016). Exercise and the Hypothalamo-Pituitary-Adrenal Axis. *Frontiers of Hormone Research*, *47*, 12–26. https://doi.org/10.1159/000445149

Dugan, S. A., Gabriel, K. P., Lange-Maia, B. S., & Karvonen-Gutierrez, C. (2018). Physical activity and physical function: moving and aging. *Obstetrics and Gynecology Clinics of North America*, *45*(4), 723–736. https://doi.org/10.1016/j.ogc.2018.07.009

Eldridge, S. M., Chan, C. L., Campbell, M. J., Bond, C. M., Hopewell, S., Thabane, L., Lancaster, G. A., & PAFS consensus group. (2016). CONSORT 2010 statement: extension to randomised pilot and feasibility trials. *BMJ (Clinical Research Ed.)*, *355*, i5239. https://doi.org/10.1136/bmj.i5239

Ferrari, E., Cravello, L., Muzzoni, B., Casarotti, D., Paltro, M., Solerte, S. B., Fioravanti, M., Cuzzoni, G., Pontiggia, B., & Magri, F. (2001). Age-related changes of the hypothalamic-pituitary-adrenal axis: pathophysiological correlates. *European Journal of Endocrinology*, *144*(4), 319–329. https://doi.org/10.1530/eje.0.1440319

Fragala, M. S., Kraemer, W. J., Denegar, C. R., Maresh, C. M., Mastro, A. M., & Volek, J. S. (2011). Neuroendocrine-immune interactions and responses to exercise. *Sports Medicine (Auckland, N.Z.)*, *41*(8), 621–639. https://doi.org/10.2165/11590430-000000000-00000

Fried, L. P., Tangen, C. M., Walston, J., Newman, A. B., Hirsch, C., Gottdiener, J., Seeman, T., Tracy, R., Kop, W. J., Burke, G., & McBurnie, M. A. (2001). Frailty in older adults: Evidence for a phenotype. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *56*(3), M146-56. https://doi.org/10.1093/gerona/56.3.m146

Gale, C. R., Martyn, C. N., Cooper, C., & Sayer, A. A. (2007). Grip strength, body composition, and mortality. *International Journal of Epidemiology*, *36*(1), 228–235. https://doi.org/10.1093/ije/dyl224

Guralnik, J. M., Simonsick, E. M., Ferrucci, L., Glynn, R. J., Berkman, L. F., Blazer, D. G., Scherr, P. A., & Wallace, R. B. (1994). A short physical performance battery assessing lower extremity function: Association with self-reported disability and prediction of mortality and nursing home admission. *Journal of Gerontology*, *49*(2), M85-94. https://doi.org/10.1093/geronj/49.2.M85

Heaney, J. L. J., Carroll, D., & Phillips, A. C. (2014). Physical activity, life events stress, cortisol, and DHEA: preliminary findings that physical activity may buffer against the negative effects of stress. *Journal of Aging and Physical Activity*, *22*(4), 465–473. https://doi.org/10.1123/japa.2012-0082

Hill, E. E., Zack, E., Battaglini, C., Viru, M., Viru, A., & Hackney, A. C. (2008). Exercise and circulating cortisol levels: the intensity threshold effect. *Journal of Endocrinological Investigation*, *31*(7), 587–591. https://doi.org/10.1007/BF03345606

Hoben, M., Clarke, A., Huynh, K. T., Kobagi, N., Kent, A., Hu, H., Pereira, R. A. C., Xiong, T., Yu, K., Xiang, H., & Yoon, M. N. (2017). Barriers and facilitators in providing oral care to nursing home residents, from the perspective of care aides: A systematic review and meta-analysis. *International Journal of Nursing Studies, 73*, 34–51. https://doi.org/10.1016/j.ijnurstu.2017.05.003

Holt-Lunstad, J., Smith, T. B., Baker, M., Harris, T., & Stephenson, D. (2015). Loneliness and social isolation as risk factors for mortality: a meta-analytic review. *Perspectives on Psychological Science*, *10*(2), 227–237. https://doi.org/10.1177/1745691614568352

Hwang, P. W.-N., & Braun, K. L. (2015). The effectiveness of dance interventions to improve older adults' health: A systematic literature review. *Alternative Therapies in Health and Medicine*, *21*(5), 64–70.

Jakubowski, K., & Eerola, T. (2022). Music evokes fewer but more positive autobiographical memories than emotionally matched sound and word cues. *Journal of Applied Research in Memory and Cognition*, *11*(2), 272–288. https://doi.org/10.1016/j.jarmac.2021.09.002

Kraaijkamp, J. J. M., van Dam van Isselt, E. F., Persoon, A., Versluis, A., Chavannes, N. H., & Achterberg, W. P. (2021). eHealth in Geriatric Rehabilitation: Systematic Review of Effectiveness, Feasibility, and Usability. *Journal of Medical Internet Research*, *23*(8), e24015. https://doi.org/10.2196/24015

Kraemer, H. C., Giese-Davis, J., Yutsis, M., O'Hara, R., Neri, E., Gallagher-Thompson, D., Taylor, C. B., & Spiegel, D. (2006). Design decisions to optimize reliability of daytime cortisol slopes in an older population. *The American Journal of Geriatric Psychiatry, 14*(4), 325–333. https://doi.org/10.1097/01.JGP.0000201816.26786.5b

Kraemer, W. J., Ratamess, N. A., Hymer, W. C., Nindl, B. C., & Fragala, M. S. (2020). Growth Hormone(s), Testosterone, Insulin-Like Growth Factors, and Cortisol: Roles and

Integration for Cellular Development and Growth With Exercise. *Frontiers in Endocrinology*, *11*, 33. https://doi.org/10.3389/fendo.2020.00033

Kraemer, W. J., & Ratamess, N. A. (2005). Hormonal responses and adaptations to resistance exercise and training. *Sports Medicine (Auckland, N.Z.)*, *35*(4), 339–361. https://doi.org/10.2165/00007256-200535040-00004

Kroboth, P. D., Salek, F. S., Pittenger, A. L., Fabian, T. J., & Frye, R. F. (1999). DHEA and DHEA-S: a review. *Journal of Clinical Pharmacology*, *39*(4), 327–348. https://doi.org/10.1177/00912709922007903

Kubzansky, L. D., Kawachi, I., & Sparrow, D. (1999). Socioeconomic status, hostility, and risk factor clustering in the Normative Aging Study: any help from the concept of allostatic load? *Annals of Behavioral Medicine*, *21*(4), 330–338. https://doi.org/10.1007/BF02895966

Lindsay-Smith, G., Eime, R., O'Sullivan, G., Harvey, J., & van Uffelen, J. G. Z. (2019). A mixed-methods case study exploring the impact of participation in community activity groups for older adults on physical activity, health and wellbeing. *BMC Geriatrics*, *19*(1), 243. https://doi.org/10.1186/s12877-019-1245-5

Liu, X., Shen, P.-L., & Tsai, Y.-S. (2021). Dance intervention effects on physical function in healthy older adults: a systematic review and meta-analysis. *Aging Clinical and Experimental Research*, *33*(2), 253–263. https://doi.org/10.1007/s40520-019-01440-y

Maninger, N., Wolkowitz, O. M., Reus, V. I., Epel, E. S., & Mellon, S. H. (2009). Neurobiological and neuropsychiatric effects of dehydroepiandrosterone (DHEA) and DHEA sulfate (DHEAS). *Frontiers in Neuroendocrinology*, *30*(1), 65–91. https://doi.org/10.1016/j.yfrne.2008.11.002

Maula, A., LaFond, N., Orton, E., Iliffe, S., Audsley, S., Vedhara, K., & Kendrick, D. (2019). Use it or lose it: a qualitative study of the maintenance of physical activity in older adults. *BMC Geriatrics*, *19*(1), 349. https://doi.org/10.1186/s12877-019-1366-x

McPhee, J. S., French, D. P., Jackson, D., Nazroo, J., Pendleton, N., & Degens, H. (2016). Physical activity in older age: perspectives for healthy ageing and frailty. *Biogerontology*, *17*(3), 567–580. https://doi.org/10.1007/s10522-016-9641-0

Medina-Mirapeix, F., Bernabeu-Mora, R., Llamazares-Herrán, E., Sánchez-Martínez, M. P., García-Vidal, J. A., & Escolar-Reina, P. (2016). Interobserver reliability of peripheral muscle strength tests and short physical performance battery in patients with chronic obstructive pulmonary disease: A prospective observational study. *Archives of Physical Medicine and Rehabilitation*, *97*(11), 2002–2005. https://doi.org/10.1016/j.apmr.2016.05.004

Mellor, K., Albury, C., Dutton, S. J., Eldridge, S., & Hopewell, S. (2023). Recommendations for progression criteria during external randomised pilot trial design, conduct, analysis and reporting. *Pilot and Feasibility Studies*, *9*(1), 59. https://doi.org/10.1186/s40814-023-01291-5

Menon, V., & Levitin, D. J. (2005). The rewards of music listening: response and physiological connectivity of the mesolimbic system. *Neuroimage*, *28*(1), 175–184. https://doi.org/10.1016/j.neuroimage.2005.05.053

Milne. (2016). *Mental health and older people: A guide for primary care practitioners* (C. A. Chew-Graham & M. Ray, Eds.; pp. 145–160). Springer International Publishing. https://doi.org/10.1007/978-3-319-29492-6

Moilanen, T., Kangasniemi, M., Papinaho, O., Mynttinen, M., Siipi, H., Suominen, S., & Suhonen, R. (2021). Older people's perceived autonomy in residential care: An integrative review. *Nursing Ethics*, *28*(3), 414–434. https://doi.org/10.1177/0969733020948115

Mollinedo Cardalda, I., López, A., & Cancela Carral, J. M. (2019). The effects of different types of physical exercise on physical and cognitive function in frail institutionalized older adults with mild to moderate cognitive impairment. A randomized controlled trial. *Archives of Gerontology and Geriatrics*, *83*, 223–230. https://doi.org/10.1016/j.archger.2019.05.003

Morucci, G., Ryskalin, L., Pratesi, S., Branca, J. J. V., Modesti, A., Modesti, P. A., Gulisano, M., & Gesi, M. (2022). Effects of a 24-Week Exercise Program on Functional Fitness, Oxidative Stress, and Salivary Cortisol Levels in Elderly Subjects. *Medicina (Kaunas, Lithuania)*, *58*(10). https://doi.org/10.3390/medicina58101341

Muellmann, S., Forberger, S., Möllers, T., Bröring, E., Zeeb, H., & Pischke, C. R. (2018). Effectiveness of eHealth interventions for the promotion of physical activity in older adults: A systematic review. *Preventive Medicine*, *108*, 93–110. https://doi.org/10.1016/j.ypmed.2017.12.026

Nakrem, S. (2015). Understanding organizational and cultural premises for quality of care in nursing homes: an ethnographic study. *BMC Health Services Research*, *15*, 508. https://doi.org/10.1186/s12913-015-1171-y

Nishchyk, A., Chen, W., Pripp, A. H., & Bergland, A. (2021). The Effect of Mixed Reality Technologies for Falls Prevention Among Older Adults: Systematic Review and Meta-analysis. *JMIR Aging*, *4*(2), e27972. https://doi.org/10.2196/27972

Nocivelli, B., Shepherd, V., Hood, K., Wallace, C., & Wood, F. (2023). Identifying barriers and facilitators to the inclusion of older adults living in UK care homes in research: a scoping review. *BMC Geriatrics*, *23*(1), 446. https://doi.org/10.1186/s12877-023-04126-3

Nusselder, W. J., Looman, C. W. N., Franco, O. H., Peeters, A., Slingerland, A. S., & Mackenbach, J. P. (2008). The relation between non-occupational physical activity and years lived with and without disability. *Journal of Epidemiology and Community Health*, *62*(9), 823–828. https://doi.org/10.1136/jech.2007.067165

Nyman, S. R., & Victor, C. R. (2011). Older people's recruitment, sustained participation, and adherence to falls prevention interventions in institutional settings: a supplement to the Cochrane systematic review. *Age and Ageing*, *40*(4), 430–436. https://doi.org/10.1093/ageing/afr016

OECD. (2021). *Health at a glance 2021: OECD indicators*. OECD Publishing. https://doi.org/10.1787/ae3016b9-en

Office for National Statistics. (2021, February 23). *Health state life expectancy, all ages, UK*. https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/healthandlifeexpectancies/datasets/healthstatelifeexpectancyallagesuk

Ofosu, Esther Frema, de Nys, L., Connelly, J., Ryde, G. C., & Whittaker, A. C. (2023). Dimensions of Physical Activity Are Important in Managing Anxiety in Older Adults: A Systematic Review and Meta-Analysis. *Journal of Aging and Physical Activity*, 1–14. https://doi.org/10.1123/japa.2022-0098

Ofosu, E F, De Nys, L., Connelly, J., Ryde, G. C., & Whittaker, A. C. (2023). A realist evaluation of the feasibility of a randomised controlled trial of a digital music and movement intervention for older people living in care homes. *BMC Geriatrics*, *23*(1), 125. https://doi.org/10.1186/s12877-023-03794-5

Olatunji, B. O., Cisler, J. M., & Tolin, D. F. (2007). Quality of life in the anxiety disorders: a meta-analytic review. *Clinical Psychology Review*, *27*(5), 572–581. https://doi.org/10.1016/j.cpr.2007.01.015

Olsen, C. F., & Bergland, A. (2017). “Reliability of the Norwegian version of the short physical performance battery in older people with and without dementia”. *BMC Geriatrics*, *17*(1), 124. https://doi.org/10.1186/s12877-017-0514-4

Paterson, D. H., & Warburton, D. E. (2010). Physical activity and functional limitations in older adults: a systematic review related to Canada’s Physical Activity Guidelines. *The International Journal of Behavioral Nutrition and Physical Activity*, *7*, 38. https://doi.org/10.1186/1479-5868-7-38

Pedersen, B. K., & Saltin, B. (2015). Exercise as medicine - evidence for prescribing exercise as therapy in 26 different chronic diseases. *Scandinavian Journal of Medicine & Science in Sports*, *25 Suppl 3*, 1–72. https://doi.org/10.1111/sms.12581

Petruzzello, S. J., Landers, D. M., Hatfield, B. D., Kubitz, K. A., & Salazar, W. (1991). A Meta-Analysis on the Anxiety-Reducing Effects of Acute and Chronic Exercise. *Sports Medicine*, *11*(3), 143–182. https://doi.org/10.2165/00007256-199111030-00002

Phillips, A. C., Burns, V. E., & Lord, J. M. (2007). Stress and exercise: Getting the balance right for aging immunity. *Exercise and Sport Sciences Reviews*, *35*(1), 35–39. https://doi.org/10.1097/jes.0b013e31802d7008

Phillips, A. C., Carroll, D., Gale, C. R., Lord, J. M., Arlt, W., & Batty, G. D. (2010). Cortisol, DHEA sulphate, their ratio, and all-cause and cause-specific mortality in the Vietnam Experience Study. *European Journal of Endocrinology*, *163*(2), 285–292. https://doi.org/10.1530/EJE-10-0299

Preschl, B., Wagner, B., Forstmeier, S., & Maercker, A. (2011). E-health interventions for depression, anxiety disorders, dementia, and other disorders in old age: A review - Zurich Open Repository and Archive. *Journal of CyberTherapy and Rehabilitation*.

Priest, D. L., Karageorghis, C. I., & Sharp, N. C. C. (2004). The characteristics and effects of motivational music in exercise settings: the possible influence of gender, age, frequency of attendance, and time of attendance. *The Journal of Sports Medicine and Physical Fitness*, *44*(1), 77–86.

Pruessner, J. C., Wolf, O. T., Hellhammer, D. H., Buske-Kirschbaum, A., von Auer, K., Jobst, S., Kaspers, F., & Kirschbaum, C. (1997). Free cortisol levels after awakening: a reliable biological marker for the assessment of adrenocortical activity. *Life Sciences*, *61*(26), 2539–2549. https://doi.org/10.1016/S0024-3205(97)01008-4

Radloff, L. S. (1977). The CES-D scale: A self-report depression scale for research in the general population. *Applied Psychological Measurement*, *1*(3), 385–401. https://doi.org/10.1177/014662167700100306

Rodrigues-Krause, J., Krause, M., & Reischak-Oliveira, A. (2019). Dancing for healthy aging: functional and metabolic perspectives. *Alternative Therapies in Health and Medicine*, *25*(1), 44–63.

Sackley, C., Levin, S., Cardoso, K., & Hoppitt, T. (2006). Observations of activity levels and social interaction in a residential care setting. *International Journal of Therapy and Rehabilitation*, *13*(8), 370–373. https://doi.org/10.12968/ijtr.2006.13.8.370

Saghaei, M. (2004). Random allocation software for parallel group randomized trials. *BMC Medical Research Methodology*, *4*, 26. https://doi.org/10.1186/1471-2288-4-26

Schuch, F. B., Vancampfort, D., Richards, J., Rosenbaum, S., Ward, P. B., & Stubbs, B. (2016). Exercise as a treatment for depression: A meta-analysis adjusting for publication bias. *Journal of Psychiatric Research*, *77*, 42–51. https://doi.org/10.1016/j.jpsychires.2016.02.023

Sebastião, E., & Mirda, D. (2021). Group-based physical activity as a means to reduce social isolation and loneliness among older adults. *Aging Clinical and Experimental Research*, *33*(7), 2003–2006. https://doi.org/10.1007/s40520-020-01722-w

Segerstrom, S. C., Boggero, I. A., Smith, G. T., & Sephton, S. E. (2014). Variability and reliability of diurnal cortisol in younger and older adults: implications for design decisions. *Psychoneuroendocrinology*, *49*, 299–309. https://doi.org/10.1016/j.psyneuen.2014.07.022

Sellami, M., Bragazzi, N. L., Slimani, M., Hayes, L., Jabbour, G., De Giorgio, A., & Dugué, B. (2019). The Effect of Exercise on Glucoregulatory Hormones: A Countermeasure to Human Aging: Insights from a Comprehensive Review of the Literature. *International Journal of Environmental Research and Public Health*, *16*(10). https://doi.org/10.3390/ijerph16101709

Sherrington, C., Whitney, J. C., Lord, S. R., Herbert, R. D., Cumming, R. G., & Close, J. C. T. (2008). Effective exercise for the prevention of falls: a systematic review and meta-analysis. *Journal of the American Geriatrics Society*, *56*(12), 2234–2243. https://doi.org/10.1111/j.1532-5415.2008.02014.x

Sooktho, S., Songserm, N., Woradet, S., & Suksatan, W. (2022). A Meta-analysis of Dance Programs on Physical Performance: An Appropriate Health Promotion for Healthy Older Adults. *Annals of Geriatric Medicine and Research*. https://doi.org/10.4235/agmr.22.0066

Stenholm, S., Westerlund, H., Head, J., Hyde, M., Kawachi, I., Pentti, J., Kivimäki, M., & Vahtera, J. (2015). Comorbidity and functional trajectories from midlife to old age: the Health and Retirement Study. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *70*(3), 332–338. https://doi.org/10.1093/gerona/glu113

Stonerock, G. L., Hoffman, B. M., Smith, P. J., & Blumenthal, J. A. (2015). Exercise as treatment for anxiety: systematic review and analysis. *Annals of Behavioral Medicine*, *49*(4), 542–556. https://doi.org/10.1007/s12160-014-9685-9

Stubbs, B., Vancampfort, D., Rosenbaum, S., Firth, J., Cosco, T., Veronese, N., Salum, G. A., & Schuch, F. B. (2017). An examination of the anxiolytic effects of exercise for people with anxiety and stress-related disorders: A meta-analysis. *Psychiatry Research*, *249*, 102–108. https://doi.org/10.1016/j.psychres.2016.12.020

Swales, B., Ryde, G. C., & Whittaker, A. C. (2022). A randomized controlled feasibility trial evaluating a resistance training intervention with frail older adults in residential care: the keeping active in residential elderly trial. *Journal of Aging and Physical Activity*, *30*(3), 364–388. https://doi.org/10.1123/japa.2021-0130

Taekema, D. G., Gussekloo, J., Westendorp, R. G. J., de Craen, A. J. M., & Maier, A. B. (2012). Predicting survival in oldest old people. *The American Journal of Medicine, 125*(12), 1188-1194.e1. https://doi.org/10.1016/j.amjmed.2012.01.034

Taylor, H. L., Jacobs, D. R., Schucker, B., Knudsen, J., Leon, A. S., & Debacker, G. (1978). A questionnaire for the assessment of leisure time physical activities. *Journal of Chronic Diseases*, *31*(12), 741–755. https://doi.org/10.1016/0021-9681(78)90058-9

Tolley, A. P. L., Ramsey, K. A., Rojer, A. G. M., Reijnierse, E. M., & Maier, A. B. (2021). Objectively measured physical activity is associated with frailty in community-dwelling older adults: A systematic review. *Journal of Clinical Epidemiology*, *137,* 218–230. https://doi.org/10.1016/j.jclinepi.2021.04.009

Tonga, E., Srikesavan, C., Williamson, E., & Lamb, S. E. (2022). Components, design and effectiveness of digital physical rehabilitation interventions for older people: A systematic review. *Journal of Telemedicine and Telecare*, *28*(3), 162–176. https://doi.org/10.1177/1357633X20927587

United Nations Department of Economic and Social Affairs Population Division. (2022). *World Population Prospects 2022: Summary of Results.* United Nations Department of Economic and Social Affairs Population Division. https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/wpp2022_summary_of_results.pdf

Vancampfort, D., Koyanagi, A., Hallgren, M., Probst, M., & Stubbs, B. (2017). The relationship between chronic physical conditions, multimorbidity and anxiety in the general population: A global perspective across 42 countries. *General Hospital Psychiatry*, *45*, 1–6. https://doi.org/10.1016/j.genhosppsych.2016.11.002

van den Beld, A. W., Kaufman, J.-M., Zillikens, M. C., Lamberts, S. W. J., Egan, J. M., & van der Lely, A. J. (2018). The physiology of endocrine systems with ageing. *The Lancet. Diabetes & Endocrinology*, *6*(8), 647–658. https://doi.org/10.1016/S2213-8587(18)30026-3

Vordos, Z., Kouidi, E., Mavrovouniotis, F., Metaxas, T., Dimitros, E., Kaltsatou, A., & Deligiannis, A. (2017). Impact of traditional Greek dancing on jumping ability, muscular strength and lower limb endurance in cardiac rehabilitation programmes. *European Journal of Cardiovascular Nursing : Journal of the Working Group on Cardiovascular Nursing of the European Society of Cardiology*, *16*(2), 150–156. https://doi.org/10.1177/1474515116636980

Wang, C.-Y., & Chen, L.-Y. (2010). Grip strength in older adults: test-retest reliability and cutoff for subjective weakness of using the hands in heavy tasks. *Archives of Physical Medicine and Rehabilitation*, *91*(11), 1747–1751. https://doi.org/10.1016/j.apmr.2010.07.225

Warburton, D. E. R., Nicol, C. W., & Bredin, S. S. D. (2006). Health benefits of physical activity: the evidence. *Canadian Medical Association Journal*, *174*(6), 801–809. https://doi.org/10.1503/cmaj.051351

Wiener, J., Anderson, W., & Brown, D. (2009). *Why Are Nursing Home Utilization Rates Declining*. US Department of Health and Human Services, Centers for Medicare and Medicaid Services.

Witham, M. D., & McMurdo, M. E. T. (2007). How to get older people included in clinical studies. *Drugs & Aging*, *24*(3), 187–196. https://doi.org/10.2165/00002512-200724030-00002

Zouhal, H., Jayavel, A., Parasuraman, K., Hayes, L. D., Tourny, C., Rhibi, F., Laher, I., Abderrahman, A. B., & Hackney, A. C. (2022). Effects of Exercise Training on Anabolic and Catabolic Hormones with Advanced Age: A Systematic Review. *Sports Medicine (Auckland, N.Z.)*, *52*(6), 1353–1368. https://doi.org/10.1007/s40279-021-01612-9

Chapter 6

Ackerman, L. S., & Chopik, W. J. (2021). Cross-Cultural Comparisons in Implicit and Explicit Age Bias. *Personality and Social Psychology Bulletin*, *47*(6), 953–968. https://doi.org/10.1177/0146167220950070

Agbangla, N. F., Séba, M.-P., Bunlon, F., Toulotte, C., & Fraser, S. A. (2023). Effects of Physical Activity on Physical and Mental Health of Older Adults Living in Care Settings: A Systematic Review of Meta-Analyses. *International Journal of Environmental Research and Public Health*, *20*(13), 6226. https://doi.org/10.3390/ijerph20136226

Ahn, R.-S., Lee, Y.-J., Choi, J.-Y., Kwon, H.-B., & Chun, S.-I. (2007). Salivary cortisol and DHEA levels in the Korean population: age-related differences, diurnal rhythm, and correlations with serum levels. *Yonsei Medical Journal*, *48*(3), 379–388. https://doi.org/10.3349/ymj.2007.48.3.379

Akacha, M., Branson, J., Bretz, F., Dharan, B., Gallo, P., Gathmann, I., Hemmings, R., Jones, J., Xi, D., & Zuber, E. (2020). Challenges in Assessing the Impact of the COVID-19 Pandemic on the Integrity and Interpretability of Clinical Trials. *Statistics in Biopharmaceutical Research*, *12*(4), 419–426. https://doi.org/10.1080/19466315.2020.1788984

Alsop, T., Lehman, E., Brauer, S., Forbes, R., Hanson, C. L., Healy, G., Milton, K., Reid, H., Rosbergen, I., & Gomersall, S. (2023). What should all health professionals know about movement behaviour change? An international Delphi-based consensus statement. *British Journal of Sports Medicine*. https://doi.org/10.1136/bjsports-2023-106870

Althubaiti, A. (2016). Information bias in health research: definition, pitfalls, and adjustment methods. *Journal of Multidisciplinary Healthcare*, *9*, 211–217. https://doi.org/10.2147/JMDH.S104807

Arrieta, H., Rezola-Pardo, C., Gil, S. M., Virgala, J., Iturburu, M., Antón, I., González-Templado, V., Irazusta, J., & Rodriguez-Larrad, A. (2019). Effects of Multicomponent Exercise on Frailty in Long-Term Nursing Homes: A Randomized Controlled Trial. *Journal of the American Geriatrics Society*, *67*(6), 1145–1151. https://doi.org/10.1111/jgs.15824

Arrieta, H., Rezola-Pardo, C., Zarrazquin, I., Echeverria, I., Yanguas, J. J., Iturburu, M., Gil, S. M., Rodriguez-Larrad, A., & Irazusta, J. (2018). A multicomponent exercise program improves physical function in long-term nursing home residents: A randomized controlled trial. *Experimental Gerontology*, *103*, 94–100. https://doi.org/10.1016/j.exger.2018.01.008

Aznar, C., Blake, M., Mackie, M., Pickering, K., & Rehsi, A. (2021). *Representativeness of Adult Social Care Surveys: Main Report*. Ipsos MORI. https://www.ipsos.com/sites/default/files/ct/news/documents/2021-04/Social_Care_Survey_Review_Main_Report.pdf

Bell, M. L., Whitehead, A. L., & Julious, S. A. (2018). Guidance for using pilot studies to inform the design of intervention trials with continuous outcomes. *Clinical Epidemiology*, *10*, 153–157. https://doi.org/10.2147/CLEP.S146397

Berr, C., Lafont, S., Debuire, B., Dartigues, J. F., & Baulieu, E. E. (1996). Relationships of dehydroepiandrosterone sulfate in the elderly with functional, psychological, and mental status, and short-term mortality: a French community-based study. *Proceedings of the National Academy of Sciences of the United States of America*, *93*(23), 13410–13415. https://doi.org/10.1073/pnas.93.23.13410

Bigarella, L. G., Ballotin, V. R., Mazurkiewicz, L. F., Ballardin, A. C., Rech, D. L., Bigarella, R. L., & Selistre, L. da S. (2022). Exercise for depression and depressive symptoms in older adults: an umbrella review of systematic reviews and Meta-analyses. *Aging & Mental Health*, *26*(8), 1503–1513. https://doi.org/10.1080/13607863.2021.1951660

Bill, V., Wilke, A., Sonsmann, F., & Rocholl, M. (2023). What is the current state of research concerning self-efficacy in exercise behaviour? Protocol for two systematic evidence maps. *BMJ Open*, *13*(8), e070359. https://doi.org/10.1136/bmjopen-2022-070359

Borst, S. E., Vincent, K. R., Lowenthal, D. T., & Braith, R. W. (2002). Effects of resistance training on insulin-like growth factor and its binding proteins in men and women aged 60 to 85. *Journal of the American Geriatrics Society*, *50*(5), 884–888. https://doi.org/10.1046/j.1532-5415.2002.50215.x

Bouchard, C., Shephard, R. J., & Brubaker, P. H. (1994). Physical activity, fitness, and health. *Medicine & Science in Sports & Exercise*, *26*(1), 119. https://doi.org/10.1249/00005768-199401000-00024

Brach, M., de Bruin, E. D., Levin, O., Hinrichs, T., Zijlstra, W., & Netz, Y. (2023). Evidence-based yet still challenging! Research on physical activity in old age. *European Review of Aging and Physical Activity : Official Journal of the European Group for Research into Elderly and Physical Activity*, *20*(1), 7. https://doi.org/10.1186/s11556-023-00318-3

Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., Carty, C., Chaput, J.-P., Chastin, S., Chou, R., Dempsey, P. C., DiPietro, L., Ekelund, U., Firth, J., Friedenreich, C. M., Garcia, L., Gichu, M., Jago, R., Katzmarzyk, P. T., … Willumsen, J. F. (2020). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British Journal of Sports Medicine*, *54*(24), 1451–1462. https://doi.org/10.1136/bjsports-2020-102955

Burnet, K., Kelsch, E., Zieff, G., Moore, J. B., & Stoner, L. (2019). How fitting is F.I.T.T.?: A perspective on a transition from the sole use of frequency, intensity, time, and type in exercise prescription. *Physiology & Behavior*, *199*, 33–34. https://doi.org/10.1016/j.physbeh.2018.11.007

Burton, E., Lewin, G., & Boldy, D. (2015). A systematic review of physical activity programs for older people receiving home care services. *Journal of Aging and Physical Activity*, *23*(3), 460–470. https://doi.org/10.1123/japa.2014-0086

Butcher, S. K., Killampalli, V., Lascelles, D., Wang, K., Alpar, E. K., & Lord, J. M. (2005). Raised cortisol:DHEAS ratios in the elderly after injury: potential impact upon neutrophil function and immunity. *Aging Cell*, *4*(6), 319–324. https://doi.org/10.1111/j.1474-9726.2005.00178.x

Cadegiani, F. A., & Kater, C. E. (2019). Enhancement of hypothalamic-pituitary activity in male athletes: evidence of a novel hormonal mechanism of physical conditioning. *BMC Endocrine Disorders*, *19*(1), 117. https://doi.org/10.1186/s12902-019-0443-7

Caiozzo, V. J., Davis, J. A., Ellis, J. F., Azus, J. L., Vandagriff, R., Prietto, C. A., & McMaster, W. C. (1982). A comparison of gas exchange indices used to detect the anaerobic threshold. *Journal of Applied Physiology: Respiratory, Environmental and Exercise Physiology*, *53*(5), 1184–1189. https://doi.org/10.1152/jappl.1982.53.5.1184

Calabrese, E. J. (2013). Hormetic mechanisms. *Critical Reviews in Toxicology*, *43*(7), 580–606. https://doi.org/10.3109/10408444.2013.808172

Catalan-Matamoros, D., Gomez-Conesa, A., Stubbs, B., & Vancampfort, D. (2016). Exercise improves depressive symptoms in older adults: An umbrella review of systematic reviews and meta-analyses. *Psychiatry Research*, *244*, 202–209. https://doi.org/10.1016/j.psychres.2016.07.028

Chen, T., Chen, S., Honda, T., Nofuji, Y., Kishimoto, H., & Narazaki, K. (2023). Longitudinal Changes in Moderate to Vigorous Physical Activity in Community-Dwelling Older Men and Women: A 2-Year Prospective Cohort Study in Japan. *Journal of Physical Activity & Health*, 1–8. https://doi.org/10.1123/jpah.2022-0411

Chodzko-Zajko, W., Schwingel, A., & Chae Hee Park. (2009). Successful aging: the role of physical activity. *American Journal of Lifestyle Medicine*, *3*(1), 20–28. https://doi.org/10.1177/1559827608325456

Chodzko-Zajko, W. J., Proctor, D. N., Fiatarone Singh, M. A., Minson, C. T., Nigg, C. R., Salem, G. J., & Skinner, J. S. (2009). American College of Sports Medicine position stand. Exercise and physical activity for older adults. *Medicine and Science in Sports and Exercise*, *41*(7), 1510–1530. https://doi.org/10.1249/MSS.0b013e3181a0c95c

Clair, A. A. (1996). Therapeutic uses of music with older adults. In *Music in physical exercise.* (pp. 151–167). Health professions.

Clow, A., Thorn, L., Evans, P., & Hucklebridge, F. (2004). The awakening cortisol response: methodological issues and significance. *Stress (Amsterdam, Netherlands)*, *7*(1), 29–37. https://doi.org/10.1080/10253890410001667205

Coste, J., Strauch, G., Letrait, M., & Bertagna, X. (1994). Reliability of hormonal levels for assessing the hypothalamic-pituitary-adrenocortical system in clinical pharmacology. *British Journal of Clinical Pharmacology*, *38*(5), 474–479. https://doi.org/10.1111/j.1365-2125.1994.tb04386.x

Cross, R., Greaves, C., Withall, J., Kritz, M., & Stathi, A. (2023). A qualitative longitudinal study of motivation in the REtirement in ACTion (REACT) physical activity intervention for older adults with mobility limitations. *The International Journal of Behavioral Nutrition and Physical Activity*, *20*(1), 50. https://doi.org/10.1186/s12966-023-01434-0

Daskalopoulou, C., Stubbs, B., Kralj, C., Koukounari, A., Prince, M., & Prina, A. M. (2017). Physical activity and healthy ageing: A systematic review and meta-analysis of longitudinal cohort studies. *Ageing Research Reviews*, *38*, 6–17. https://doi.org/10.1016/j.arr.2017.06.003

Das, P., & Horton, R. (2012). Rethinking our approach to physical activity. *The Lancet*, *380*(9838), 189–190. https://doi.org/10.1016/S0140-6736(12)61024-1

Davies, C. A., Spence, J. C., Vandelanotte, C., Caperchione, C. M., & Mummery, W. K. (2012). Meta-analysis of internet-delivered interventions to increase physical activity levels. *The International Journal of Behavioral Nutrition and Physical Activity*, *9*, 52. https://doi.org/10.1186/1479-5868-9-52

Davies, S. C., Winpenny, E., Ball, S., Fowler, T., Rubin, J., & Nolte, E. (2014). For debate: a new wave in public health improvement. *The Lancet, 384*(9957), 1889–1895. https://doi.org/10.1016/S0140-6736(13)62341-7

da Fonseca, M. H., Kovaleski, F., Picinin, C. T., Pedroso, B., & Rubbo, P. (2021). E-Health Practices and Technologies: A Systematic Review from 2014 to 2019. *Healthcare (Basel), 9*(9). https://doi.org/10.3390/healthcare9091192

de Souto Barreto, P., Morley, J. E., Chodzko-Zajko, W., H Pitkala, K., Weening-Djiksterhuis, E., Rodriguez-Mañas, L., Barbagallo, M., Rosendahl, E., Sinclair, A., Landi, F., Izquierdo, M., Vellas, B., Rolland, Y., & International Association of Gerontology and Geriatrics – Global Aging Research Network (IAGG-GARN) and the IAGG European Region Clinical Section. (2016). Recommendations on Physical Activity and Exercise for Older Adults Living in Long-Term Care Facilities: A Taskforce Report. *Journal of the American Medical Directors Association, 17*(5), 381–392. https://doi.org/10.1016/j.jamda.2016.01.021

Deer, L. K., Shields, G. S., Ivory, S. L., Hostinar, C. E., & Telzer, E. H. (2018). Racial/ethnic disparities in cortisol diurnal patterns and affect in adolescence. *Development and Psychopathology, 30*(5), 1977–1993. https://doi.org/10.1017/S0954579418001098

De Nys, L., Anderson, K., Ofosu, E. F., Ryde, G. C., Connelly, J., & Whittaker, A. C. (2022). The effects of physical activity on cortisol and sleep: A systematic review and meta-analysis. *Psychoneuroendocrinology, 143*, 105843. https://doi.org/10.1016/j.psyneuen.2022.105843

De Nys, L., Ofosu, E. F., Ryde, G. C., Connelly, J., & Whittaker, A. C. (2022). Physical Activity Influences Cortisol and Dehydroepiandrosterone (Sulfate) Levels in Older Adults:

A Systematic Review and Meta-Analysis. *Journal of Aging and Physical Activity*, 1–22. https://doi.org/10.1123/japa.2021-0501

Del Pozo-Cruz, B., Mañas, A., Martín-García, M., Marín-Puyalto, J., García-García, F. J., Rodriguez-Mañas, L., Guadalupe-Grau, A., & Ara, I. (2017). Frailty is associated with objectively assessed sedentary behaviour patterns in older adults: Evidence from the Toledo Study for Healthy Aging (TSHA). *Plos One*, *12*(9), e0183911. https://doi.org/10.1371/journal.pone.0183911

Diener, J., Rayling, S., Bezold, J., Krell-Roesch, J., Woll, A., & Wunsch, K. (2022). Effectiveness and Acceptability of e- and m-Health Interventions to Promote Physical Activity and Prevent Falls in Nursing Homes-A Systematic Review. *Frontiers in Physiology*, *13*, 894397. https://doi.org/10.3389/fphys.2022.894397

Dingle, G. A., Sharman, L. S., Bauer, Z., Beckman, E., Broughton, M., Bunzli, E., Davidson, R., Draper, G., Fairley, S., Farrell, C., Flynn, L. M., Gomersall, S., Hong, M., Larwood, J., Lee, C., Lee, J., Nitschinsk, L., Peluso, N., Reedman, S. E., … Wright, O. R. L. (2021). How Do Music Activities Affect Health and Well-Being? A Scoping Review of Studies Examining Psychosocial Mechanisms. *Frontiers in Psychology*, *12*, 713818. https://doi.org/10.3389/fpsyg.2021.713818

Dmitrieva, N. O., Almeida, D. M., Dmitrieva, J., Loken, E., & Pieper, C. F. (2013). A day-centered approach to modeling cortisol: diurnal cortisol profiles and their associations among U.S. adults. *Psychoneuroendocrinology*, *38*(10), 2354–2365. https://doi.org/10.1016/j.psyneuen.2013.05.003

Dogra, S., Copeland, J. L., Altenburg, T. M., Heyland, D. K., Owen, N., & Dunstan, D. W. (2022). Start with reducing sedentary behavior: A stepwise approach to physical activity counseling in clinical practice. *Patient Education and Counseling*, *105*(6), 1353–1361. https://doi.org/10.1016/j.pec.2021.09.019

Duclos, M, Gouarne, C., & Bonnemaison, D. (2003). Acute and chronic effects of exercise on tissue sensitivity to glucocorticoids. *Journal of Applied Physiology: Respiratory, Environmental and Exercise Physiology*, *94*(3), 869–875. https://doi.org/10.1152/japplphysiol.00108.2002

Duclos, Martine, & Tabarin, A. (2016). Exercise and the Hypothalamo-Pituitary-Adrenal Axis. *Frontiers of Hormone Research*, *47*, 12–26. https://doi.org/10.1159/000445149

Dugan, S. A., Gabriel, K. P., Lange-Maia, B. S., & Karvonen-Gutierrez, C. (2018). Physical activity and physical function: moving and aging. *Obstetrics and Gynecology Clinics of North America*, *45*(4), 723–736. https://doi.org/10.1016/j.ogc.2018.07.009

Dunstan, D. W., Dogra, S., Carter, S. E., & Owen, N. (2021). Sit less and move more for cardiovascular health: emerging insights and opportunities. *Nature Reviews. Cardiology*, *18*(9), 637–648. https://doi.org/10.1038/s41569-021-00547-y

Ellis, C. L., & Salmoni, A. W. (2021). Descriptive analysis of university-student music preferences during different forms of physical activity. *Psychology of Music*, *49*(2), 177–192. https://doi.org/10.1177/0305735619847759

Elsawy, B., & Higgins, K. E. (2010). Physical activity guidelines for older adults. *American Family Physician*, *81*(1), 55–59.

Ferreira, C. B., Teixeira, P. D. S., Alves Dos Santos, G., Dantas Maya, A. T., Americano do Brasil, P., Souza, V. C., Córdova, C., Ferreira, A. P., Lima, R. M., & Nóbrega, O. de T. (2018). Effects of a 12-Week Exercise Training Program on Physical Function in

Institutionalized Frail Elderly. *Journal of Aging Research, 2018*, 7218102. https://doi.org/10.1155/2018/7218102

Fessler, L., Maltagliati, S., Sieber, S., Cullati, S., Tessitore, E., Craviari, C., Luthy, C., Hanna, E., Meyer, P., Orsholits, D., Sarrazin, P., & Cheval, B. (2023). Physical activity matters for everyone's health, but individuals with multimorbidity benefit more. *Preventive Medicine Reports*, *34*, 102265. https://doi.org/10.1016/j.pmedr.2023.102265

Fragala, M. S., Kraemer, W. J., Denegar, C. R., Maresh, C. M., Mastro, A. M., & Volek, J. S. (2011). Neuroendocrine-immune interactions and responses to exercise. *Sports Medicine (Auckland, N.Z.)*, *41*(8), 621–639. https://doi.org/10.2165/11590430-000000000-00000

French, D. P., Olander, E. K., Chisholm, A., & Mc Sharry, J. (2014). Which behaviour change techniques are most effective at increasing older adults' self-efficacy and physical activity behaviour? A systematic review. *Annals of Behavioral Medicine*, *48*(2), 225–234. https://doi.org/10.1007/s12160-014-9593-z

Gallagher, P., Leitch, M. M., Massey, A. E., McAllister-Williams, R. H., & Young, A. H. (2006). Assessing cortisol and dehydroepiandrosterone (DHEA) in saliva: effects of collection method. *Journal of Psychopharmacology*, *20*(5), 643–649. https://doi.org/10.1177/0269881106060585

Garcia-Hermoso, A., López-Gil, J. F., Ramírez-Vélez, R., Alonso-Martínez, A. M., Izquierdo, M., & Ezzatvar, Y. (2023). Adherence to aerobic and muscle-strengthening activities guidelines: a systematic review and meta-analysis of 3.3 million participants across 32 countries. *British Journal of Sports Medicine*, *57*(4), 225–229. https://doi.org/10.1136/bjsports-2022-106189

Garcia, L., Pearce, M., Abbas, A., Mok, A., Strain, T., Ali, S., Crippa, A., Dempsey, P. C., Golubic, R., Kelly, P., Laird, Y., McNamara, E., Moore, S., de Sa, T. H., Smith, A. D., Wijndaele, K., Woodcock, J., & Brage, S. (2023). Non-occupational physical activity and risk of cardiovascular disease, cancer and mortality outcomes: a dose-response meta-analysis of large prospective studies. *British Journal of Sports Medicine*, *57*(15), 979–989. https://doi.org/10.1136/bjsports-2022-105669

Gichu, M., & Harwood, R. H. (2023). Measurement of healthy ageing. *Age and Ageing*, *52*(Suppl 4), iv3–iv5. https://doi.org/10.1093/ageing/afad118

Goldstein, D. S., & McEwen, B. (2002). Allostasis, homeostats, and the nature of stress. *Stress (Amsterdam, Netherlands)*, *5*(1), 55–58. https://doi.org/10.1080/102538902900012345

Gomes, M., Figueiredo, D., Teixeira, L., Poveda, V., Paúl, C., Santos-Silva, A., & Costa, E. (2017). Physical inactivity among older adults across Europe based on the SHARE database. *Age and Ageing*, *46*(1), 71–77. https://doi.org/10.1093/ageing/afw165

GOV.UK. (2023, June 12). *Ethnicity facts and figures*. https://www.ethnicity-facts-figures.service.gov.uk/health/social-care/adult-social-care-long-term-support/latest

Granger, D. A., Schwartz, E. B., Booth, A., Curran, M., & Zakaria, D. (1999). Assessing dehydroepiandrosterone in saliva: a simple radioimmunoassay for use in studies of children, adolescents and adults. *Psychoneuroendocrinology*, *24*(5), 567–579. https://doi.org/10.1016/s0306-4530(99)00013-x

Granja, C., Janssen, W., & Johansen, M. A. (2018). Factors Determining the Success and Failure of eHealth Interventions: Systematic Review of the Literature. *Journal of Medical Internet Research*, *20*(5), e10235. https://doi.org/10.2196/10235

Guzmán-García, A., Hughes, J. C., James, I. A., & Rochester, L. (2013). Dancing as a psychosocial intervention in care homes: a systematic review of the literature. *International Journal of Geriatric Psychiatry*, *28*(9), 914–924. https://doi.org/10.1002/gps.3913

Hackney, A. C. (2006a). Exercise as a stressor to the human neuroendocrine system. *Medicina (Kaunas, Lithuania)*, *42*(10), 788–797.

Hackney, A. C. (2006b). Stress and the neuroendocrine system: the role of exercise as a stressor and modifier of stress. *Expert Review of Endocrinology & Metabolism*, *1*(6), 783–792. https://doi.org/10.1586/17446651.1.6.783

Häkkinen, A., Pakarinen, A., Hannonen, P., Kautiainen, H., Nyman, K., Kraemer, W. J., & Häkkinen, K. (2005). Effects of prolonged combined strength and endurance training on physical fitness, body composition and serum hormones in women with rheumatoid arthritis and in healthy controls. *Clinical and Experimental Rheumatology*, *23*(4), 505–512.

Hayes, L. D., Grace, F. M., Sculthorpe, N., Herbert, P., Ratcliffe, J. W., Kilduff, L. P., & Baker, J. S. (2013). The effects of a formal exercise training programme on salivary hormone concentrations and body composition in previously sedentary aging men. *SpringerPlus*, *2*(1), 18. https://doi.org/10.1186/2193-1801-2-18

Heaney, J. L. J., Carroll, D., & Phillips, A. C. (2013). DHEA, DHEA-S and cortisol responses to acute exercise in older adults in relation to exercise training status and sex. *Age*, *35*(2), 395–405. https://doi.org/10.1007/s11357-011-9345-y

Heaney, J. L. J., Carroll, D., & Phillips, A. C. (2014). Physical activity, life events stress, cortisol, and DHEA: preliminary findings that physical activity may buffer against the negative effects of stress. *Journal of Aging and Physical Activity*, *22*(4), 465–473. https://doi.org/10.1123/japa.2012-0082

Hellhammer, D. H., Wüst, S., & Kudielka, B. M. (2009). Salivary cortisol as a biomarker in stress research. *Psychoneuroendocrinology*, *34*(2), 163–171. https://doi.org/10.1016/j.psyneuen.2008.10.026

Hellhammer, J., Fries, E., Schweisthal, O. W., Schlotz, W., Stone, A. A., & Hagemann, D. (2007). Several daily measurements are necessary to reliably assess the cortisol rise after awakening: state- and trait components. *Psychoneuroendocrinology*, *32*(1), 80–86. https://doi.org/10.1016/j.psyneuen.2006.10.005

Hill, E. E., Zack, E., Battaglini, C., Viru, M., Viru, A., & Hackney, A. C. (2008). Exercise and circulating cortisol levels: the intensity threshold effect. *Journal of Endocrinological Investigation*, *31*(7), 587–591. https://doi.org/10.1007/BF03345606

Hollands, G. J., Shemilt, I., Marteau, T. M., Jebb, S. A., Kelly, M. P., Nakamura, R., Suhrcke, M., & Ogilvie, D. (2013). Altering micro-environments to change population health behaviour: towards an evidence base for choice architecture interventions. *BMC Public Health*, *13*, 1218. https://doi.org/10.1186/1471-2458-13-1218

Hwang, P. W.-N., & Braun, K. L. (2015). The effectiveness of dance interventions to improve older adults' health: A systematic literature review. *Alternative Therapies in Health and Medicine*, *21*(5), 64–70.

Izquierdo, M., & Fiatarone Singh, M. (2023). Urgent need for integrating physical exercise into geriatric medicine: a call to action. *British Journal of Sports Medicine*. https://doi.org/10.1136/bjsports-2023-106912

Jepson, R. G., Dawson, A., McCabe, L., Greasley-Adams, C., Biggs, H., & Bowes, A. (2023). Development of an intervention programme theory to increase movement in care homes for people with cognitive impairment: Care homes achieving realistic movement strategies (CHARMS). *Evaluation and Program Planning*, *100*, 102348. https://doi.org/10.1016/j.evalprogplan.2023.102348

Juntunen, M.-L., & Sutela, K. (2023). The effectiveness of music-movement integration for vulnerable groups: a systematic literature review. *Frontiers in Psychology*, *14*, 1127654. https://doi.org/10.3389/fpsyg.2023.1127654

Karlamangla, A. S., Singer, B. H., McEwen, B. S., Rowe, J. W., & Seeman, T. E. (2002). Allostatic load as a predictor of functional decline. MacArthur studies of successful aging. *Journal of Clinical Epidemiology*, *55*(7), 696–710. https://doi.org/10.1016/s0895-4356(02)00399-2

Kim, H. J., Oh, S. Y., Joo, J. H., Choi, D.-W., & Park, E.-C. (2019). The Relationship between Sleep Duration and Perceived Stress: Findings from the 2017 Community Health Survey in Korea. *International Journal of Environmental Research and Public Health*, *16*(17). https://doi.org/10.3390/ijerph16173208

King, A. C., Rejeski, W. J., & Buchner, D. M. (1998). Physical activity interventions targeting older adultsaaThis paper was a background paper for the Cooper Institute Conference Series Physical Activity Interventions, an ACSM Specialty Conference.

American Journal of Preventive Medicine, *15*(4), 316–333. https://doi.org/10.1016/S0749-3797(98)00085-3

Kirschbaum, C., & Hellhammer, D. H. (1994). Salivary cortisol in psychoneuroendocrine research: recent developments and applications. *Psychoneuroendocrinology*, *19*(4), 313–333. https://doi.org/10.1016/0306-4530(94)90013-2

Kraaijkamp, J. J. M., van Dam van Isselt, E. F., Persoon, A., Versluis, A., Chavannes, N. H., & Achterberg, W. P. (2021). eHealth in Geriatric Rehabilitation: Systematic Review of Effectiveness, Feasibility, and Usability. *Journal of Medical Internet Research*, *23*(8), e24015. https://doi.org/10.2196/24015

Kraemer, W. J., Ratamess, N. A., Hymer, W. C., Nindl, B. C., & Fragala, M. S. (2020). Growth Hormone(s), Testosterone, Insulin-Like Growth Factors, and Cortisol: Roles and Integration for Cellular Development and Growth With Exercise. *Frontiers in Endocrinology*, *11*, 33. https://doi.org/10.3389/fendo.2020.00033

Kraemer, W. J., & Ratamess, N. A. (2005). Hormonal responses and adaptations to resistance exercise and training. *Sports Medicine (Auckland, N.Z.)*, *35*(4), 339–361. https://doi.org/10.2165/00007256-200535040-00004

Kredlow, M. A., Capozzoli, M. C., Hearon, B. A., Calkins, A. W., & Otto, M. W. (2015). The effects of physical activity on sleep: a meta-analytic review. *Journal of Behavioral Medicine*, *38*(3), 427–449. https://doi.org/10.1007/s10865-015-9617-6

Kubzansky, L. D., Kawachi, I., & Sparrow, D. (1999). Socioeconomic status, hostility, and risk factor clustering in the Normative Aging Study: any help from the concept of allostatic load? *Annals of Behavioral Medicine*, *21*(4), 330–338. https://doi.org/10.1007/BF02895966

Kudielka, B. M., Hellhammer, D. H., & Wüst, S. (2009). Why do we respond so differently? Reviewing determinants of human salivary cortisol responses to challenge. *Psychoneuroendocrinology*, *34*(1), 2–18. https://doi.org/10.1016/j.psyneuen.2008.10.004

Kutschar, P., Osterbrink, J., & Weichbold, M. (2022). Interviewer effects in a survey examining pain intensity and pain interference in nursing home residents. *Age and Ageing*, *51*(2). https://doi.org/10.1093/ageing/afac008

Lai, D. L., & Lai, C. K. (2017). A case study on a home-based caregiver-delivered music-with-movement intervention for people with early dementia. *SAGE Open Medical Case Reports*, *5*, 2050313X17730264. https://doi.org/10.1177/2050313X17730264

Lauffenburger, J. C., Choudhry, N. K., Russo, M., Glynn, R. J., Ventz, S., & Trippa, L. (2022). Designing and conducting adaptive trials to evaluate interventions in health services and implementation research: practical considerations. *BMJ Medicine*, *1*(1). https://doi.org/10.1136/bmjmed-2022-000158

Laughlin, G. A., & Barrett-Connor, E. (2000). Sexual dimorphism in the influence of advanced aging on adrenal hormone levels: the Rancho Bernardo Study. *The Journal of Clinical Endocrinology and Metabolism*, *85*(10), 3561–3568. https://doi.org/10.1210/jcem.85.10.6861

Liu, X., Shen, P.-L., & Tsai, Y.-S. (2021). Dance intervention effects on physical function in healthy older adults: a systematic review and meta-analysis. *Aging Clinical and Experimental Research*, *33*(2), 253–263. https://doi.org/10.1007/s40520-019-01440-y

Low, L. F., Carroll, S., Merom, D., Baker, J. R., Kochan, N., Moran, F., & Brodaty, H. (2016). We think you can dance! A pilot randomised controlled trial of dance for nursing home residents with moderate to severe dementia. *Complementary Therapies in Medicine, 29*, 42–44. https://doi.org/10.1016/j.ctim.2016.09.005

Luger, A., Deuster, P. A., Kyle, S. B., Gallucci, W. T., Montgomery, L. C., Gold, P. W., Loriaux, D. L., & Chrousos, G. P. (1987). Acute hypothalamic-pituitary-adrenal responses to the stress of treadmill exercise. Physiologic adaptations to physical training. *The New England Journal of Medicine, 316*(21), 1309–1315. https://doi.org/10.1056/NEJM198705213162105

Marteau, T. M., Ogilvie, D., Roland, M., Suhrcke, M., & Kelly, M. P. (2011). Judging nudging: can nudging improve population health? *BMJ (Clinical Research Ed.), 342*, d228. https://doi.org/10.1136/bmj.d228

Mastorakos, G., & Pavlatou, M. (2005). Exercise as a stress model and the interplay between the hypothalamus-pituitary-adrenal and the hypothalamus-pituitary-thyroid axes. *Hormone and Metabolic Research*, *37*(9), 577–584. https://doi.org/10.1055/s-2005-870426

Mazat, L., Lafont, S., Berr, C., Debuire, B., Tessier, J. F., Dartigues, J. F., & Baulieu, E. E. (2001). Prospective measurements of dehydroepiandrosterone sulfate in a cohort of elderly subjects: relationship to gender, subjective health, smoking habits, and 10-year mortality. *Proceedings of the National Academy of Sciences of the United States of America*, *98*(14), 8145–8150. https://doi.org/10.1073/pnas.121177998

McEwen, B. (1998). Stress, adaptation, and disease. Allostasis and allostatic load. *Annals of the New York Academy of Sciences*, *840*, 33–44. https://doi.org/10.1111/j.1749-6632.1998.tb09546.x

McGarrigle, L., & Todd, C. (2020). Promotion of Physical Activity in Older People Using mHealth and eHealth Technologies: Rapid Review of Reviews. *Journal of Medical Internet Research*, *22*(12), e22201. https://doi.org/10.2196/22201

Mollinedo Cardalda, I., López, A., & Cancela Carral, J. M. (2019). The effects of different types of physical exercise on physical and cognitive function in frail institutionalized older adults with mild to moderate cognitive impairment. A randomized controlled trial. *Archives of Gerontology and Geriatrics*, *83*, 223–230. https://doi.org/10.1016/j.archger.2019.05.003

Moore, G. F., Audrey, S., Barker, M., Bond, L., Bonell, C., Hardeman, W., Moore, L., O’Cathain, A., Tinati, T., Wight, D., & Baird, J. (2015). Process evaluation of complex interventions: Medical Research Council guidance. *BMJ (Clinical Research Ed.)*, *350*, h1258. https://doi.org/10.1136/bmj.h1258

Morelhao, P. K., Oliveira, C. B., & Franco, M. R. (2017). Interventions to increase physical activity among older adults (PEDro synthesis). *British Journal of Sports Medicine*, *51*(18), 1375–1376. https://doi.org/10.1136/bjsports-2016-096859

Muellmann, S., Forberger, S., Möllers, T., Bröring, E., Zeeb, H., & Pischke, C. R. (2018). Effectiveness of eHealth interventions for the promotion of physical activity in older adults: A systematic review. *Preventive Medicine*, *108*, 93–110. https://doi.org/10.1016/j.ypmed.2017.12.026

Nagata, C. de A., Garcia, P. A., Hamu, T. C. D. da S., Caetano, M. B. D., Costa, R. R., Leal, J. C., Bastos, J. A. I., Cadore, E. L., & Durigan, J. L. Q. (2023). Are dose-response relationships of resistance training reliable to improve functional performance in frail and pre-frail older adults? A systematic review with meta-analysis and meta-regression of randomized controlled trials. *Ageing Research Reviews*, *91*, 102079. https://doi.org/10.1016/j.arr.2023.102079

Nusselder, W. J., Looman, C. W. N., Franco, O. H., Peeters, A., Slingerland, A. S., & Mackenbach, J. P. (2008). The relation between non-occupational physical activity and years lived with and without disability. *Journal of Epidemiology and Community Health*, *62*(9), 823–828. https://doi.org/10.1136/jech.2007.067165

Ofosu, Esther Frema, de Nys, L., Connelly, J., Ryde, G. C., & Whittaker, A. C. (2023). Dimensions of Physical Activity Are Important in Managing Anxiety in Older Adults: A Systematic Review and Meta-Analysis. *Journal of Aging and Physical Activity*, 1–14. https://doi.org/10.1123/japa.2022-0098

Ofosu, E F, De Nys, L., Connelly, J., Ryde, G. C., & Whittaker, A. C. (2023). A realist evaluation of the feasibility of a randomised controlled trial of a digital music and movement intervention for older people living in care homes. *BMC Geriatrics*, *23*(1), 125. https://doi.org/10.1186/s12877-023-03794-5

Paterson, D. H., & Warburton, D. E. (2010). Physical activity and functional limitations in older adults: a systematic review related to Canada's Physical Activity Guidelines. *The International Journal of Behavioral Nutrition and Physical Activity*, *7*, 38. https://doi.org/10.1186/1479-5868-7-38

Pawson, R., & Manzano-Santaella, A. (2012). A realist diagnostic workshop. *Evaluation*, *18*(2), 176–191. https://doi.org/10.1177/1356389012440912

Peterson, M. J., Giuliani, C., Morey, M. C., Pieper, C. F., Evenson, K. R., Mercer, V., Cohen, H. J., Visser, M., Brach, J. S., Kritchevsky, S. B., Goodpaster, B. H., Rubin, S., Satterfield, S., Newman, A. B., Simonsick, E. M., & Health, Aging and Body Composition Study Research Group. (2009). Physical activity as a preventative factor for frailty: the health, aging, and body composition study. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *64*(1), 61–68. https://doi.org/10.1093/gerona/gln001

Petrovsky, D., Cacchione, P. Z., & George, M. (2015). Review of the effect of music interventions on symptoms of anxiety and depression in older adults with mild dementia. *International Psychogeriatrics*, *27*(10), 1661–1670. https://doi.org/10.1017/S1041610215000393

Phillips, A. C., Burns, V. E., & Lord, J. M. (2007). Stress and exercise: Getting the balance right for aging immunity. *Exercise and Sport Sciences Reviews*, *35*(1), 35–39. https://doi.org/10.1097/jes.0b013e31802d7008

Priest, D. L., Karageorghis, C. I., & Sharp, N. C. C. (2004). The characteristics and effects of motivational music in exercise settings: the possible influence of gender, age, frequency of attendance, and time of attendance. *The Journal of Sports Medicine and Physical Fitness*, *44*(1), 77–86.

Pruessner, J. C., Gaab, J., Hellhammer, D. H., Lintz, D., Schommer, N., & Kirschbaum, C. (1997). Increasing correlations between personality traits and cortisol stress responses obtained by data aggregation. *Psychoneuroendocrinology*, *22*(8), 615–625. https://doi.org/10.1016/s0306-4530(97)00072-3

Pruessner, J. C., Wolf, O. T., Hellhammer, D. H., Buske-Kirschbaum, A., von Auer, K., Jobst, S., Kaspers, F., & Kirschbaum, C. (1997). Free cortisol levels after awakening: a reliable biological marker for the assessment of adrenocortical activity. *Life Sciences*, *61*(26), 2539–2549. https://doi.org/10.1016/S0024-3205(97)01008-4

Reid, H., Ridout, A. J., Tomaz, S. A., Kelly, P., Jones, N., & Physical Activity Risk Consensus group. (2022). Benefits outweigh the risks: a consensus statement on the risks of physical activity for people living with long-term conditions. *British Journal of Sports Medicine*, *56*(8), 427–438. https://doi.org/10.1136/bjsports-2021-104281

Sansano-Nadal, O., Giné-Garriga, M., Brach, J. S., Wert, D. M., Jerez-Roig, J., Guerra-Balic, M., Oviedo, G., Fortuño, J., Gómara-Toldrà, N., Soto-Bagaria, L., Pérez, L. M., Inzitari, M., Solà, I., Martin-Borràs, C., & Roqué, M. (2019). Exercise-Based Interventions to Enhance Long-Term Sustainability of Physical Activity in Older Adults: A Systematic Review and Meta-Analysis of Randomized Clinical Trials. *International Journal of Environmental Research and Public Health*, *16*(14). https://doi.org/10.3390/ijerph16142527

Sapolsky, R. M., Romero, L. M., & Munck, A. U. (2000). How do glucocorticoids influence stress responses? Integrating permissive, suppressive, stimulatory, and preparative actions. *Endocrine Reviews, 21*(1), 55–89. https://doi.org/10.1210/edrv.21.1.0389

Sayegh, P., & Knight, B. G. (2013). Cross-cultural differences in dementia: the Sociocultural Health Belief Model. *International Psychogeriatrics*, *25*(4), 517–530. https://doi.org/10.1017/S104161021200213X

Schuch, F. B., Vancampfort, D., Richards, J., Rosenbaum, S., Ward, P. B., & Stubbs, B. (2016). Exercise as a treatment for depression: A meta-analysis adjusting for publication bias. *Journal of Psychiatric Research, 77*, 42–51. https://doi.org/10.1016/j.jpsychires.2016.02.023

Seeman, T. E., Singer, B. H., Rowe, J. W., Horwitz, R. I., & McEwen, B. S. (1997). Price of adaptation--allostatic load and its health consequences. MacArthur studies of successful aging. *Archives of Internal Medicine*, *157*(19), 2259–2268. https://doi.org/10.1001/archinte.157.19.2259

Segerstrom, S. C., Boggero, I. A., Smith, G. T., & Sephton, S. E. (2014). Variability and reliability of diurnal cortisol in younger and older adults: implications for design decisions. *Psychoneuroendocrinology*, *49*, 299–309. https://doi.org/10.1016/j.psyneuen.2014.07.022

Sellami, M., Bragazzi, N. L., Slimani, M., Hayes, L., Jabbour, G., De Giorgio, A., & Dugué, B. (2019). The Effect of Exercise on Glucoregulatory Hormones: A Countermeasure to Human Aging: Insights from a Comprehensive Review of the Literature. *International Journal of Environmental Research and Public Health*, *16*(10). https://doi.org/10.3390/ijerph16101709

Sherrington, C., Fairhall, N., Kwok, W., Wallbank, G., Tiedemann, A., Michaleff, Z. A., Ng, C. A. C. M., & Bauman, A. (2020). Evidence on physical activity and falls prevention for people aged 65+ years: systematic review to inform the WHO guidelines on physical activity and sedentary behaviour. *The International Journal of Behavioral Nutrition and Physical Activity*, *17*(1), 144. https://doi.org/10.1186/s12966-020-01041-3

Shirtcliff, E. A., Granger, D. A., Schwartz, E., & Curran, M. J. (2001). Use of salivary biomarkers in biobehavioral research: cotton-based sample collection methods can interfere with salivary immunoassay results. *Psychoneuroendocrinology*, *26*(2), 165–173. https://doi.org/10.1016/s0306-4530(00)00042-1

Silverman, H. G., & Mazzeo, R. S. (1996). Hormonal responses to maximal and submaximal exercise in trained and untrained men of various ages. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *51*(1), B30-7. https://doi.org/10.1093/gerona/51a.1.b30

Singh, B., Olds, T., Curtis, R., Dumuid, D., Virgara, R., Watson, A., Szeto, K., O'Connor, E., Ferguson, T., Eglitis, E., Miatke, A., Simpson, C. E., & Maher, C. (2023). Effectiveness of physical activity interventions for improving depression, anxiety and distress: an overview of systematic reviews. *British Journal of Sports Medicine*, *57*(18), 1203–1209. https://doi.org/10.1136/bjsports-2022-106195

Skivington, K., Matthews, L., Simpson, S. A., Craig, P., Baird, J., Blazeby, J. M., Boyd, K. A., Craig, N., French, D. P., McIntosh, E., Petticrew, M., Rycroft-Malone, J., White, M., & Moore, L. (2021). A new framework for developing and evaluating complex interventions: update of Medical Research Council guidance. *BMJ (Clinical Research Ed.)*, *374*, n2061. https://doi.org/10.1136/bmj.n2061

Solis-Navarro, L., Gismero, A., Fernández-Jané, C., Torres-Castro, R., Solá-Madurell, M., Bergé, C., Pérez, L. M., Ars, J., Martín-Borràs, C., Vilaró, J., & Sitjà-Rabert, M. (2022). Effectiveness of home-based exercise delivered by digital health in older adults: a systematic review and meta-analysis. *Age and Ageing*, *51*(11). https://doi.org/10.1093/ageing/afac243

Sooktho, S., Songserm, N., Woradet, S., & Suksatan, W. (2022). A Meta-analysis of Dance Programs on Physical Performance: An Appropriate Health Promotion for Healthy Older Adults. *Annals of Geriatric Medicine and Research*. https://doi.org/10.4235/agmr.22.0066

Sothmann, M. S., Buckworth, J., Claytor, R. P., Cox, R. H., White-Welkley, J. E., & Dishman, R. K. (1996). Exercise training and the cross-stressor adaptation hypothesis. *Exercise and Sport Sciences Reviews*, *24*, 267–287.

Sterling, P., & Eyer, J. (1988). Allostasis: A new paradigm to explain arousal pathology. *Undefined*. https://www.semanticscholar.org/paper/Allostasis%3A-A-new-paradigm-to-explain-arousal-Sterling-Eyer/26009c73354023e6c1c3b81fbd200706e9972c34

Stubbs, B., Vancampfort, D., Rosenbaum, S., Firth, J., Cosco, T., Veronese, N., Salum, G. A., & Schuch, F. B. (2017). An examination of the anxiolytic effects of exercise for people with anxiety and stress-related disorders: A meta-analysis. *Psychiatry Research*, *249*, 102–108. https://doi.org/10.1016/j.psychres.2016.12.020

Sully, B. G. O., Julious, S. A., & Nicholl, J. (2013). A reinvestigation of recruitment to randomised, controlled, multicenter trials: a review of trials funded by two UK funding agencies. *Trials*, *14*, 166. https://doi.org/10.1186/1745-6215-14-166

Swales, B., Ryde, G. C., & Whittaker, A. C. (2022). A randomized controlled feasibility trial evaluating a resistance training intervention with frail older adults in residential care: the keeping active in residential elderly trial. *Journal of Aging and Physical Activity*, *30*(3), 364–388. https://doi.org/10.1123/japa.2021-0130

Sylvia, L. G., Bernstein, E. E., Hubbard, J. L., Keating, L., & Anderson, E. J. (2014). Practical guide to measuring physical activity. *Journal of the Academy of Nutrition and Dietetics*, *114*(2), 199–208. https://doi.org/10.1016/j.jand.2013.09.018

Taylor, J. R., Milne, A. J., & Macritchie, J. (2023). New musical interfaces for older adults in residential care: assessing a user-centred design approach. *Disability and Rehabilitation. Assistive Technology*, *18*(5), 519–531. https://doi.org/10.1080/17483107.2021.1881172

Towers, A.-M., Rand, S., Collins, G., Smith, N., Palmer, S., & Cassell, J. (2023). Measuring quality of life in care homes when self-report is challenging: the construct validity, structural characteristics and internal consistency of the mixed-methods adult social care outcomes toolkit. *Age and Ageing*, *52*(9). https://doi.org/10.1093/ageing/afad168

Towers, A.-M., Smith, N., Allan, S., Vadean, F., Collins, G., Rand, S., Bostock, J., Ramsbottom, H., Forder, J., Lanza, S., & Cassell, J. (2021). *Care home residents' quality of life and its association with CQC ratings and workforce issues: the MiCareHQ mixed-methods study*. NIHR Journals Library. https://doi.org/10.3310/hsdr09190

Uchida, S., Shioda, K., Morita, Y., Kubota, C., Ganeko, M., & Takeda, N. (2012). Exercise effects on sleep physiology. *Frontiers in Neurology*, *3*, 48. https://doi.org/10.3389/fneur.2012.00048

VanBruggen, M. D., Hackney, A. C., McMurray, R. G., & Ondrak, K. S. (2011). The relationship between serum and salivary cortisol levels in response to different intensities of exercise. *International Journal of Sports Physiology and Performance*, *6*(3), 396–407. https://doi.org/10.1123/ijspp.6.3.396

Vankova, H., Holmerova, I., Machacova, K., Volicer, L., Veleta, P., & Celko, A. M. (2014). The effect of dance on depressive symptoms in nursing home residents. *Journal of the American Medical Directors Association*, *15*(8), 582–587. https://doi.org/10.1016/j.jamda.2014.04.013

Van de Water, A. T. M., Holmes, A., & Hurley, D. A. (2011). Objective measurements of sleep for non-laboratory settings as alternatives to polysomnography--a systematic review. *Journal of Sleep Research*, *20*(1 Pt 2), 183–200. https://doi.org/10.1111/j.1365-2869.2009.00814.x

Vaz, S., Hang, J.-A., Codde, J., Bruce, D., Spilsbury, K., & Hill, A.-M. (2022). Prescribing tailored home exercise program to older adults in the community using a tailored self-modeled video: A pre-post study. *Frontiers in Public Health*, *10*, 974512. https://doi.org/10.3389/fpubh.2022.974512

Warburton, D. E. R., & Bredin, S. S. D. (2017). Health benefits of physical activity: a systematic review of current systematic reviews. *Current Opinion in Cardiology*, *32*(5), 541–556. https://doi.org/10.1097/HCO.0000000000000437

Werry, A., Daniel, M., & Bergström, B. (2016). C-77Ethnic Group Differences in Normal Neuropsychological Test Performance for Older Adults. *Archives of Clinical Neuropsychology*, *31*(6), 669.1-669. https://doi.org/10.1093/arclin/acw043.226

Whetzel, C. A., & Klein, L. C. (2010). Measuring DHEA-S in saliva: time of day differences and positive correlations between two different types of collection methods. *BMC Research Notes*, *3*, 204. https://doi.org/10.1186/1756-0500-3-204

Youngstedt, S. D. (2005). Effects of exercise on sleep. *Clinics in Sports Medicine*, *24*(2), 355–365, xi. https://doi.org/10.1016/j.csm.2004.12.003

Zhang, X., van der Schans, C. P., Liu, Y., Krijnen, W. P., & Hobbelen, J. S. M. (2023). Efficacy of dance intervention for improving frailty among chinese older adults living in the community: A randomized controlled trial. *Journal of Aging and Physical Activity*, *31*(5), 806–814. https://doi.org/10.1123/japa.2021-0500

Zhao, Z.-Y., Lu, F.-H., Xie, Y., Fu, Y.-R., Bogdan, A., & Touitou, Y. (2003). Cortisol secretion in the elderly. Influence of age, sex and cardiovascular disease in a Chinese population. *Steroids*, *68*(6), 551–555. https://doi.org/10.1016/S0039-128X(03)00083-7

Zhu, K., McKnight, B., Stergachis, A., Daling, J. R., & Levine, R. S. (1999). Comparison of self-report data and medical records data: results from a case-control study on prostate cancer. *International Journal of Epidemiology*, *28*(3), 409–417. https://doi.org/10.1093/ije/28.3.409

Zouhal, H., Jayavel, A., Parasuraman, K., Hayes, L. D., Tourny, C., Rhibi, F., Laher, I., Abderrahman, A. B., & Hackney, A. C. (2022). Effects of Exercise Training on Anabolic and Catabolic Hormones with Advanced Age: A Systematic Review. *Sports Medicine (Auckland, N.Z.)*, *52*(6), 1353–1368. https://doi.org/10.1007/s40279-021-01612-9

Zubala, A., MacGillivray, S., Frost, H., Kroll, T., Skelton, D. A., Gavine, A., Gray, N. M., Toma, M., & Morris, J. (2017). Promotion of physical activity interventions for community dwelling older adults: A systematic review of reviews. *Plos One*, *12*(7), e0180902. https://doi.org/10.1371/journal.pone.0180902

Zumoff, B., Strain, G. W., Miller, L. K., & Rosner, W. (1995). Twenty-four-hour mean plasma testosterone concentration declines with age in normal premenopausal women. *The Journal of Clinical Endocrinology and Metabolism*, *80*(4), 1429–1430. https://doi.org/10.1210/jcem.80.4.7714119

Appendices

Appendix 1: Other Personal Contributions

Appendix 2.1: Methodology of systematic review 1 and 2

Appendix 2.2: PRISMA 2020 Checklist

Appendix 2.3: Detailed search strategy for database searches

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Appendix 2.5: Characteristics of excluded cross-sectional and intervention studies

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Appendix 2.8: TiDieR checklist

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Appendix 3.1: Electronic database search strategy

Appendix 3.2: Computations and transformations of data

Appendix 3.3: Funnel plot by Egger for the cortisol outcome and the sleep outcome

Appendix 3.4: Characteristics of excluded non- Controlled Trials

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Appendix 3.6: Meta-analysis with subgroups

Appendix 3.7: Chart of study characteristics of the excluded non-RCTs

Appendix 3.8: Certainty of evidence

Appendix 4.1: Methodology of intervention 1 and 2

Appendix 4.4: danceSing Care resources description

Appendix 4.5: Care home attendance sheet

Appendix 4.6: Interview/Focus group Guide

Appendix 4.7: Weekly notes from care homes on delivery challenges

Appendix 1: Other Personal Contributions

1.1 Scientific contributions

- Reviewer of Psychophysiology Journal, BMC Geriatrics, International Journal of Behavioral Nutrition and PA, Stress and Health, and STRESS, Journal of Sleep Research.
- Member of scientific cell and lecturer at Research Methodology at Flanders International School of Osteopathy (FICO)

1.2 Impact projects in clinical practice or the general public

- Semi-finalist of Converge Challenge 2022: Kickstart challenge about creating a Lifestyle Medicine clinic.
- Founder of an online Lifestyle Medicine education and consultancy platform (www.huisderlevensstijl.be)
- Healthy Ageing lectures at European organisations for professionals such as SmartEducation, Physioboost, PQK, ACREHAB, LifeMe, and FysioLearning.
- Board member of LifeMe vzw. (www.lifeme.be)
- Research dissemination:
    - Organiser of two symposia (Elk jaar jonger?, VUB & Onze hormonen, onderschatte helden?, KUL)
    - Host of a lifestyle medicine (LifeMe) podcast (https://anchor.fm/lifeme)

Appendix 2.1: Methodology of the systematic reviews

The present methodological section gives more details about the research's comprehensive approach. It explains and rationalises the methods implemented to address the research questions and the reliability and validity of the methodologies utilised in the two systematic reviews.

2.1.1 Research methodology of systematic reviews

Systematic reviews are a cornerstone of post-graduate research, providing a methodological approach to comprehensively and transparently appraise and synthesise existing literature (Ham-Baloyi & Jordan, 2016). This systematic approach is pertinent for enhancing scholarly understanding of the existing literature, paving the way for theoretical advancement, and informing practitioners and policymakers in this domain (Cook et al., 1997; Mallidou, 2014).

In adherence to best practices, the methodology was consistent with the PRISMA statement (Page et al., 2021), while the Cochrane Handbook was used as a primary resource for further guidance (Higgins et al., 2019).

2.1.2 Participant, Intervention, Comparison, Outcome (PICO) criteria

The following paragraphs will cover the Participant, intervention, comparison, and intervention (PICO) criteria (Schardt et al., 2007), an established method for formulating research questions in systematic reviews. Each component of the PICO framework, as adapted for this research, is detailed below:

- Participants (P) The SHAPE project focused on improving the well-being of older adults. Therefore, older adults (65 years or older) were included in the first review. However, after a first pilot search for the second review, adults aged 26-47, middle-aged adults aged 48-64, and older adults aged 65 were included due to a lack of PA trials focusing exclusively on older adults. The decision to exclude the 18-26 age group was informed by the distinct psychosocial and neurophysiological factors prevalent in this younger demographic, warranting a dedicated review.

- Intervention (I) The first review encompassed both observational and RCTs, aiming to uncover associations between PA and cortisol and/or DHEA(S) markers. The subsequent review highlighted the efficacy of PA interventions targeting cortisol and sleep. Therefore, only RCTs were incorporated.

- (C) Both systematic reviews included articles, regardless of study design, including controls having an inactive/sedentary lifestyle or receiving no intervention or usual care. This was *a priori* defined in the protocols and is considered best practice to reduce bias when evaluating the effects of interventions (Higgins et al., 2019).

- Outcomes (O) were selected appropriate to the research question. The rationale for the research question of both systematic reviews is extensively explained in Chapter One.

2.1.3 Critical appraisal tools: Cochrane Risk of Bias 2.0 and JBI tool

For the assessment of RCTs, the Cochrane Risk of Bias (RoB) 2.0 Tool was employed (Farrah et al., 2019), recognising its wide acceptance and recommendation (Higgins et al., 2011; Ma et al., 2020). However, evaluating non-randomised studies is more challenging due to the variety of available tools. The Newcastle-Ottawa Scale (NOS) and the Joanna Briggs Institute (JBI) tools are often used for the critical appraisal of these study designs when there are different designs included in the review (Farrah et al., 2019). However, some studies have questioned the reliability and validity of the NOS scale (Ma et al., 2020). Most studies agree that there is no real consensus on a preferred appraisal tool for non-randomised studies, so researchers are advised to use different appropriate tools based on the study designs identified by the researcher (Briere et al., 2018; Quigley et al., 2019). Because the applicable range of JBI is the widest (Ma et al., 2020), the JBI tool was chosen as the most appropriate RoB assessment for non-randomised studies.

To further define the quality of the body of evidence, we used the GRADE approach (Schünemann et al., 2013), as advised by the Cochrane Collaboration (Higgins et al., 2011). This involves considering the within-study risk of bias (methodological quality), directness of evidence, heterogeneity, the precision of effect estimates and the risk of publication bias. The GRADE approach further specifies four levels of quality (very low, low, moderate or high-quality evidence). The highest quality rating is for RCTs; observational studies are generally graded as low quality. Review authors can further downgrade (or upgrade) the quality based on the abovementioned considerations. The overall grading decisions are based on specified guidance (Schünemann et al., 2013). However, some subjectivity is present during the decision process. Therefore, two independent researchers consistently performed the grading process (LDN and EO). Further, an additional forest plot by Egger (Egger et al., 1997) was performed to consider publication bias.

2.1.4 Data collection and synthesis

The first review collected data from cross-sectional studies and RCTs to investigate how PA influences physiological markers of cortisol and/or DHEA(S) in older adults (De Nys et al., 2022). The justification for including observational studies in the systematic review was to provide evidence of the effects of PA in a broader context than under controlled intervention situations, e.g., long-term outcomes of PA or different populations or settings.

According to existing guidance, we analysed observational studies separately from intervention studies. Further, we quantified the average effect of PA interventions on reducing cortisol and/or increasing DHEA(S) levels (Systematic review One) and/or improving sleep outcomes in older adults. More in-depth outlining of the analyses and the results are provided in Chapters Two and Three.

2.1.5 Reflections on the two systematic reviews

It was aimed to articulate fully the limitations and considerations of the process of each systematic review conducted. Overall, common pitfalls were considered in the systematic review process, such as assessing study quality or publication bias, exploring heterogeneity and interpreting the evidence (for a brief overview, see (Farquhar & Vail, 2006)).

Further, a non-exhaustive list of valuable recourses used during the conducted research is the following:

- Guidance from the PRISMA statement (Page et al., 2021)
- Guidance from the Cochrane Handbook for systematic reviews of interventions (Higgins et al., 2019).
- Resources for authors from the Cochrane Consumers and Communication Group https://cccrg.cochrane.org/author-resources)
- Guidance from the Synthesis Without Meta-analysis (SWiM) reporting guideline (Campbell et al., 2020)
- Guidance of conducting systematic reviews and meta-analyses of observational studies of aetiology (COSMOS-E) (Dekkers et al., 2019).

2.1.6 Peer review suggestions

The two systematic reviews underwent a rigorous peer-review process and were finally accepted for publication in two journals (De Nys et al., 2022a; De Nys et al., 2022b). During the peer review process for JAPA (Journal of Aging and PA), a reviewer pointed out that physiological exercise responses are driven by genetic differences, epigenetic changes, and gene transcription mechanisms (Hawley et al., 2014). Consequently, it would be interesting to measure these factors alongside hormone levels in future exercise/PA interventions as they drive exercise effects on hormones via mechanisms such as changing receptor number or sensitivity (Hackney & Hackney, 2005). Further, during the peer-review process of the second review, a reviewer rightly suggested that the discrepancy in the female-to-male ratio should be highlighted more and that sex differences in cortisol regulation should be added to the Discussion section. It was discovered that more research is needed with standardised methodological protocols to strictly distinguish between the total cortisol secretion and the bioavailable cortisol levels and to differentiate between pre- and post-menopausal states and menstrual cycle phases to provide more definitive conclusions.

Appendix 2.2 PRISMA 2020 Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Title
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	JAPA abstract
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Background
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Background

Section and Topic	Item #	Checklist item	Location where item is reported
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Methods
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Methods
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Appendix
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Methods

Section and Topic	Item #	Checklist item	Location where item is reported
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Methods
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Methods
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Methods
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Methods

Section and Topic	Item #	Checklist item	Location where item is reported
Effect measures	12	Specify for each outcome the effect measure(s) (e.g., risk ratio, mean difference) used in synthesising or presenting results.	Methods
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Methods
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	Appendix
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	Methods
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	Methods

Section and Topic	Item #	Checklist item	Location where item is reported
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	Methods
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	Methods
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	Methods
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	Methods
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Results

Section and Topic	Item #	Checklist item	Location where item is reported
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Appendix
Study characteristics	17	Cite each included study and present its characteristics.	Results,
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Results
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Results
	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Results

Section and Topic	Item #	Checklist item	Location where item is reported
Results of syntheses	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	Results
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	Results, Appendix
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	Results
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	Results
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	Results
DISCUSSION			

Section and Topic	Item #	Checklist item	Location where item is reported
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Discussion
	23b	Discuss any limitations of the evidence included in the review.	Discussion
	23c	Discuss any limitations of the review processes used.	Discussion
	23d	Discuss implications of the results for practice, policy, and future research.	Conclusion
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	Methods
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	Methods
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	/

Section and Topic	Item #	Checklist item	Location where item is reported
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	/
Competing interests	26	Declare any competing interests of review authors.	Competing interests
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	/

Note. From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

For more information, visit: http://www.prisma-statement.org/

Appendix 2.3 Detailed search strategy for database searches

Pubmed search 2/9/21

("Aged"[Mesh] OR Aged OR "Aged, 80 and over"[Mesh] OR "Frail Elderly"[Mesh] OR 'older adults' OR elderly OR '65 years')

AND ("Exercise"[Mesh] OR exercise OR "Exercise Therapy"[Mesh] OR "Exercise Test"[Mesh] OR "Circuit-Based Exercise"[Mesh] OR "Physical Exertion"[Mesh] OR "Physical Fitness"[Mesh] OR "Sedentary Behavior"[Mesh] OR "Sedentary behaviour" OR 'sedentary behavior' OR "Healthy Lifestyle"[Mesh] OR "Life Style"[Mesh] OR "Health Behavior"[Mesh] OR "Healthy Aging"[Mesh] OR "Yoga"[Mesh] OR yoga OR "Tai Ji"[Mesh] OR 'Tai Chi' OR 'sedentary lifestyle' OR 'sedentary time' OR 'physical activity' OR Leisure time)

AND ("Dehydroepiandrosterone"[Mesh] OR "Dehydroepiandrosterone Sulfate"[Mesh] OR cortisol OR DHEA OR DHEAS)

NOT (drug OR pharmacological OR "Pharmaceutical Preparations"[Mesh] OR "Dietary Supplements"[Mesh])

1,601 results

Cochrane search 2/9/21

(Aged OR frail elderly OR elderly OR older adults OR 65 years) AND (Leisure time OR Exercise OR Physical fitness OR sedentary behavior OR physical activity OR sedentary time OR yoga OR tai ji OR tai chi) AND (Cortisol OR DHEA OR DHEAS OR dehydroepiandrosterone OR dehydroepiandrosterone sulfate) NOT (drug OR pharmacological)

172 results

Web of Science search 02/09/21

(TS=('Physical activity' OR 'physical exercise' OR exercise OR fitness OR 'healthy lifestyle' OR 'sedentary time' OR 'sedentary behavior' OR 'tai chi' OR 'taj ji' OR yoga)) AND (TS=(elderly OR 'older adults' OR '80 and over' OR '65 years' OR 'older population' OR 'aged population' OR 'ageing population' OR 'aging population')) AND (TS=(dehydroepiandrosterone OR 'dehydroepiadrostrone sulfate' OR DHEA OR DHEAS OR cortisol)) NOT (TS=(Pharmacological OR 'dietary supplements'))

721 results

OVID search 02/9/21
(((((Aged or Aged, 80) and over) or Frail Elderly or elderly or 65 years or older adults) and (exercise or Exercise Therapy or Physical Exertion or Physical Fitness or Sedentary Behavior or sedentary behaviour or Healthy Lifestyle or Life Style or Health Behavior or Healthy Aging or Yoga or Tai Chi or sedentary lifestyle or sedentary time or physical activity or Leisure time) and (Dehydroepiandrosterone or Dehydroepiandrosterone Sulfate or cortisol or DHEA or DHEAS)) not (drug or pharmacological or Pharmaceutical Preparations or Dietary Supplements)).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]

859 results

APA PsychInfo search 2/9/21

aged or elderly or senior or older people or geriatric or 65+ OR frail elderly or older adults

exercise or physical activity or fitness or physical exercise or leisure time or sedentary behavior or sedentary behaviour or sedentary time or yoga or tai chi or taj ji

Cortisol OR DHEA OR DHEAS OR dehydroepiandrosterone OR dehydroepiandrosterone sulfate

drugs or pharmaceuticals or medications or prescriptions

253 results

CINAHL search 2/9/21

older adults or elderly or geriatric or geriatrics or aging or senior or seniors or older people or aged 65 or 65+

exercise or physical activity or fitness or physical exercise or leisure time or sedentary behavior or sedentary behaviour or sedentary time or yoga or tai chi or taj ji

Cortisol OR DHEA OR DHEAS OR dehydroepiandrosterone OR dehydroepiandrosterone sulfate

drugs or pharmaceuticals or medications or prescriptions

197

PEDRO search 2/9/21

Combined searches Abstract & Title aged AND cortisol / "older adults" AND cortisol / elderly AND cortisol / aged AND DHEA / DHEAS / “older adults” AND dhea / dheas/ “older adults” AND dhea / DHEAS

41 results

Clinicaltrials.gov 2/9/21

Condition: aged OR elderly OR senior OR "older people" OR geriatric OR "frail elderly" OR "older adults"

Intervention: exercise OR "physical activity" OR fitness OR "physical exercise" OR "leisure time" OR "sedentary behavior" OR "sedentary behaviour" OR "sedentary time" OR yoga OR "tai chi" OR "taj ji"

Outcome: Cortisol OR DHEA OR DHEAS OR dehydroepiandrosterone OR "dehydroepiandrosterone sulfate"

28 results

Google search (Haddaway, Collins, Coughlin, & Kirk, 2015) 2/9/21

allintitle: ~elderly OR "older people" OR "older adults" OR ~aged OR ~exercise OR "physical activity" OR "~sedentary" OR ~fitness OR yoga OR "taj ji" OR "tai chi" OR cortisol OR DHEA OR DHEAS OR dehydroepiandrosterone OR "dehydroepiandrosterone sulfate"

all viewable results: 962 of 701,000

Appendix 2.4 Transformations of data

Extraction equations that can be used prior to analysis to get missed variables

Estimation of mean and SD

When the included study had reported the mean and SE, the mean and SD were estimated by following equations (Higgins, Li, & Deeks, n.d.):

$$SD = SE \times \sqrt{N}$$

Calculated from within a single intervention group.

Comparing cortisol measures

Baseline cortisol.

Cortisol value at baseline. Included studies took measurements at the same time of day pre- and post-intervention to reduce variability between measurement timing.

Mean cortisol.

Average cortisol values across all samples.
= Σ(baseline + x time after awakening + y time + z time)/n samples

AUCg

Area under the curve with respect to ground.
= {[(20 min value + baseline value)/2] x time} + {[(40 min value + 20 min value)/2] x time}

When cortisol were reported in AUCg, this measure (as mean +-SD) was taken to be compared with one-time point values of other studies to compare the mean +-SD pre-post effects. This because AUCg is assumed to be a measure which is related to total hormonal output (Fekedulegn et al., 2007).

Computing change from baseline

The mean change in each group can be obtained by subtracting the post-intervention mean from the baseline mean even if it has not been presented explicitly.

Related methods can be used to derive SDs from certain F statistics, since taking the square root of an F statistic may produce the same t statistic.

From t statistic to standard error

The t statistic is the ratio of the MD to the SE of the MD. The SE of the MD can therefore be obtained by dividing it by the t statistic:

$$\mathrm{SE} = \left|\frac{\mathrm{MD}}{t}\right|,$$

From standard error to standard deviation

The within-group SD can be obtained from the SE of the MD using the following formula:

$$\mathrm{SD} = \frac{\mathrm{SE}}{\sqrt{\frac{1}{N_E} + \frac{1}{N_C}}}.$$

Appendix 2.5 Characteristics of excluded cross-sectional studies

Study	Country	Population			PA measurement	Outcome		Relevant findings
		Sample size n (%male)	Age range or mean age (SD) in years	Main group – subgroups		Cortisol (times - measure)	DHEA(S) (times - measure)	
No distinct age categories for older adults aged 65+								
Gubelman et al., 2018	Switzerland	1948	45-86 years	Generally healthy – active vs sedentary	Counts: accelerometry	Saliva sample (4x – diurnal slop)		Low sedentary behaviour and high physical activity are related to lower cortisol secretion.
Not possible to extract the relationship between physical activity and cortisol directly								
Heaney et al., 2012	United Kingdom - Birmingham	48	75.6 (6.35)	Generally healthy – younger vs older	Time/week: categorical questionnaire about physical activity	Saliva sample (5x – diurnal slope)		Of health behaviours, diet had most interaction with cortisol.

Study	Country	Population			PA measurement	Outcome	Relevant findings
Physical activity is solely measured to determine frailty, no further analyses are with this							
Holanda et al., 2011	Brazil	69	77.5 (7.8)	Residents of long-stay institutions - Metabolic – frailty levels	Energy expenditure: International Physical Activity Questionnaire (IPAQ)	Saliva sample (3x – diurnal slop)	Frail aged individuals display higher cortisol values in the morning.
No data available for physical activity vs cortisol, as the focus was on food intake vs stress							
Laugero et al., 2011	Boston, Massachusetts	1336	45-75 years	Generally healthy Puerto Rican – perceived stress	Energy expenditure: Paffenbarger questionnaire of the Harvard Alumni Activity Survey	Urine sample (1x – afternoon)	Stress was positively correlated with cortisol and higher intake of sweets.
Physical activity was measured in relation to a questionnaire on life satisfaction, not in relation with cortisol or DHEA(S)							

Study	Country		Population		PA measurement	Outcome		Relevant findings
Lebrun et al., 2006	Utrecht, Netherlands	402	56-73 years	Postmenopausal – life satisfaction	Categorical questionnaire	Blood sample (1x – morning)	Blood sample (1x – morning)	No consistent relation between health behaviours and relevant hormones.
Contacted authors for specific information about the questionnaire, with no response								
Chehab et al., 2007	Tunisia	63	75.17 (7.66)	Generally healthy – Men vs women	Energy expenditure: non-specified standard questionnaire	Blood sample (1x – morning)	Blood sample (1x – morning)	Physical activity does not influence DHEA-S levels. Decreases in DHEA-S is associated with ageing and high cortisol:DHEA accelerates adult diseases.
Not the right age category								
Hawkins et al., 2019	United states	493	45-80 years	Generally healthy – activity quartiles	Counts: accelerometry	-	Blood sample (1x – morning)	Multiple aspects of physical activity were independently associated with sex hormones
DHEAS only compared together with other hormones, too difficult to draw conclusions								

Study	Country	Population			PA measurement		Outcome	Relevant findings
Hwang et al., 2016	Taiwan	1839	63.9 (9.3)	Generally healthy – age categories	Energy expenditure: IPAQ		Blood sample (1x – morning)	Low physical activity was modestly correlated with higher DHEA-S in women.
DHEA was considered as a mediator, no direct association was made between physical activity and DHEA								
McTiernan et al., 2006	United States	300	50-79	Postmenopausal – age groups	Time/week: categorical questionnaire "hours per week"	-	Blood sample (1x – morning)	No consistent relation between physical activity and DHEA.
Not possible to extract data specifically from the age category of interest								
Muller et al., 2003	Utrecht, Netherlands	400	40-80	Generally healthy,– age groups	Categorical: Voorrips questionnaire	-	Blood sample (1x – morning)	Besides ageing, important determinants of DHEA were BMI, general health behaviours and status, and physical activity.

Note. Studies were excluded because they did not meet the *a priori* defined PICO criteria, or the available data was not clear enough to make relevant assumptions about the research question.

Characteristics of excluded intervention studies

Study	Population				Intervention			Outcome		Relevant findings
	Sample size n (%male)	Mean age (SD) (years)	Setting	Health status	Type	Duration	Control group	Cortisol (times - measure)	DHEA(S) (times - measure)	
RCT, but not sufficient information to extract data										
Baker et al., 2010	33 (50%)	55-85 (M= 70)	Veteran clinical research unit	Cognitive impairment	aerobic exercise	24 weeks 4x per week (45-60mins/session)	stretching	Blood sample (1x time na)	-	plasma cortisol was reduced in women
Studies with experimental features, but non-RCTs										
Drogos et al., 2019	38 (40%)	65.0 (5.1)	Free living	Generally healthy	Aerobic exercise	24 weeks 3x per week (60min/session)	No control group	Saliva sample (7x CAR and	-	Aerobic exercise increased CAR

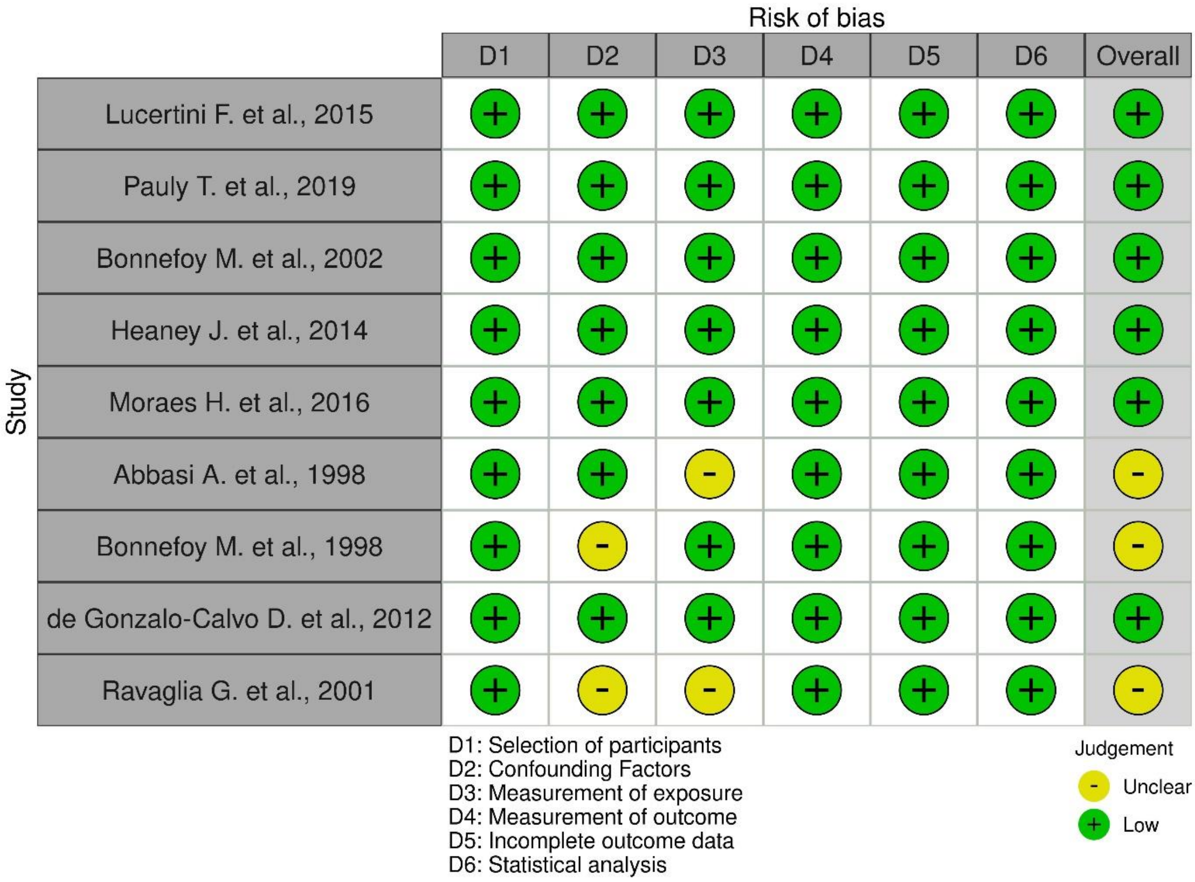
								diurnal slope)		
Fouladbakhsh et al., 2014	7 (33%)	67 (6.5)	Cancer support center	Cancer survivors	Yoga	14 week 1x per week (40min/session)	No control group	Saliva sample (after each session)		Yoga decreased cortisol
Galvao et al., 2006	10 (100%)	70.3 (8.3)	Free living	Cancer	Resistance	20 weeks 2x per week (60min/session)	No control group	Blood sample (1x morning)	-	Exercise did not change cortisol
Ibanez et al., 2007	20 (100%)	64.8 (2.6)	Free living	Metabolic-diabetic	Resistance	16 weeks 2x per week (45-60min/session)	Generally healthy controls receiving same intervention	Blood sample (1x time morning)	-	Strength training produced no systematic change in cortisol
Ponzio et al., 2015	28 (25%)	64.82 (1.45)	Free living	Generally healthy	Qi gong	12 weeks	No control group	Saliva sample (5x diurnal slope)	-	Qi gong reduced cortisol levels across the day

Sanches et al., 2020	12 (0%)	71 (2.9)	Free living	Metabolic – diabetic	Combined exercise	12 weeks (60min/session)	No control group	Saliva sample (1x morning)		Exercise reduced cortisol levels
Tortosa-Martinez et al., 2014	39 (41%)	75.64 (7.18)	Neurology unit from hospital	Cognitive impairment	Aerobic exercise	12weeks 3x per week (6Omin/session)	No exercise protocol (non-randomised)	Saliva sample (5x diurnal slope)	-	Exercise enhanced diurnal cortisol profile compared to the control group
Vale et al., 2009	35 (0%)	68 (5.1)	Free living	Generally healthy	Strength training / aquatic exercise	12weeks 3x per week (50min/session)	No exercise protocol (non-randomised)	Blood sample (1x morning)	-	Interventions did not alter cortisol levels
Alghadir & Gabr, 2020	80 (63%)	69 (5.3)	Free living	Mood disorder	Aerobic	12 weeks 3x per week (45-60min/session)	Generally healthy receiving same intervention	Blood sample (1x morning)	Blood sample (1x morning)	Exercise significantly decreased cortisol and cortisol/DHEA ratio, and

										increased DHEA compared to the healthy training group
Huang et al., 2006	16 (0%)	83.9 (0.85)	Institutionalised	Generally healthy	Aerobic/ resistance	12 weeks +5x per week (60min/session	High DHEA-S level compared to low DHEA-S level	-	Saliva sample (no information	Exercise training did not affect DHEA-S in either groups
Sato et al., 2014	13 (100%)	67.4 (1.82)	Free living	Generally healthy	Resistance	12 weeks 3x per week (short strength session)	Young adults receiving same intervention	-	Muscle sample (DHT) (1x morning	Strength training significantly improved DHEA levels in older adult group.

Note. Studies were excluded because they did not meet the *a priori* defined PICO criteria, or the available data was not clear enough to make relevant assumptions about the research question.

Appendix 2.6 Traffic light plot for risk of bias assessment: Observational studies



Traffic light plots for risk of bias assessment: Intervention studies

Appendix 2.7 Other sources of bias

Allocation (selection bias)

RCTs used random allocation, stratified sampling to randomise participants into either intervention or control groups. However, some concerns arose because of the randomisation in two studies. In one (Tada, 2018), a pragmatic approach was taken to the allocation of participants to the intervention and control groups because community centres were unwilling to be randomised so, participants were allocated to either group, based on their community centre. In the other (Hersey et al., 1994), researchers honoured the requests of three participants to enrol in a specific group to maximise adherence.

Blinding (performance bias and detection bias)

Saliva or blood sampling of cortisol and DHEA(S) is objective, so less affected by lack of blinding than subjective outcomes. All included studies standardised the sample timing and test environment as far as possible. Judgments about risk of bias arising from methods used by included studies is therefore rated low.

Incomplete outcome data (attrition bias)

In the cross-sectional analyses, incomplete data (e.g., the occurrence of unusable samples) was not clearly mentioned, and this would also be less likely to affect the main outcomes as it consists of a one-point in time measurement. However, missing samples implicate a decreased sample size, possibly increasing standard deviations, decreasing the power of the analysis. In RCTs, the overall adherence in studies was never lower than expected in studies that *a priori* incorporated attrition rates or performed power analyses. Studies mentioned dropout rates as 'none', as 'few' or less than five; or as a percentage ranging from 75 to 80% adherence. Some studies mentioned that, however, dropouts were present, or that fewer dropouts were seen in the intervention group, or stated that although they registered dropouts, it was not due to adverse effects of the intervention itself.

Appendix 2.8 TiDieR checklist

Study ID	N receiving intervention	Name of intervention	Rationale (why) essential to the intervention	Who provided the intervention or supervision	Mode of delivery (how)	Where did the intervention occur	Specificities about the intervention program	Strategies used to maintain or improve fidelity (if any) and drop outs
				Aerobic intervention program				
Ho et al., 2020	56 & 56	Dance movement therapy & physical exercise	Effect of training on psychophysiological outcomes	Registered dance-movement therapist or fitness instructor	Group	Training facility	- 60min 2x week12 weeks - Exercise group: mild to moderate exercise program, 15min warm up, 15min stretching and joint movements, 15 min tower exercises and 15min cool down	20% drop out - not willing to do follow-up assessments, hospitalisation or passing away

Study ID	N receiving intervention	Name of intervention	Rationale (why) essential to the intervention	Who provided the intervention or supervision	Mode of delivery (how)	Where did the intervention occur	Specificities about the intervention program	Strategies used to maintain or improve fidelity (if any) and drop outs
Prakhinkit et al., 2014	14 & 15	Buddhist walking meditation and traditional walking	Effects of interventions on depression, functional fitness, and vascular reactivity - mild-moderate depression	Researchers	Individual - supervised	University hospital setting	- 30min/day 3x week, 12 weeks - Walking + stretching (+ mindfulness component) - W1-6: Mild intensity (20-39% HRR), W7-12: Moderate (40-50% HRR),	Three drop outs

Study ID	N receiving intervention	Name of intervention	Rationale (why) essential to the intervention	Who provided the intervention or supervision	Mode of delivery (how)	Where did the intervention occur	Specificities about the intervention program	Strategies used to maintain or improve fidelity (if any) and drop outs
Rieping et al., 2019	19 & 15	Chair-based exercise programmes	Effectiveness of CBE on stress markers in institutionalised older women	Professional	Group	Institution training facility	- 45min 3x week 14weeks (35 total) - Chair aerobic & strength: 5min warming up - 35min moderate ex - 5min cooling down	Attendance of classes of 60-70%

Study ID	N receiving intervention	Name of intervention	Rationale (why) essential to the intervention	Who provided the intervention or supervision	Mode of delivery (how)	Where did the intervention occur	Specificities about the intervention program	Strategies used to maintain or improve fidelity (if any) and drop outs
Sin et al.,2015	44	Walking	Effect of a walking programme on walking behaviour, stress, depressive symptoms ad CVD biomarkers	NA	Individual	Home-based	- 12 weeks - Light – moderate walking	- Positive reinforcement (buddy system & drinking coupon) - Two drop outs due to health and one due to lack of commitment
Venturelli et al., 2016	20	Aerobic exercise	To reduce symptoms of Alzheimer's via downregulation of cortisol	Instructions from physiotherapist and research staff	Individual - supervised	Institution (care-unit)	- 60min/day 5x week 12 weeks - Walking in moderate intensity "fastest" walking speed	- Intervention was performed in collaboration with patients' caregivers - No drop out

Study ID	N receiving intervention	Name of intervention	Rationale (why) essential to the intervention	Who provided the intervention or supervision	Mode of delivery (how)	Where did the intervention occur	Specificities about the intervention program	Strategies used to maintain or improve fidelity (if any) and drop outs
Vrinceanu et al., 2019	12 & 14	Aerobic exercise (AE) and dance-movement therapy (DMT)	If training affects cortisol awakening response	Professional	Group	training facility	- 60min/day 3x week 12 weeks - Standards of American Dance Therapy Association; - A. 20min 60% of Maximal Aerobic Power (MAP) - B. interval training 60-100% MAP.	21 drop outs (AE= 6, DMT= 11, and waitlist= 4)

Study ID	N receiving intervention	Name of intervention	Rationale (why) essential to the intervention	Who provided the intervention or supervision	Mode of delivery (how)	Where did the intervention occur	Specificities about the intervention program	Strategies used to maintain or improve fidelity (if any) and drop outs
Yamada et al., 2015	71	Walking	Effects of intervention for sarcopenia prevention on muscle mass and anabolic hormones	NA	Individual	Home-based	- 24 weeks - Pedometer-based walking programme - Walk with an ankle weight - Increase daily steps by 10% each month	- Monthly activity logs and record step count at end of the day - monthly brief feedback by mail - 98;6% adherence rate - No fall incident or health problems
Resistance training intervention								

Study ID	N receiving intervention	Name of intervention	Rationale (why) essential to the intervention	Who provided the intervention or supervision	Mode of delivery (how)	Where did the intervention occur	Specificities about the intervention program	Strategies used to maintain or improve fidelity (if any) and drop outs
Borst et al., 2002	24 & 22	Low-intensity and high intensity resistance training (MedX resistance machines)	Effects of low- versus high-intensity training on hormones	NA	Individual - supervised	Training facility	- 3x week 24 weeks - Low intensity: 50% of 1 RM (13 repetitions) - High-intensity: 80% of 1 RM (8 repetitions) - Load increased by 5 when RPE dropped below 18	25% drop outs (not adhering to training protocol, inconvenience or personal reasons)

Study ID	N receiving intervention	Name of intervention	Rationale (why) essential to the intervention	Who provided the intervention or supervision	Mode of delivery (how)	Where did the intervention occur	Specificities about the intervention program	Strategies used to maintain or improve fidelity (if any) and drop outs
Hersey et al., 1994	16 & 17	Endurance and resistance training	Whether training alters DHEA levels in older adults	Researchers	Individual - supervised	Training facility	- 3x week 24 weeks - Walking at 50% HRR for 20-40min to 75-85% HRR for 35-45min - 10 resistance machines targeting the whole body, submaximal. to maximal intensity. (unable to complete full range of motion)	Five drop outs

Study ID	N receiving intervention	Name of intervention	Rationale (why) essential to the intervention	Who provided the intervention or supervision	Mode of delivery (how)	Where did the intervention occur	Specificities about the intervention program	Strategies used to maintain or improve fidelity (if any) and drop outs
Mura et al., 2014	21	Vigorous physical activity	Whether cortisol level changes were associated with QOL changes after an exercise program	Professional	Individual - supervised	Training facility	- 60 min 3x week 12 weeks (36 sessions) - Warm up 10min (60% HRR), active phase 45min (60-84%) and cool down 10min	Two drop outs

Study ID	N receiving intervention	Name of intervention	Rationale (why) essential to the intervention	Who provided the intervention or supervision	Mode of delivery (how)	Where did the intervention occur	Specificities about the intervention program	Strategies used to maintain or improve fidelity (if any) and drop outs
Son et al., 2020	10	Resistance band exercise training	Effect of training on ageing-related hormones	Researchers and trainers	Group	Training facility	- 60min 3x week 12 weeks - INT increase every 4 weeks (W1-4: 40-50% 13-14 RPE -> W9-12: 60-70% 15-16 RPE	5 drop outs due to non-compliance (exercise group= 2, control group= 3) no side effects
Tada, 2018	32	Resistance training (Thera-Band)	Effects of exercise to improve mental health	NA	Individual	Home-based	- 20min/day daily 24 weeks - 12-13 rated perceived exertion (RPE)	- Reminder letter after 3 months - Lower dropout rate in intervention group
Combined training intervention								

Study ID	N receiving intervention	Name of intervention	Rationale (why) essential to the intervention	Who provided the intervention or supervision	Mode of delivery (how)	Where did the intervention occur	Specificities about the intervention program	Strategies used to maintain or improve fidelity (if any) and drop outs
Kim et al., 2018	10	Combination of aerobic and resistance training	Effect of training on HRV and dynamic pulmonary function in obese older adults	Researchers	Individual - supervised	Training facility	- 90-120 min 3x week 12 weeks - Aerobic (AE) exercise on a treadmill, aerobic exercise on a bicycle, and elastic resistance (RES) training (30-40min). - AE: 60% of HRmax, RES: 60-70% of 1RM	No drop outs mentioned

Study ID	N receiving intervention	Name of intervention	Rationale (why) essential to the intervention	Who provided the intervention or supervision	Mode of delivery (how)	Where did the intervention occur	Specificities about the intervention program	Strategies used to maintain or improve fidelity (if any) and drop outs
Banitalebi et al., 2018	12 & 12 & 12	Resistance training before or after aerobic exercise	Effects of consecutive training AE/RES on hormonal status	Professional	Group	Training facility	- 50min 3x week 12 weeks - For endurance: 60% HRmax cycling, For resistance: 40% of 1RM ACSM guidelines for progression	20% drop out

Study ID	N receiving intervention	Name of intervention	Rationale (why) essential to the intervention	Who provided the intervention or supervision	Mode of delivery (how)	Where did the intervention occur	Specificities about the intervention program	Strategies used to maintain or improve fidelity (if any) and drop outs
Furtado et al., 2020	20 & 21	Chair elastic-band muscle strength ex and chair-multimodal exercise	Effect of exercise on steroid hormones and functional disabilities in frail older women	Professional	Group	Training facility	- 45 min 2-3x week 28 weeks (74 sessions) - Chair-multimodal exercise ACSM guidelines for progression - Multimodal: 50-75% HRmax (low-moderate), Elastic-band: 55-80%	- Contacted after 2 consecutive absences - No drop out due to injuries or adverse responses to intervention

Study ID	N receiving intervention	Name of intervention	Rationale (why) essential to the intervention	Who provided the intervention or supervision	Mode of delivery (how)	Where did the intervention occur	Specificities about the intervention program	Strategies used to maintain or improve fidelity (if any) and drop outs
Furtado et al., 2021	32	Combined chair-based exercise	Effects on cortisol and link with functional status and mental well-being	Professional	Group	Training facility	- 2-3x /week 14 weeks - 50- 75 HR max 7 min warm-up 15 min elastic band ex, 15 min of balance ex, 15min of gait speed training, 7min cool down	20% drop out equal in exercise and control group

Study ID	N receiving intervention	Name of intervention	Rationale (why) essential to the intervention	Who provided the intervention or supervision	Mode of delivery (how)	Where did the intervention occur	Specificities about the intervention program	Strategies used to maintain or improve fidelity (if any) and drop outs
Ha et al., 2018	10	Combination of aerobic and anaerobic (resistance) exercise	Effects of training on insulin resistance and ageing-related hormones	Researcher	Group	Training facility	- 60min/day 3x week 12 weeks - 20min of resistance band exercises + 30min walking ACSM guidelines for progression - 40-70% HRR (mild-moderate)	No drop out
Mind-body intervention								

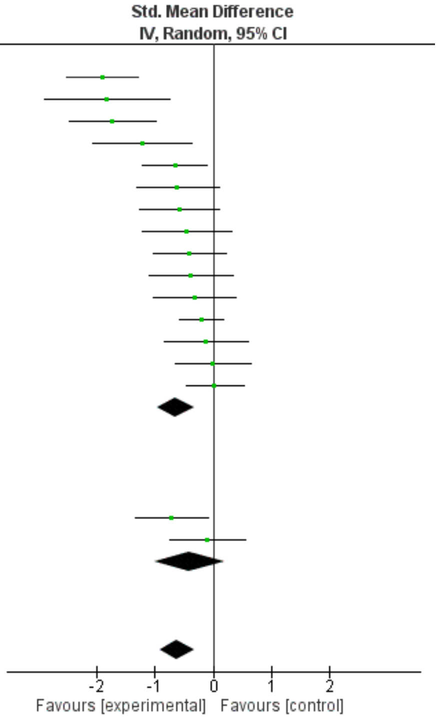
Study ID	N receiving intervention	Name of intervention	Rationale (why) essential to the intervention	Who provided the intervention or supervision	Mode of delivery (how)	Where did the intervention occur	Specificities about the intervention program	Strategies used to maintain or improve fidelity (if any) and drop outs
Campo et al., 2013	32	Tai Chi	Exercise to reduce chronic disease risk factors	Experienced instructor	Group	Training facility	- 60min/day 3x week 12 weeks - 20-25 movements, seated if needed	- Missed classes: contacted by phone call or mail - Lower dropout in intervention group
Furtado et al., 2016	20	Chair-yoga exercise	Effect of training on ADL, cortisol and alpha amylase	Professional	Group	Training facility	- 2-3x week 14 weeks (32 sessions) - Hatha yoga and its asanas - 50-75% max HR (low-moderate ACSM)	- Contacted after 2 consecutive absences - 65-75% adherence rate

Study ID	N receiving intervention	Name of intervention	Rationale (why) essential to the intervention	Who provided the intervention or supervision	Mode of delivery (how)	Where did the intervention occur	Specificities about the intervention program	Strategies used to maintain or improve fidelity (if any) and drop outs
Im et al., 2019	14	Yoga & Korean dance	Physical function & hormonal status for postmenopausal women	Professional	Group	Training facility	- 60min/day 3x week 12 weeks - Static or dynamic balance exercise, stretching, breathing, meditation - RPE 12-13	No drop outs
Lu et al., 2020	14	Qigong	Effects of training on serotonin, cortisol, BDNF levels and their effects of depressive symptoms	Qualified instructors	Group	Training facility	- 60min 2x week 12 weeks - Eight-Section Brocades	4 drop outs (exercise group= 1, control group 3)

Study ID	N receiving intervention	Name of intervention	Rationale (why) essential to the intervention	Who provided the intervention or supervision	Mode of delivery (how)	Where did the intervention occur	Specificities about the intervention program	Strategies used to maintain or improve fidelity (if any) and drop outs
Tsang et al., 2013	17	Qigong	Effects of training on psychological, physical and neurophysiological markers	Qualified instructors	Group	Training facility	- 45min 3x week 12 week (36 sessions) - 8 forms of movement (Eight-Section Brocades protocol) - Mindfulness and rhythmic breathing at the beginning and in-between successive cycles	No adverse effects

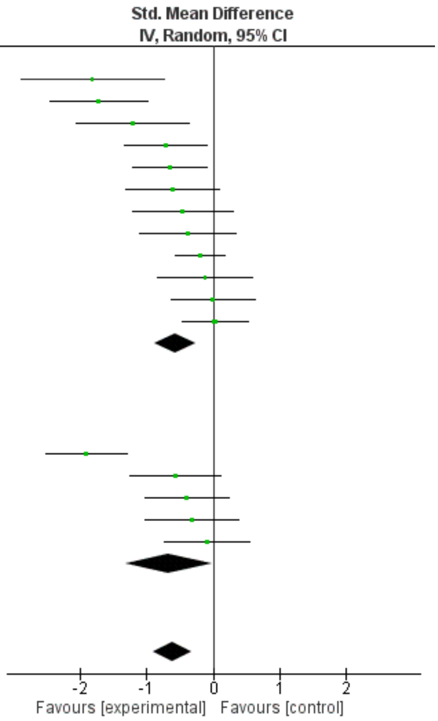
Appendix 2.9 Forest plot for cortisol, sub-grouped by intensity.

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.9.1 Low-moderate								
Tada 2018	0.14	0.01	32	0.17	0.02	29	6.2%	-1.90 [-2.51, -1.29]
Kim 2018	0.23	0.06	10	0.41	0.12	10	3.9%	-1.82 [-2.90, -0.74]
Venturelli 2016	7.6	1.7	20	12.1	3.2	20	5.5%	-1.72 [-2.46, -0.99]
Vrinceanu 2019	17	6.1	12	24.6	6.02	14	4.9%	-1.22 [-2.07, -0.36]
Campo 2015	24.65	8.18	29	29.95	7.8	25	6.6%	-0.65 [-1.20, -0.10]
Banitalebi 2018	23.6	4.47	24	25.94	1.33	12	5.7%	-0.61 [-1.32, 0.10]
Furtado 2016	0.62	0.16	20	0.73	0.22	15	5.8%	-0.57 [-1.26, 0.11]
Prakhinkit 2014	12.3	3.36	14	13.7	2.5	13	5.4%	-0.46 [-1.22, 0.31]
Furtado 2020	0.21	0.12	20	0.27	0.17	19	6.1%	-0.40 [-1.04, 0.23]
Tsang 2013	-2.61	9.07	14	0.89	9.07	16	5.6%	-0.38 [-1.10, 0.35]
Furtado 2021	0.26	0.09	17	0.31	0.2	15	5.7%	-0.32 [-1.02, 0.38]
Ho 2020	4.9	2.7	56	5.5	3.4	55	7.6%	-0.19 [-0.57, 0.18]
Lu 2020	107.24	19.63	14	109.65	19.58	16	5.6%	-0.12 [-0.84, 0.60]
Rieping 2019	0.3	0.23	34	0.3	0.14	13	6.1%	0.00 [-0.64, 0.64]
Sin 2015	3.94	2.91	44	3.86	2.99	24	6.9%	0.03 [-0.47, 0.52]
Subtotal (95% CI)			**360**			**296**	**87.8%**	**-0.65 [-0.96, -0.33]**
Heterogeneity: Tau² = 0.27; Chi² = 50.10, df = 14 (P < 0.00001); I² = 72%								
Test for overall effect: Z = 3.99 (P < 0.0001)								
1.9.2 Moderate-high								
Mura 2014	188.36	38.56	21	233.74	79.74	21	6.2%	-0.71 [-1.34, -0.09]
Borst 2002	120	46.9	22	125	60	16	6.1%	-0.09 [-0.74, 0.55]
Subtotal (95% CI)			**43**			**37**	**12.2%**	**-0.41 [-1.01, 0.20]**
Heterogeneity: Tau² = 0.09; Chi² = 1.82, df = 1 (P = 0.18); I² = 45%								
Test for overall effect: Z = 1.32 (P = 0.19)								
Total (95% CI)			**403**			**333**	**100.0%**	**-0.61 [-0.90, -0.33]**
Heterogeneity: Tau² = 0.24; Chi² = 52.23, df = 16 (P < 0.0001); I² = 69%								
Test for overall effect: Z = 4.23 (P < 0.0001)								
Test for subgroup differences: Chi² = 0.47, df = 1 (P = 0.49), I² = 0%								



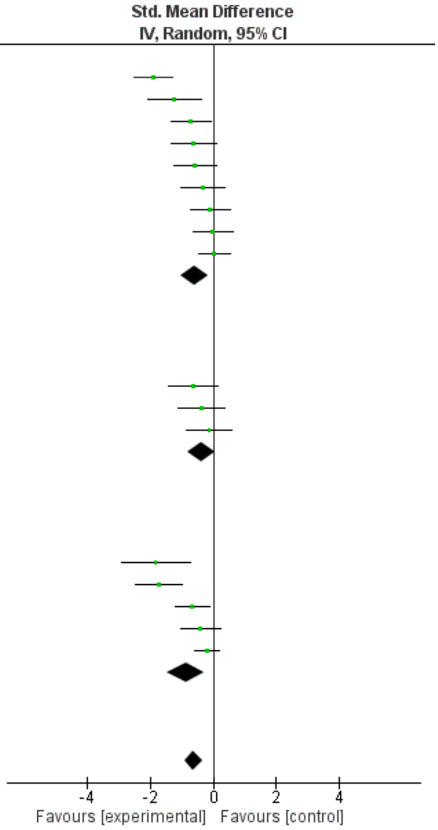
Forest plot for cortisol, sub-grouped by duration.

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.8.1 12 weeks								
Kim 2018	0.23	0.06	10	0.41	0.12	10	3.9%	-1.82 [-2.90, -0.74]
Venturelli 2016	7.6	1.7	20	12.1	3.2	20	5.5%	-1.72 [-2.46, -0.99]
Vrinceanu 2019	17	6.107	12	24.6	6.02	14	4.9%	-1.21 [-2.06, -0.36]
Mura 2014	188.36	38.56	21	233.74	79.74	21	6.2%	-0.71 [-1.34, -0.09]
Campo 2015	24.65	8.18	29	29.95	7.8	25	6.6%	-0.65 [-1.20, -0.10]
Banitalebi 2018	23.6	4.47	24	25.94	1.33	12	5.7%	-0.61 [-1.32, 0.10]
Prakhinkit 2014	12.3	3.36	14	13.7	2.5	13	5.4%	-0.46 [-1.22, 0.31]
Tsang 2013	-2.61	9.07	14	0.89	9.07	16	5.6%	-0.38 [-1.10, 0.35]
Ho 2020	4.9	2.7	56	5.5	3.4	55	7.6%	-0.19 [-0.57, 0.18]
Lu 2020	107.24	19.63	14	109.65	19.58	16	5.6%	-0.12 [-0.84, 0.60]
Rieping 2019	0.3	0.23	34	0.3	0.14	13	6.1%	0.00 [-0.64, 0.64]
Sin 2015	3.94	2.91	44	3.86	2.99	24	6.9%	0.03 [-0.47, 0.52]
Subtotal (95% CI)			**292**			**239**	**70.0%**	**-0.58 [-0.89, -0.27]**
Heterogeneity: Tau² = 0.18; Chi² = 30.17, df = 11 (P = 0.001); I² = 64%								
Test for overall effect: Z = 3.65 (P = 0.0003)								
1.8.2 +12 weeks								
Tada 2018	0.14	0.01	32	0.17	0.02	29	6.2%	-1.90 [-2.51, -1.29]
Furtado 2016	0.62	0.16	20	0.73	0.22	15	5.8%	-0.57 [-1.26, 0.11]
Furtado 2020	0.21	0.12	20	0.27	0.17	19	6.1%	-0.40 [-1.04, 0.23]
Furtado 2021	0.26	0.09	17	0.31	0.2	15	5.7%	-0.32 [-1.02, 0.38]
Borst 2002	120	46.9	22	125	60	16	6.1%	-0.09 [-0.74, 0.55]
Subtotal (95% CI)			**111**			**94**	**30.0%**	**-0.67 [-1.32, -0.01]**
Heterogeneity: Tau² = 0.45; Chi² = 20.36, df = 4 (P = 0.0004); I² = 80%								
Test for overall effect: Z = 1.98 (P = 0.05)								
Total (95% CI)			**403**			**333**	**100.0%**	**-0.61 [-0.90, -0.33]**
Heterogeneity: Tau² = 0.24; Chi² = 52.23, df = 16 (P < 0.0001); I² = 69%								
Test for overall effect: Z = 4.23 (P < 0.0001)								
Test for subgroup differences: Chi² = 0.06, df = 1 (P = 0.81), I² = 0%								



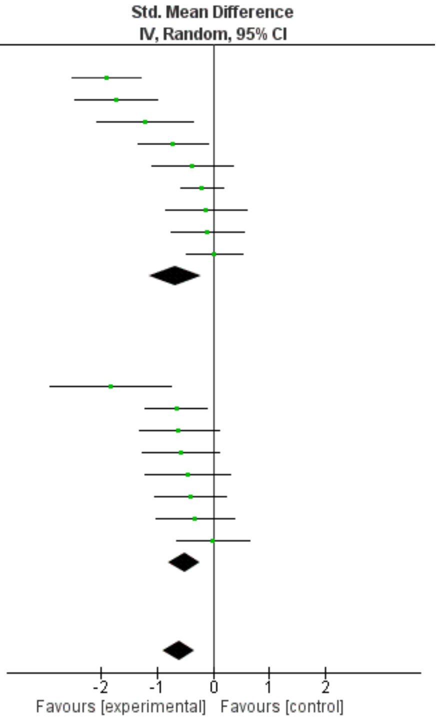
Forest plot for cortisol, sub-grouped by health status.

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.5.1 Generally healthy								
Tada 2018	0.14	0.01	32	0.17	0.02	29	6.3%	-1.90 [-2.51, -1.29]
Vrinceanu 2019	16.97	6.11	12	24.6	6.02	14	4.9%	-1.22 [-2.07, -0.37]
Mura 2014	188.36	38.56	21	233.74	79.74	21	6.2%	-0.71 [-1.34, -0.09]
Banitalebi 2018	23.6	4.47	24	25.94	1.33	12	5.7%	-0.61 [-1.32, 0.10]
Furtado 2016	0.62	0.16	20	0.73	0.22	15	5.8%	-0.57 [-1.26, 0.11]
Furtado 2021	0.26	0.09	17	0.31	0.2	15	5.7%	-0.32 [-1.02, 0.38]
Borst 2002	120	46.9	22	125	60	16	6.1%	-0.09 [-0.74, 0.55]
Rieping 2019	0.3	0.23	34	0.3	0.14	13	6.1%	0.00 [-0.64, 0.64]
Sin 2015	3.94	2.91	44	3.86	2.99	24	6.9%	0.03 [-0.47, 0.52]
Subtotal (95% CI)			**226**			**159**	**53.7%**	**-0.59 [-1.02, -0.15]**
Heterogeneity: Tau² = 0.32; Chi² = 31.78, df = 8 (P = 0.0001); I² = 75%								
Test for overall effect: Z = 2.66 (P = 0.008)								
1.5.2 Mood disorders								
Prakhinkit 2014	11.9	3	14	13.7	2.52	13	5.3%	-0.63 [-1.40, 0.15]
Tsang 2013	-2.61	9.07	14	0.89	9.07	16	5.6%	-0.38 [-1.10, 0.35]
Lu 2020	107.24	19.63	14	109.65	19.58	16	5.6%	-0.12 [-0.84, 0.60]
Subtotal (95% CI)			**42**			**45**	**16.5%**	**-0.36 [-0.79, 0.06]**
Heterogeneity: Tau² = 0.00; Chi² = 0.89, df = 2 (P = 0.64); I² = 0%								
Test for overall effect: Z = 1.66 (P = 0.10)								
1.5.4 Other								
Kim 2018	0.23	0.06	10	0.41	0.12	10	3.9%	-1.82 [-2.90, -0.74]
Venturelli 2016	7.6	1.7	20	12.1	3.2	20	5.5%	-1.72 [-2.46, -0.99]
Campo 2015	24.65	8.18	29	29.95	7.8	25	6.6%	-0.65 [-1.20, -0.10]
Furtado 2020	0.21	0.12	20	0.27	0.17	19	6.1%	-0.40 [-1.04, 0.23]
Ho 2020	4.9	2.7	56	5.5	3.4	55	7.6%	-0.19 [-0.57, 0.18]
Subtotal (95% CI)			**135**			**129**	**29.8%**	**-0.86 [-1.46, -0.26]**
Heterogeneity: Tau² = 0.35; Chi² = 18.76, df = 4 (P = 0.0009); I² = 79%								
Test for overall effect: Z = 2.82 (P = 0.005)								
Total (95% CI)			**403**			**333**	**100.0%**	**-0.62 [-0.91, -0.34]**
Heterogeneity: Tau² = 0.24; Chi² = 52.27, df = 16 (P < 0.00001); I² = 69%								
Test for overall effect: Z = 4.30 (P < 0.0001)								
Test for subgroup differences: Chi² = 1.81, df = 2 (P = 0.40), I² = 0%								



Forest plot for cortisol, sub-grouped by sex

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.7.1 Both								
Tada 2018	0.14	0.01	32	0.17	0.02	29	6.2%	-1.90 [-2.51, -1.29]
Venturelli 2016	7.6	1.7	20	12.1	3.2	20	5.5%	-1.72 [-2.46, -0.99]
Vrinceanu 2019	17	6.11	12	24.6	6.02	14	4.9%	-1.21 [-2.06, -0.36]
Mura 2014	188.36	38.56	21	233.74	79.74	21	6.2%	-0.71 [-1.34, -0.09]
Tsang 2013	-2.61	9.07	14	0.89	9.07	16	5.6%	-0.38 [-1.10, 0.35]
Ho 2020	4.9	2.7	56	5.5	3.4	55	7.6%	-0.19 [-0.57, 0.18]
Lu 2020	107.24	19.63	14	109.65	19.58	16	5.6%	-0.12 [-0.84, 0.60]
Borst 2002	120	46.9	22	125	60	16	6.1%	-0.09 [-0.74, 0.55]
Sin 2015	3.94	2.91	44	3.86	2.99	24	6.9%	0.03 [-0.47, 0.52]
Subtotal (95% CI)			**235**			**211**	**54.7%**	**-0.68 [-1.15, -0.20]**
Heterogeneity: Tau² = 0.42; Chi² = 43.29, df = 8 (P < 0.00001); I² = 82%								
Test for overall effect: Z = 2.81 (P = 0.005)								
1.7.2 Female								
Kim 2018	0.23	0.06	10	0.41	0.12	10	3.9%	-1.82 [-2.90, -0.74]
Campo 2015	24.65	8.18	29	29.95	7.8	25	6.6%	-0.65 [-1.20, -0.10]
Banitalebi 2018	23.6	4.47	24	25.94	1.33	12	5.7%	-0.61 [-1.32, 0.10]
Furtado 2016	0.62	0.16	20	0.73	0.22	15	5.8%	-0.57 [-1.26, 0.11]
Prakhinkit 2014	12.3	3.36	14	13.7	2.5	13	5.4%	-0.46 [-1.22, 0.31]
Furtado 2020	0.21	0.12	20	0.27	0.17	19	6.1%	-0.40 [-1.04, 0.23]
Furtado 2021	0.26	0.09	17	0.31	0.2	15	5.7%	-0.32 [-1.02, 0.38]
Rieping 2019	0.3	0.23	34	0.3	0.14	13	6.1%	0.00 [-0.64, 0.64]
Subtotal (95% CI)			**168**			**122**	**45.3%**	**-0.52 [-0.79, -0.24]**
Heterogeneity: Tau² = 0.03; Chi² = 8.86, df = 7 (P = 0.26); I² = 21%								
Test for overall effect: Z = 3.66 (P = 0.0003)								
Total (95% CI)			**403**			**333**	**100.0%**	**-0.61 [-0.90, -0.33]**
Heterogeneity: Tau² = 0.24; Chi² = 52.23, df = 16 (P < 0.0001); I² = 69%								
Test for overall effect: Z = 4.23 (P < 0.0001)								
Test for subgroup differences: Chi² = 0.34, df = 1 (P = 0.56), I² = 0%								



References Appendix 2

Fekedulegn, D. B., Andrew, M. E., Burchfiel, C. M., Violanti, J. M., Hartley, T. A., Charles, L. E., & Miller, D. B. (2007). Area under the curve and other summary indicators of repeated waking cortisol measurements. *Psychosomatic Medicine*, *69*(7), 651–659. doi:10.1097/PSY.0b013e31814c405c

Haddaway, N. R., Collins, A. M., Coughlin, D., & Kirk, S. (2015). The role of google scholar in evidence reviews and its applicability to grey literature searching. *Plos One*, *10*(9), e0138237. doi:10.1371/journal.pone.0138237

Hersey, W. C., Graves, J. E., Pollock, M. L., Gingerich, R., Shireman, R. B., Heath, G. W., … Hagberg, J. M. (1994). Endurance exercise training improves body composition and plasma insulin responses in 70- to 79-year-old men and women. *Metabolism: Clinical and Experimental*, *43*(7), 847–854. doi:10.1016/0026-0495(94)90265-8

Higgins, J. P. T., Li, T., & Deeks, J. J. (n.d.). Chapter 6: Choosing effect measures and computing estimates of effect . Retrieved June 28, 2021, from https://training.cochrane.org/handbook/current/chapter-06

Tada, A. (2018). Psychological effects of exercise on community-dwelling older adults. *Clinical Interventions in Aging*, *13*, 271–276. doi:10.2147/CIA.S152939

Appendix 3.1 Electronic database search strategy

Pubmed 08/10

("Adult" OR "Adult"[Mesh] OR "Aged"[Mesh] OR "Middle Aged"[Mesh] OR "Aged, 80 and over"[Mesh] OR "Frail Elderly"[Mesh] OR 'older adults' OR elderly) AND ("Exercise"[Mesh] OR exercise OR "Exercise Therapy"[Mesh] OR "Exercise Test"[Mesh] OR "Circuit-Based Exercise"[Mesh] OR "Physical Exertion"[Mesh] OR "Physical Fitness"[Mesh] OR "Sedentary Behavior"[Mesh] OR "Sedentary behaviour" OR 'sedentary behavior' OR "Healthy Lifestyle"[Mesh] OR "Life Style"[Mesh] OR "Health Behavior"[Mesh] OR "Healthy Aging"[Mesh] OR "Yoga"[Mesh] OR yoga OR "Tai Ji"[Mesh] OR 'Tai Chi' OR 'sedentary lifestyle' OR 'sedentary time' OR 'physical activity' OR Leisure time OR 'Mind-body' OR 'mind body') AND (cortisol OR distress OR HPA axis OR 'HPA axis') AND ("Sleep"[Mesh] OR sleep[Text Word] OR "Sleep, REM"[Mesh] OR "Sleep Stages"[Mesh] OR "Sleep Hygiene"[Mesh] OR sleep quality[Text Word] OR sleep duration[Text Word] OR polysomnography[Text Word] OR electroencephalogram[Text Word] OR actigraphy[Text Word] OR sleep observation[Text Word] OR subjective sleep[Text Word] OR sleep hygiene[Text Word] OR circadian[Text Word])

1,102 results

Cochrane 17/05

703 results

PsychINFO 17/05

Adults or middle aged adults or elderly or senior or older people or older adults

exercise or physical activity or fitness or physical exercise or leisure time or sedentary behavior or sedentary behaviour or sedentary time or yoga or tai chi or taj ji or mind body

cortisol or hpa axis or hypothalamic pituitary adrenal axis sleep or sleep quality or sleep hygiene or sleep duration or sleep deprivation or sleep disturbance or sleep quality or sleep quality or polysomnography or actigraphy or sleep quality or subjective sleep or objective sleep

75

OVID

((adults or middle aged adults or elderly or senior or older people or 65+ or older adults) and (exercise or fitness or Exercise Therapy or Physical Exertion or Physical Fitness or Sedentary Behavior or sedentary behaviour or Yoga or Tai Chi or mind body) and (stress or cortisol or hpa axis or hypothalamic pituitary adrenal axis) and (sleep or sleep quality or sleep hygiene or sleep duration or sleep deprivation or sleep disturbance or sleep quality or sleep quality or polysomnography or actigraphy or sleep quality or subjective sleep or objective sleep)).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]

277

CINAHL

Adults or middle aged adults or elderly or senior or older people or older adults

exercise or physical activity or fitness or physical exercise or leisure time or sedentary behavior or sedentary behaviour or sedentary time or yoga or tai chi or taj ji or mind body

cortisol or hpa axis or hypothalamic pituitary adrenal axis

sleep or sleep quality or sleep hygiene or sleep duration or sleep deprivation or sleep disturbance or sleep quality or sleep quality or polysomnography or actigraphy or sleep quality or subjective sleep or objective sleep

52

Web of Science

TS=('adults' OR 'middle aged adults' OR elderly OR 'older adults' OR '80 and over' OR '65 years' OR 'older population' OR 'aged population') AND TS=('Physical activity' OR 'physical exercise' OR exercise OR fitness OR 'tai chi' OR 'taj ji' OR yoga OR 'mind-body' OR 'mind body') AND TS=(cortisol OR 'hpa axis' OR 'hypothalamic pituitary adrenal axis') AND TS=(sleep OR 'sleep quality' OR 'sleep hygiene' OR 'sleep duration' OR 'sleep quality' OR 'sleep quality' OR polysomnography OR actigraphy OR 'sleep quality' OR 'subjective sleep' OR 'objective sleep')

125

Clinical trials.gov

Interventional Studies | aged OR middle aged adults OR elderly OR senior OR "older people" OR geriatric OR "frail elderly" OR "older adults" | exercise OR "physical activity" OR fitness OR "physical exercise" OR yoga OR "tai chi" OR "taj ji" | cortisol OR hpa axis OR hypothalamic pituitary adrenal axis OR stress OR distress OR sleep OR sleep quality OR sleep hygiene OR sleep duration OR sleep deprivation OR sleep quality OR polysomnography OR actigraphy

253 studies

Google scholar

allintitle: "adults" OR "older adults" OR ~aged OR ~exercise OR "physical activity" OR ~fitness OR yoga OR "taj ji" OR "tai chi" OR cortisol OR stress OR "HPA axis" OR "perceived stress" OR sleep OR "Sleep hygiene" OR "sleep measurement"

all viewable results: 993

Appendix 3.2 Transformations and computations

Computing the SD for Payne, 2008.

Cortisol outcome: As there was a mention of mean values for both groups in the normal range of cortisol (6-23 mcg/dl) (Payne, 2008) p640, the SD was computed as follows:

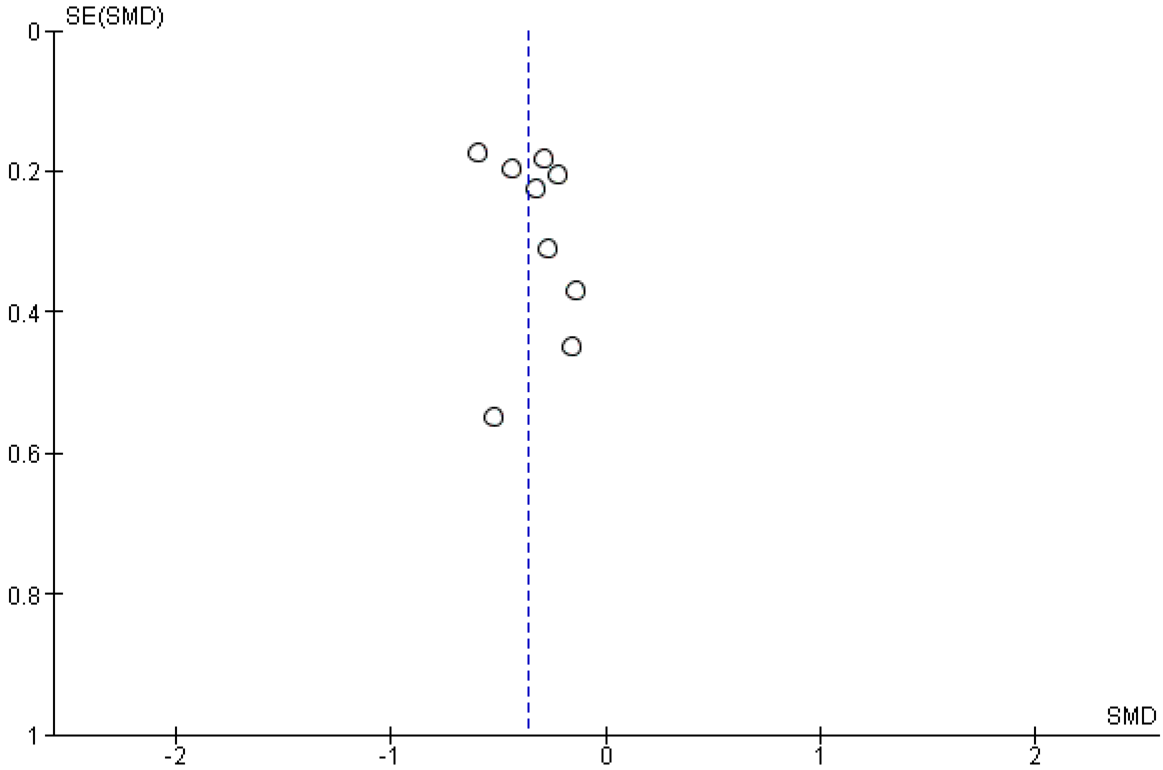
Each outcome (8 mcg/dl for the experimental group and 9 mcg/dl for the control group) was subtracted from the normal mean = 14.5 (mean of 6 and 23) and squared. Then, the mean was taken of those squared differences. Finally, the square root was taken to find the SD of this sample.

Sleep outcome: As the Pittsburg Sleep Quality Index in used in seven out of nine studies included in the meta-analysis, we can take the mean and SD of those studies (of experimental and control groups combined) to compute the SD of Payne, 2008.

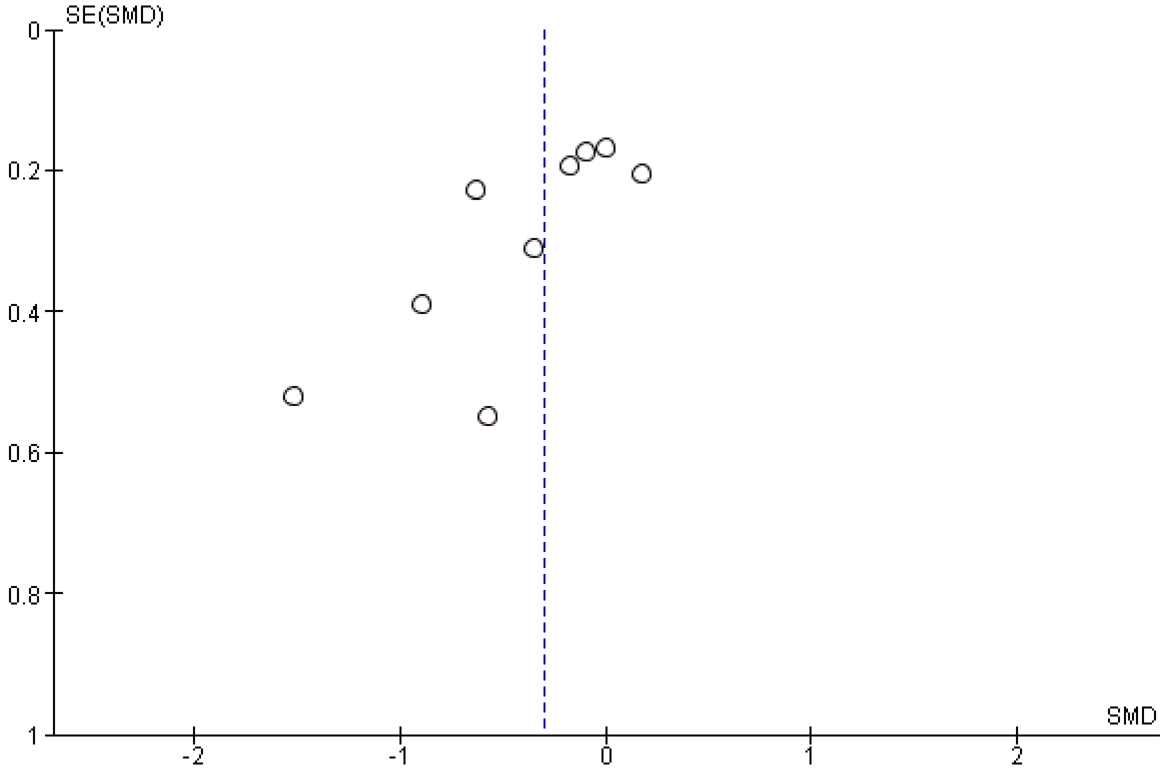
Computing the mean and SD for the sleep outcome (PSQI) in Arikawa, 2013.

“Although both groups reported a significant decrease in PSQI score, there were no differences between groups in sleep hours, bedtimes, or PSQI scores at the end of the study.” p1635. Therefore, the mean of all included studies with a PSQI was reported as mean, with the same calculation for the SD as done for Payne (2008)

Appendix 3.3.1 Funnel plot by Egger for the cortisol outcome



Appendix 3.3.2 Funnel plot by Egger for the sleep outcome



Appendix 3.4,Characteristics of excluded studies with reasons for exclusion

Study	Country	Population			Intervention	Outcome		Relevant findings	Reason for exclusion
		Sample size n (%male)	Age group[a]	Health status	Type – duration	Cortisol (times - measure)	Sleep measurement		
Vera et al., 2009	Spain	26 (36%)	Middle-aged adults	Generally healthy	n.a.	Blood sample (1x – morning)	PSQI	Long-term yoga group = better sleep quality* and modulatory action on cortisol levels*	Not an intervention design
Reid et al;, 2010	US, Chicago	17 (.6%)	Middle-aged adults	Insomnia	Aerobic – 16 weeks	n.a.	PSQI	Training programme = PSQI improved*	No measure of cortisol as a biomarker for stress
Fouladbakhsh et al., 2014	Mid-western United States	9 (33%)	Older adults	Lung cancer survivors	Mind-body – 8 weeks	Saliva sample (1x)	PSQI	Training programme = PSQI improved*, cortisol decreased,	Lack of control group

Study	Country	Population			Intervention	Outcome		Relevant findings	Reason for exclusion
		Sample size n (%male)	Age group[a]	Health status	Type – duration	Cortisol (times - measure)	Sleep measurement		
Passos et al., 2014	Brazil	21 (24%)	Middle-aged adults	Chronic primary insomnia	Aerobic – 12 weeks	Blood sample (1x – morning)	PSQI, polysomnography	Exercise training = reduction in cortisol correlated were with increases in total sleep time* and REM sleep*	Lack of control group
Leone et al., 2015	Canada	7 (n.a.)	Adults and middle-aged adults	Mood disorders	Combined exercise – 8 weeks	Blood sample (1x – morning)	SSQ	Training programme = decrease in cortisol levels and improved sleep	Lack of control group
de Bruin et al., 2017	Netherlands	22 (15%)	Adults	Stress complaints	Mindfulness training	n.a.	PSQI	Training programme = improved sleep*	No measure of cortisol as a biomarker for stress

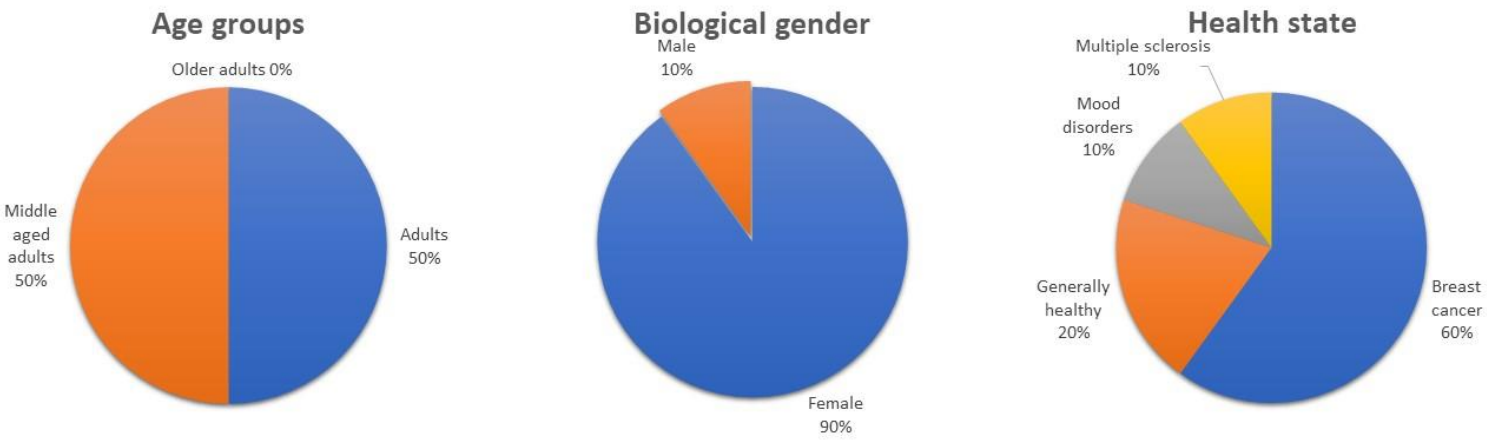
Study	Country	Population			Intervention	Outcome		Relevant findings	Reason for exclusion
		Sample size n (%male)	Age group[a]	Health status	Type – duration	Cortisol (times - measure)	Sleep measurement		
Garrido et al., 2017	Portugal	18 (0%)	Middle-aged adults	Fibromyalgia	Respiratory functional training – 8 weeks	Urine sample (1x – morning)	PSQI, activimetry	Training programme = improved sleep*	Lack of control group
Grahn Kronhed,et al., 2020	Sweden	15 (0%)	Older adults	Osteoporotic vertebral fracture	mindfulness and modified medical yoga	n.a.	Likert scale	Training programme may be feasible to improve stress and sleep	No measure of cortisol as a biomarker for stress
Zaccari et al., 2020	Portland, Oregon	17 (60%)	Middle-aged and older adults	PTSD	Mind-body – 10 weeks	Saliva sample (3x – diurnal slope)	PSQI	Yoga group = improved sleep*	Lack of control group

Note. .[a] Age groups: Adults: 26-47 years, Middle-aged adults: 48-64 years, Older adults 65 year or older

PSQI: Pittsburgh Sleep Quality Index, SSQ: Spiegel Sleep Questionnaire

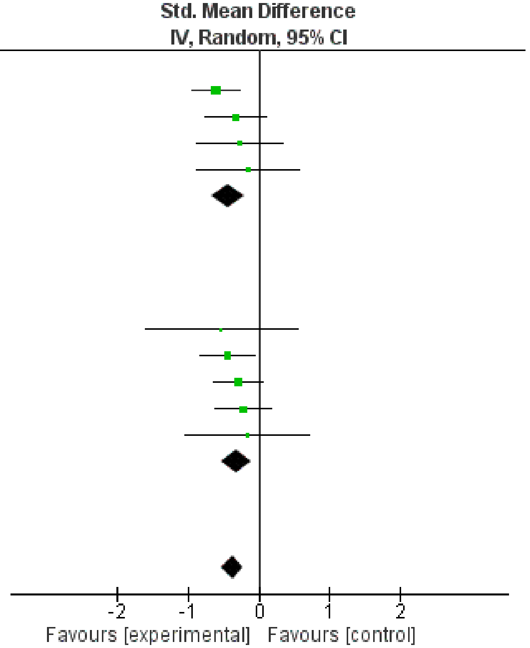
* Marks significance in study

Appendix 3.5 Discrepancy in participants' characteristics across studies



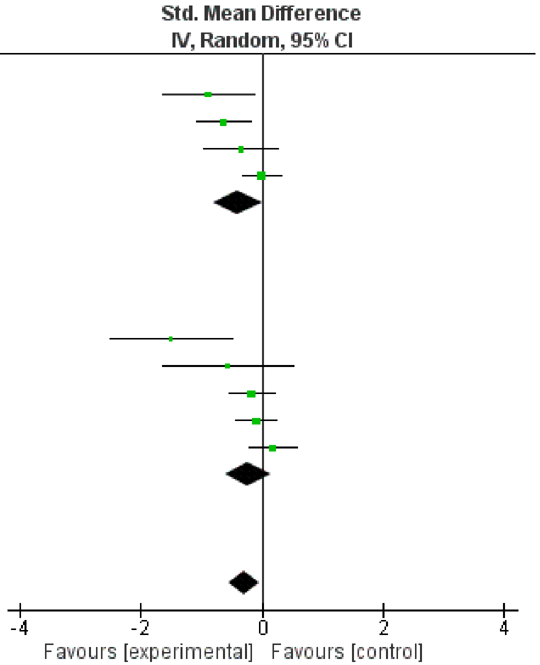
Appendix 3.6.1 Meta-analysis of the cortisol outcome, by age groups.

	Experimental			Control				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
1.6.1 Adults only (26-47)								
Arikawa 2013a	56	5	77	59	5	64	21.0%	-0.60 [-0.94, -0.26]
Hilcove 2020	-0.01	1.31	41	0.49	1.69	39	12.4%	-0.33 [-0.77, 0.11]
Imboden 2021	264.4	195.2	22	314.2	168.9	20	6.5%	-0.27 [-0.88, 0.34]
Al-Sharman 2019	10.4	4.5	17	11.01	3.58	13	4.6%	-0.14 [-0.87, 0.58]
Subtotal (95% CI)			**157**			**136**	**44.6%**	**-0.43 [-0.66, -0.19]**
Heterogeneity: Tau² = 0.00; Chi² = 2.01, df = 3 (P = 0.57); I² = 0%								
Test for overall effect: Z = 3.59 (P = 0.0003)								
1.6.2 Adults and middle-aged adults (48-64)								
Banasik 2010	2.33	0.09	7	2.45	0.29	7	2.1%	-0.52 [-1.60, 0.55]
Ratcliff 2016	-0.104	0.04	53	-0.084	0.05	54	16.4%	-0.44 [-0.82, -0.05]
Ho 2018	-6.9	2	63	-6.33	1.89	58	18.8%	-0.29 [-0.65, 0.07]
Chen 2013	-0.12	0.04	49	-0.11	0.05	47	15.0%	-0.22 [-0.62, 0.18]
Payne 2008	8	6.02	10	9	6.02	10	3.1%	-0.16 [-1.04, 0.72]
Subtotal (95% CI)			**182**			**176**	**55.4%**	**-0.32 [-0.53, -0.11]**
Heterogeneity: Tau² = 0.00; Chi² = 0.90, df = 4 (P = 0.93); I² = 0%								
Test for overall effect: Z = 2.97 (P = 0.003)								
Total (95% CI)			**339**			**312**	**100.0%**	**-0.37 [-0.52, -0.21]**
Heterogeneity: Tau² = 0.00; Chi² = 3.38, df = 8 (P = 0.91); I² = 0%								
Test for overall effect: Z = 4.61 (P < 0.00001)								
Test for subgroup differences: Chi² = 0.48, df = 1 (P = 0.49), I² = 0%								



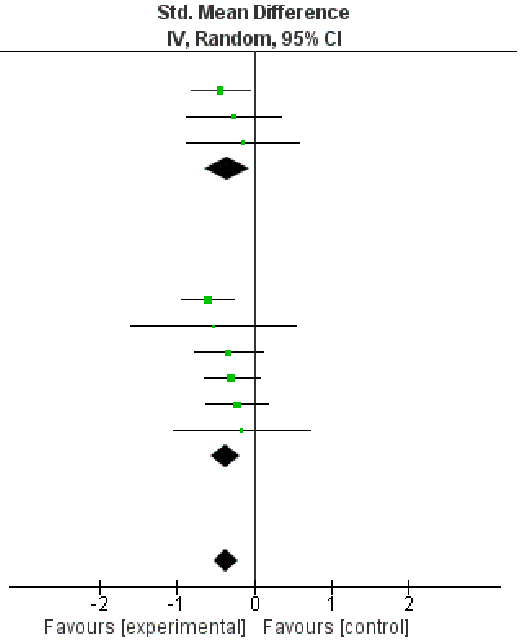
Appendix 3.6.2 Meta-analysis of the sleep outcome, by age groups.

	Experimental			Control				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
2.6.1 Adults only (26-47)								
Al-Sharman 2019	4.6	2.3	17	7.1	3.2	13	7.5%	-0.89 [-1.66, -0.13]
Hilcove 2020	0.85	0.59	41	1.24	0.64	39	13.0%	-0.63 [-1.08, -0.18]
Imboden 2021	7.2	2.9	22	8.5	4.4	20	9.7%	-0.35 [-0.96, 0.26]
Arikawa 2013a	7.93	3.62	77	7.93	3.62	64	15.9%	0.00 [-0.33, 0.33]
Subtotal (95% CI)			**157**			**136**	**46.1%**	**-0.40 [-0.81, 0.00]**
Heterogeneity: Tau² = 0.10; Chi² = 7.54, df = 3 (P = 0.06); I² = 60%								
Test for overall effect: Z = 1.96 (P = 0.05)								
2.6.2 Adults and middle-aged adults (48-64)								
Payne 2008	-3.5	3.62	10	2.2	3.62	10	4.9%	-1.51 [-2.53, -0.49]
Banasik 2010	1	0.89	7	1.57	0.98	7	4.5%	-0.57 [-1.65, 0.51]
Ratcliff 2016	6.7	3.1	53	7.3	3.7	54	14.7%	-0.17 [-0.55, 0.21]
Ho 2016	7.1	3.9	66	7.5	4.2	64	15.6%	-0.10 [-0.44, 0.25]
Chen 2013	12	4.1	49	11.3	3.7	47	14.2%	0.18 [-0.22, 0.58]
Subtotal (95% CI)			**185**			**182**	**53.9%**	**-0.23 [-0.59, 0.14]**
Heterogeneity: Tau² = 0.09; Chi² = 10.00, df = 4 (P = 0.04); I² = 60%								
Test for overall effect: Z = 1.20 (P = 0.23)								
Total (95% CI)			**342**			**318**	**100.0%**	**-0.30 [-0.56, -0.04]**
Heterogeneity: Tau² = 0.08; Chi² = 18.82, df = 8 (P = 0.02); I² = 57%								
Test for overall effect: Z = 2.27 (P = 0.02)								
Test for subgroup differences: Chi² = 0.40, df = 1 (P = 0.53), I² = 0%								



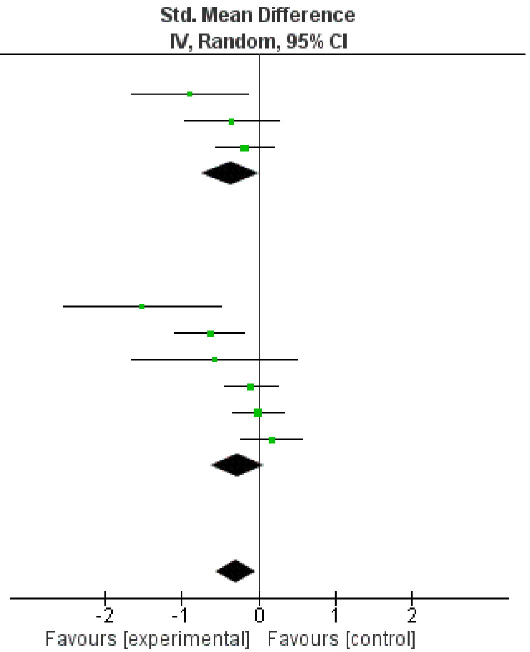
Appendix 3.6.3 Meta-analysis of the cortisol outcome, by comparison groups.

	Experimental			Control				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
1.4.1 Active control group								
Ratcliff 2016	-0.104	0.04	53	-0.084	0.05	54	16.4%	-0.44 [-0.82, -0.05]
Imboden 2021	264.4	195.2	22	314.2	168.9	20	6.5%	-0.27 [-0.88, 0.34]
Al-Sharman 2019	10.4	4.5	17	11.01	3.58	13	4.6%	-0.14 [-0.87, 0.58]
Subtotal (95% CI)			**92**			**87**	**27.6%**	**-0.35 [-0.64, -0.05]**
Heterogeneity: Tau² = 0.00; Chi² = 0.59, df = 2 (P = 0.75); I² = 0%								
Test for overall effect: Z = 2.30 (P = 0.02)								
1.4.2 Usual care or waiting list								
Arikawa 2013a	56	5	77	59	5	64	21.0%	-0.60 [-0.94, -0.26]
Banasik 2010	2.33	0.09	7	2.45	0.29	7	2.1%	-0.52 [-1.60, 0.55]
Hilcove 2020	-0.01	1.31	41	0.49	1.69	39	12.4%	-0.33 [-0.77, 0.11]
Ho 2018	-6.9	2	63	-6.33	1.89	58	18.8%	-0.29 [-0.65, 0.07]
Chen 2013	-0.12	0.04	49	-0.11	0.05	47	15.0%	-0.22 [-0.62, 0.18]
Payne 2008	8	6.02	10	9	6.02	10	3.1%	-0.16 [-1.04, 0.72]
Subtotal (95% CI)			**247**			**225**	**72.4%**	**-0.37 [-0.55, -0.19]**
Heterogeneity: Tau² = 0.00; Chi² = 2.78, df = 5 (P = 0.73); I² = 0%								
Test for overall effect: Z = 4.00 (P < 0.0001)								
Total (95% CI)			**339**			**312**	**100.0%**	**-0.37 [-0.52, -0.21]**
Heterogeneity: Tau² = 0.00; Chi² = 3.38, df = 8 (P = 0.91); I² = 0%								
Test for overall effect: Z = 4.61 (P < 0.00001)								
Test for subgroup differences: Chi² = 0.02, df = 1 (P = 0.89), I² = 0%								



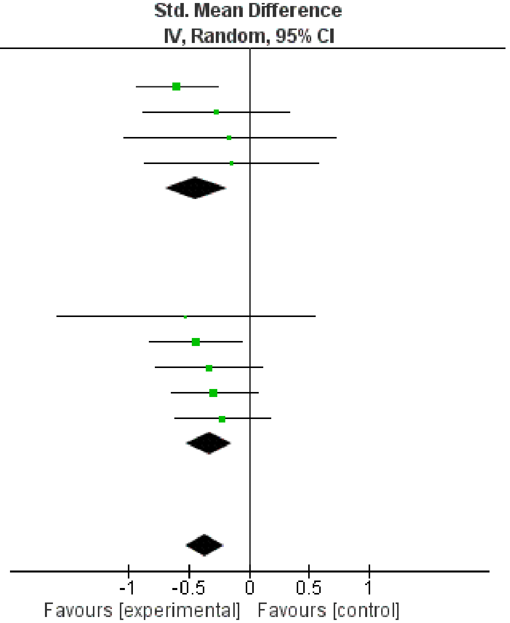
Appendix 3.6.4 Meta-analysis of the sleep outcome, by comparison groups.

	Experimental			Control				Std. Mean Difference
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Random, 95% CI**
2.4.1 Active control group								
Al-Sharman 2019	4.6	2.3	17	7.1	3.2	13	7.5%	-0.89 [-1.66, -0.13]
Imboden 2021	7.2	2.9	22	8.5	4.4	20	9.7%	-0.35 [-0.96, 0.26]
Ratcliff 2016	6.7	3.1	53	7.3	3.7	54	14.7%	-0.17 [-0.55, 0.21]
Subtotal (95% CI)			**92**			**87**	**31.9%**	**-0.36 [-0.74, 0.01]**
Heterogeneity: Tau² = 0.03; Chi² = 2.75, df = 2 (P = 0.25); I² = 27%								
Test for overall effect: Z = 1.92 (P = 0.05)								
2.4.2 Usual care or waiting list								
Payne 2008	-3.5	3.62	10	2.2	3.62	10	4.9%	-1.51 [-2.53, -0.49]
Hilcove 2020	0.85	0.59	41	1.24	0.64	39	13.0%	-0.63 [-1.08, -0.18]
Banasik 2010	1	0.89	7	1.57	0.98	7	4.5%	-0.57 [-1.65, 0.51]
Ho 2016	7.1	3.9	66	7.5	4.2	64	15.6%	-0.10 [-0.44, 0.25]
Arikawa 2013a	7.93	3.62	77	7.93	3.62	64	15.9%	0.00 [-0.33, 0.33]
Chen 2013	12	4.1	49	11.3	3.7	47	14.2%	0.18 [-0.22, 0.58]
Subtotal (95% CI)			**250**			**231**	**68.1%**	**-0.27 [-0.62, 0.08]**
Heterogeneity: Tau² = 0.11; Chi² = 15.17, df = 5 (P = 0.010); I² = 67%								
Test for overall effect: Z = 1.54 (P = 0.12)								
Total (95% CI)			**342**			**318**	**100.0%**	**-0.30 [-0.56, -0.04]**
Heterogeneity: Tau² = 0.08; Chi² = 18.82, df = 8 (P = 0.02); I² = 57%								
Test for overall effect: Z = 2.27 (P = 0.02)								
Test for subgroup differences: Chi² = 0.12, df = 1 (P = 0.73), I² = 0%								



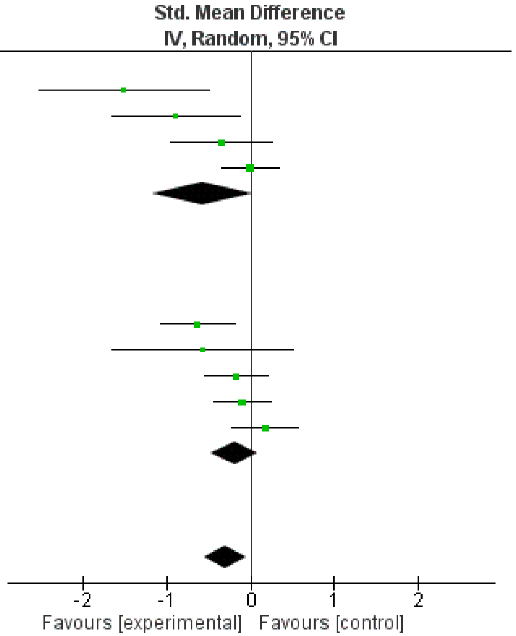
Appendix 3.6.5 Meta-analysis of the cortisol outcome, by intervention type.

	Experimental			Control				Std. Mean Difference
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Random, 95% CI**
1.7.1 Aerobic								
Arikawa 2013a	56	5	77	59	5	64	21.0%	-0.60 [-0.94, -0.26]
Imboden 2021	264.4	195.2	22	314.2	168.9	20	6.5%	-0.27 [-0.88, 0.34]
Payne 2008	8	6.02	10	9	6.02	10	3.1%	-0.16 [-1.04, 0.72]
Al-Sharman 2019	10.4	4.5	17	11.01	3.58	13	4.6%	-0.14 [-0.87, 0.58]
Subtotal (95% CI)			**126**			**107**	**35.3%**	**-0.44 [-0.70, -0.18]**
Heterogeneity: Tau² = 0.00; Chi² = 2.17, df = 3 (P = 0.54); I² = 0%								
Test for overall effect: Z = 3.28 (P = 0.001)								
1.7.2 Mind-body								
Banasik 2010	2.33	0.09	7	2.45	0.29	7	2.1%	-0.52 [-1.60, 0.55]
Ratcliff 2016	-0.104	0.04	53	-0.084	0.05	54	16.4%	-0.44 [-0.82, -0.05]
Hilcove 2020	-0.01	1.31	41	0.49	1.69	39	12.4%	-0.33 [-0.77, 0.11]
Ho 2018	-6.9	2	63	-6.33	1.89	58	18.8%	-0.29 [-0.65, 0.07]
Chen 2013	-0.12	0.04	49	-0.11	0.05	47	15.0%	-0.22 [-0.62, 0.18]
Subtotal (95% CI)			**213**			**205**	**64.7%**	**-0.33 [-0.52, -0.13]**
Heterogeneity: Tau² = 0.00; Chi² = 0.77, df = 4 (P = 0.94); I² = 0%								
Test for overall effect: Z = 3.31 (P = 0.0009)								
Total (95% CI)			**339**			**312**	**100.0%**	**-0.37 [-0.52, -0.21]**
Heterogeneity: Tau² = 0.00; Chi² = 3.38, df = 8 (P = 0.91); I² = 0%								
Test for overall effect: Z = 4.61 (P < 0.00001)								
Test for subgroup differences: Chi² = 0.45, df = 1 (P = 0.50), I² = 0%								



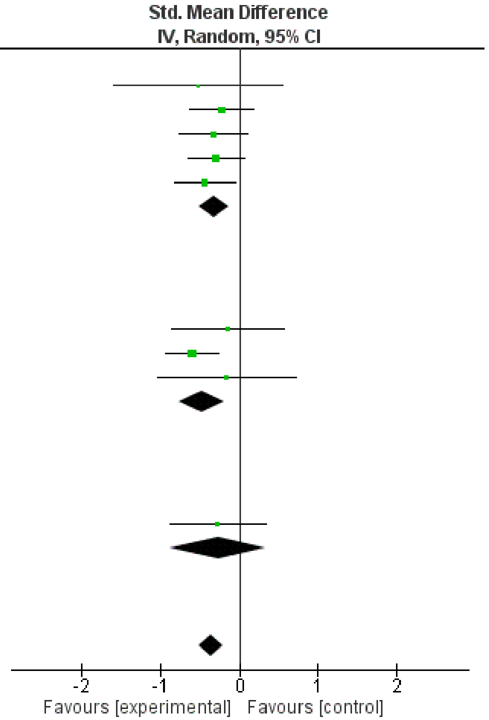
Appendix 3.6.6 Meta-analysis of the sleep outcome, by intervention type.

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
2.7.1 Aerobic								
Payne 2008	-3.5	3.62	10	2.2	3.62	10	4.9%	-1.51 [-2.53, -0.49]
Al-Sharman 2019	4.6	2.3	17	7.1	3.2	13	7.5%	-0.89 [-1.66, -0.13]
Imboden 2021	7.2	2.9	22	8.5	4.4	20	9.7%	-0.35 [-0.96, 0.26]
Arikawa 2013a	7.93	3.62	77	7.93	3.62	64	15.9%	0.00 [-0.33, 0.33]
Subtotal (95% CI)			**126**			**107**	**38.0%**	**-0.56 [-1.16, 0.03]**
Heterogeneity: Tau² = 0.26; Chi² = 10.84, df = 3 (P = 0.01); I² = 72%								
Test for overall effect: Z = 1.85 (P = 0.06)								
2.7.2 Mind-body								
Hilcove 2020	0.85	0.59	41	1.24	0.64	39	13.0%	-0.63 [-1.08, -0.18]
Banasik 2010	1	0.89	7	1.57	0.98	7	4.5%	-0.57 [-1.65, 0.51]
Ratcliff 2016	6.7	3.1	53	7.3	3.7	54	14.7%	-0.17 [-0.55, 0.21]
Ho 2016	7.1	3.9	66	7.5	4.2	64	15.6%	-0.10 [-0.44, 0.25]
Chen 2013	12	4.1	49	11.3	3.7	47	14.2%	0.18 [-0.22, 0.58]
Subtotal (95% CI)			**216**			**211**	**62.0%**	**-0.19 [-0.47, 0.09]**
Heterogeneity: Tau² = 0.04; Chi² = 7.57, df = 4 (P = 0.11); I² = 47%								
Test for overall effect: Z = 1.34 (P = 0.18)								
Total (95% CI)			**342**			**318**	**100.0%**	**-0.30 [-0.56, -0.04]**
Heterogeneity: Tau² = 0.08; Chi² = 18.82, df = 8 (P = 0.02); I² = 57%								
Test for overall effect: Z = 2.27 (P = 0.02)								
Test for subgroup differences: Chi² = 1.24, df = 1 (P = 0.27), I² = 19.4%								

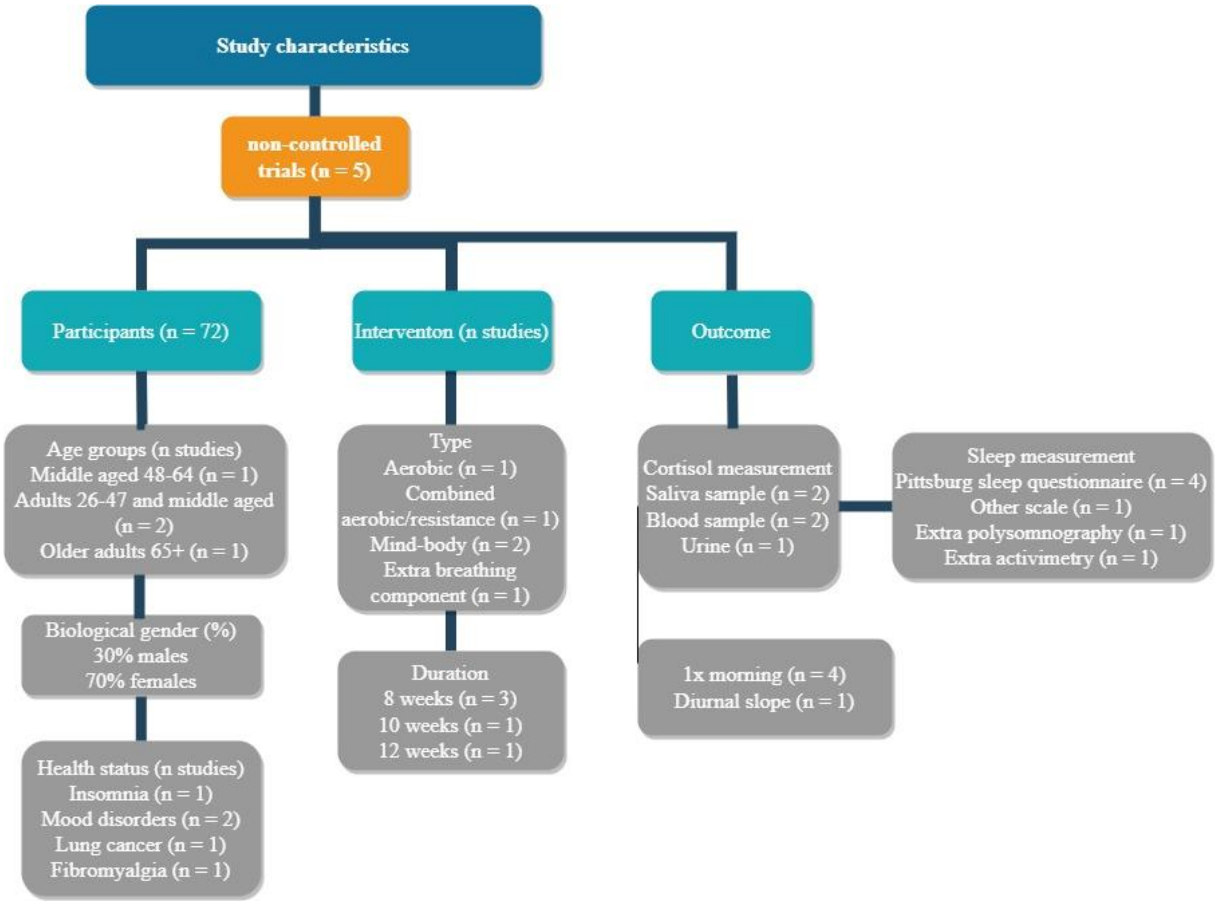


Appendix 3.6.7 Meta-analysis of the cortisol outcome, by cortisol measurement.

	Experimental			Control				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
1.9.1 Diurnal cortisol slope								
Banasik 2010	2.33	0.09	7	2.45	0.29	7	2.1%	-0.52 [-1.60, 0.55]
Chen 2013	-0.12	0.04	49	-0.11	0.05	47	15.0%	-0.22 [-0.62, 0.18]
Hilcove 2020	-0.01	1.31	41	0.49	1.69	39	12.4%	-0.33 [-0.77, 0.11]
Ho 2018	-6.9	2	63	-6.33	1.89	58	18.8%	-0.29 [-0.65, 0.07]
Ratcliff 2016	-0.1	0.04	53	-0.08	0.05	54	16.4%	-0.44 [-0.82, -0.05]
Subtotal (95% CI)			**213**			**205**	**64.7%**	**-0.33 [-0.52, -0.13]**
Heterogeneity: Tau² = 0.00; Chi² = 0.77, df = 4 (P = 0.94); I² = 0%								
Test for overall effect: Z = 3.31 (P = 0.0009)								
1.9.2 One-point in time cortisol measurement								
Al-Sharman 2019	10.4	4.5	17	11.01	3.58	13	4.6%	-0.14 [-0.87, 0.58]
Arikawa 2013a	56	5	77	59	5	64	21.0%	-0.60 [-0.94, -0.26]
Payne 2008	8	6.02	10	9	6.02	10	3.1%	-0.16 [-1.04, 0.72]
Subtotal (95% CI)			**104**			**87**	**28.8%**	**-0.48 [-0.77, -0.19]**
Heterogeneity: Tau² = 0.00; Chi² = 1.80, df = 2 (P = 0.41); I² = 0%								
Test for overall effect: Z = 3.22 (P = 0.001)								
1.9.3 Cortisol Awakening Response (CAR)								
Imboden 2021	264.4	195.2	22	314.2	168.9	20	6.5%	-0.27 [-0.88, 0.34]
Subtotal (95% CI)			**22**			**20**	**6.5%**	**-0.27 [-0.88, 0.34]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 0.86 (P = 0.39)								
Total (95% CI)			**339**			**312**	**100.0%**	**-0.37 [-0.52, -0.21]**
Heterogeneity: Tau² = 0.00; Chi² = 3.38, df = 8 (P = 0.91); I² = 0%								
Test for overall effect: Z = 4.61 (P < 0.00001)								
Test for subgroup differences: Chi² = 0.82, df = 2 (P = 0.66), I² = 0%								



Appendix 3.7 Chart of study characteristics of the excluded non-Controlled Trials



Appendix 3.8 Certainty of evidence

Studies (n)	Design	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Certainty (overall score)	Participants	Effects
Average effect of exercise interventions in (middle-aged) adults, compared to (active) controls								n (% male)	SMD [95% CI]
Cortisol									
9	RCT	+[a]	+[b]	-[d]	+[e]	+[f]	⊕⊕⊕◯	651 (10%)	-0.37 [-0.52, -0.21]
Sleep									
9	RCT	+[a]	-[c]	-[d]	+[e]	+[f]	⊕⊕◯◯	660 (10%)	-0.30 [-0.56, -0.04]

4 ⊕⊕⊕⊕ High = This research provides a very good indication of the likely effect. The likelihood that the effect will be substantially different** is low.

3 ⊕⊕⊕◯ Moderate = This research provides a good indication of the likely effect. The likelihood that the effect will be substantially different** is moderate.

2 ⊕⊕◯◯ Low = This research provides some indication of the likely effect. However, the likelihood that it will be substantially different** is high.

1⊕◯◯◯ Very low = This research does not provide a reliable indication of the likely effect. The likelihood that the effect will be substantially different** is very high.

** Substantially different = a large enough difference that it might affect a decision

RCT: Randomised Controlled Trial

[a] Most information is from studies at low risk or with some concerns, plausible bias unlikely to seriously alter the results.

[b] Inconsistency does not seem to be an issue, there is no wide variation in the effect estimates across studies, nor is there a notion of heterogeneity.

[c] Some inconsistency exists, as there is a wide variation in the effect estimates across studies, and moderate heterogeneity exists.

[d] There appears to be an issue with indirectness. The research question was set out to investigate adults regardless of health status and biological health status, however, six out of nine studies included breast cancer patients, and only 10% of participants were males.

[e] Imprecision does not appear to be an issue. First, total number of participants is higher than 400. Second, the magnitude of effect consistently range from small to medium (SMD between 0.20 or higher) (Based on Cohen, 1988 (Cohen, 1988)).

[f] Publication bias not detected or not strongly suspected. Although all results come from small studies, the funnel plot does not indicate strong evidence for publication bias.

[g] Publication bias is suspected, as the results come from small studies and the funnel plots is asymmetrical.

Based on the GRADE guidelines (Schünemann et al., 2013).

Appendix 4.1: Methodology of the intervention studies

This methodological section gives more details about the research's approach. It explains and rationalises the methods implemented to address the research questions and the reliability and validity of the methodologies utilised in the feasibility study (danceSing Care part 1) and the pilot RCT (danceSing Care part 2).

4.1.1 Introduction to the intervention studies

The feasibility study's general conduct and the randomised controlled trial were based on the CONSORT 2010 statements (Eldridge et al., 2016; Schulz et al., 2010) for each design. However, throughout the feasibility study, unforeseen barriers arose in the programme's enrolment in the care homes. The adherence and delivery of the programme were significantly affected by the COVID-19 pandemic, which was beyond the power of the research team or the care home's ACs.

The shift to realist evaluation

Given these unforeseen barriers expected during the COVID-19 pandemic, especially during the feasibility study, it became evident that traditional methodologies might fall short of adequately capturing the nuances of the study's outcomes. This realisation necessitated an alternative approach: the realist evaluation based on RAMESES II guidance (Wong et al., 2016).

Key features of the realist evaluation include:

- Interventions are assumed to be based on theories but are also active, flexible to changes and embedded in social reality. This influences how the intervention is implemented and how various actors respond (Clarke et al., 1998).
- Understanding the interaction between the components of an intervention and its broader context is key (Campbell et al., 2007; Hawe et al., 2004; Litaker et al., 2006).
- The context–mechanism–outcome (CMO) structure is central to this evaluation. It assists in identifying how various mechanisms and contextual factors correlate with the variability in outcomes. Refer to Figure 4.3 for a visual representation of the CMO framework.

- Pawson and Tilley (Pawson & Tilley, 1997) argue that an intervention can only achieve successful outcomes if the right ideas are applied to the proper context with appropriate social and cultural conditions (Clarke et al., 1998). Therefore, a realist evaluation includes a theory-driven formative evaluation (Parry & Straker, 2013), process evaluation (Craig et al., 2008), and outcomes evaluation that avoids the rigorous successionist format of experimental design.

This realist perspective describes how complex systems such as care homes have emergent properties that could interact with and influence programme outcomes. In contrast to traditional analyses of feasibility studies describing 'does this programme work', the aim became to interpret the outcomes while assessing whether and how the programme succeeds in the local setting. The study revealed four primary considerations for future implementation in a subsequent pilot RCT trial (Table 4.6 in Chapter Four), which was addressed in full in the subsequent pilot RCT, as outlined in Chapter Five.

4.1.2 Assessment of health markers for older adults in care homes

4.1.2.1 Questionnaires

In the initial phase, the research team established an advisory group (AG) comprising multiple stakeholders, including members from the Stirling PA Research Knowledge and Learning Exchange (SPARKLE) group, the Balhousie care homes group, and older adults from 'Stirling 1000 Elders', which is a group of adults aged 60+ is led by Prof. Anna Whittaker (the primary thesis supervisor) and form an essential resource for the university's healthy ageing researchers (https://1000elders.stir.ac.uk/). The primary goal was to leverage the collective expertise of these stakeholders to identify priority outcomes for the study within care home settings.

The involvement of an AG offers multiple advantages in health research (Entwistle et al., 1998), especially in enhancing patient and public participation from the project's inception (NHS Executive, 1998). The AG aimed to consolidate a list of priority outcomes, starting with drafts from various stakeholders, ensuring older adults' perspectives were incorporated. After five iterative sessions, priority areas such as psychosocial well-being, health status, stress, sleep, appetite, and weight loss were finalised.

Various standardised questionnaires were assessed to capture these outcomes, as recommended by existing guidance (Boynton & Greenhalgh, 2004). These tools were specifically chosen for their validation in older populations, particularly those with dementia. Stakeholder piloting further refined these instruments, optimising their sequence and clarity as per guidance (Palonen et al., 2016). These surveys, designed to be completed in 30-45 minutes, were planned for in-person administration. However, the challenges posed by the COVID-19 pandemic necessitated a switch to digital platforms like Teams and Zoom and, occasionally, paper versions. Despite these changes, consistency in survey delivery was maintained, leveraging JISC software for data collection (https://www.onlinesurveys.ac.uk/).

While questionnaires provided quantitative insights, qualitative data from focus groups and interviews supplemented the study. Another PhD student, EO, significantly contributed to this aspect, leading the semi-structured interviews.

Informed by the feasibility study experiences, the team streamlined the questionnaires in the subsequent pilot RCT, focusing only on the most relevant aspects for both researchers and stakeholders. Details of retained and omitted questionnaires are provided in Table A 4.1.

Table A 4.1 *Psychometric analysis of included questionnaires*

Measurement tool	Validity in older adults	Suitability for older adults with Dementia
Hospital Anxiety and Depression Scale (HADS) (Zigmond & Snaith, 1983)	Yes (Djukanovic et al., 2017)	Acceptable and feasible but difficult to interpret (Stott et al., 2017)
Perceived Stress Scale (PSS) (Cohen et al., 1983)	Yes (Ezzati et al., 2014)	Yes (Deeken et al., 2018)
Simplified Nutritional Appetite Questionnaire (SNAQ4) (Lau et al., 2020)	For an overview of studies assessing the SNAQ in older adults, see the study of Lau et al. (2020)	
Dartmouth COOP method (Nelson et al., 1987)	Widely used in clinical practices (see (Eaton et al., 2005) for references)	
EQ5D-3L (EuroQol Group, 1990b)	Yes (Pérez-Ros & Martínez-Arnau, 2020)	
Sleep satisfaction tool (Ohayon et al., 2019)	Yes (Ohayon et al., 2019)	N.a., but deemed appropriate for the care home population by the advisory group

UCLA Loneliness scale - 6 items (Russell et al., 1978)	Yes (Neto, 2014), recommended by National Academies of Sciences, Engineering and Medicine consensus report on Social Isolation and Loneliness in Older Adults: Opportunities for the Health Care System (NASEM, 2020)	N.a., but deemed appropriate for the care home population by the advisory group
Falls Efficacy Scale - International (Short Form) (Kempen et al., 2008; Yardley et al., 2005)	Yes (Hauer et al., 2011)	

4.1.2.2 Endocrine measurements

Salivary samples of cortisol and DHEA were chosen in line with recommendations from the preliminary systematic reviews of this PhD project, primarily for their less invasive nature and reliable correlation with serum levels.

Cortisol. Research seems to favour cortisol saliva measures over serum measures for the clinical assessment of adrenocortical function, as it is less invasive and salivary-free cortisol correlates with the free unbound active cortisol in serum (Aardal-Eriksson et al., 1998; Gozansky et al., 2005; Vining et al., 1983). These measurements have proven popular in psychobiology, stress, and sports medicine investigations (Nicolson, 2008). They are utilised on the notion that salivary cortisol is an acceptable indicator of hypothalamic-pituitary-adrenal (HPA) axis function. Indeed, salivary cortisol levels mimic plasma levels following ACTH and CRH stimulation and exercise-induced stress in the diagnostic situation (Lewis, 2006).

An accepted sampling design for cortisol involves five daily measurements immediately after awakening, 30-min post-awakening, at noon, in the late afternoon, and immediately before bed (Hellhammer et al., 2007), preferably over more than one day in order to capture stable characteristics and improve the reliability of the diurnal rhythm assessment (Adam & Kumari, 2009). To balance cost and accuracy, instead of multiple measures, a single salivary cortisol measure was collected at a pre-specified time and recorded alongside the time of awakening. This approach acknowledges the limitations of not considering the large intra-individual and inter-individual variations in cortisol levels (Pruessner et al., 1997). However, the time of awakening was controlled as a covariate in all cortisol level analyses.

DHEA. Salivary DHEA has the same feasibility advantages as salivary cortisol (being readily sampled and non-invasive) and is released during acute psychosocial stress along with cortisol (Izawa et al., 2008; Lennartsson et al., 2012). It is shown that the DHEA concentrations in saliva are highly correlated with those in serum (Ahn et al., 2007). Diurnal fluctuation of DHEA is present (Rosenfeld et al., 1975). However, DHEA does not appear to spike after awakening, is more stable than cortisol during the day (Hucklebridge et al., 2005), and is vastly decreased in older adults (Ceresini et al., 2000). Study differences could result from varied assay methodologies sample populations, or sampling strategies. Nevertheless, a one-time measurement of saliva DHEA is reliable when taken at a pre-specified time. In

Intervention Two, the time of awakening was controlled for as a covariate in the DHEA-level analyses.

When designing research, focusing on DHEA or DHEAS depends on the study's intent. For investigating acute stress responses, measurements of DHEA are favored due to its rapid fluctuation under stress. In contrast, chronic health considerations often prioritise DHEAS measurements, given its stability and representation of long-term health trends. Within the scope of this PhD project, a pilot RCT (Intervention Two, Chapter Five) was undertaken that emphasised salivary DHEA levels, chosen considering cost and for their stability in saliva, which mirrors the bioavailable hormone fraction and reliably indicates the body's physiological stress response.

4.1.2.3 Physical function tests

The health of older individuals is influenced by several factors, including chronic diseases, psychological states, social conditions, and environmental challenges. A key sign of deteriorating health in this demographic is reduced physical function, which manifests as decreased mobility, independence, and day-to-day activities, eventually leading to impairment and dependence (Katz et al., 1963; Lawton & Brody, 1969).

Frailty is a complex condition characterised by increased vulnerability resulting from age-related declines in reserve and function across multiple physiological systems, compromising the ability to cope with everyday or acute stressors (Xue, 2011). This condition holds significant clinical relevance given its correlation with adverse health outcomes like falls, hospitalisations, disabilities, and even mortality (Clegg et al., 2013; Fried et al., 2001; Gill et al., 2006; Rodriguez-Mañas & Fried, 2015; Shamliyan et al., 2013; Sourial et al., 2013; Sternberg et al., 2011).

Central to the diagnosis of frailty are indicators such as muscle atrophy and declining physical performance (Lee et al., 2020). Standard tools like the Timed Up-and-Go (TUG) test (Podsiadlo & Richardson, 1991), the Short Physical Performance Battery (SPPB) (Guralnik et al., 1994), gait speed (Matsuzawa et al., 2013), and hand grip strength (Syddall et al., 2003). are employed to evaluate aspects of physical functionality such as balance, walking speed, strength, and coordination.

However, the complexity of frailty transcends the physical domain, encompassing cognitive, psychological, and social facets (Xue, 2011). A comprehensive diagnosis and management, therefore, demand equally holistic assessment tools.

While the metrics above have certain limitations concerning the comprehensive nature of frailty, their clinical importance is undeniable. They have consistently predicted adverse health outcomes and have been associated with a range of subclinical and clinical conditions outside the physical realm, such as inflammation, oxidative stress, and overall mortality. Thus, they serve as markers of health burdens tied to various chronic illnesses rather than mere measurements of mobility or strength (Patrizio et al., 2021).

The research team designed a feasibility study to evaluate the physical function and markers of frailty in older adults in care homes. This study employed tools like the SPPB and handgrip strength aligned with the Fried frailty phenotype criteria (Fried et al., 2001). To maintain the test's relevance and to avoid overwhelming participants, the TUG test was deliberately excluded.

However, the COVID-19 pandemic posed unforeseen challenges. Restrictive measures prevented in-person assessments in care homes, and existing technical equipment was unsuitable for online testing, given limitations like inadequate camera functions and hearing capacities. Consequently, the feasibility study was unable to assess physical function parameters. These were integrated into the subsequent pilot RCT, emphasising the importance of testing the feasibility of new measures incorporated after the initial feasibility study.

4.1.3 Statistical plan of the danceSing Care trials

For several compelling reasons, an Intention To Treat (ITT) analysis was chosen over a per-protocol (PP) approach. Primarily, ITT analysis minimises the risk of bias that can arise from post-randomisation exclusions. Adhering to the original group assignments, regardless of protocol deviations, mitigates the potential distortion of treatment effect estimations that can occur only considering the participants who strictly adhered to the trial's protocol as in a PP analysis.

Moreover, the ITT approach enhances the external validity of the results, making them more generalisable to a broader population. ITT considers all subjects, including those who deviated from the protocol or were non-compliant. This reflects a real-world scenario where strict adherence to the treatment protocol is not always possible (Tripepi et al., 2020).

However, it must also be acknowledged that some exceptions to the ITT principle were made during both DSC trials, specifically the exclusion of individuals who withdrew consent and those missing essential baseline data or lost to follow-up. While these exclusions might appear to contradict the ITT principle, they were necessary due to the lack of critical information required for the analysis. This decision was made to prevent undue uncertainty and potential bias in the results (Lewis & Machin, 1993).

In Intervention Two, a per-protocol analysis was performed as a sensitivity analysis, revealing largely consistent outcomes between this and the ITT analysis. There were slight differences in the effect sizes for HADS-Anxiety, FES, and Brief UCLA Loneliness, with the sensitivity analysis showing slightly larger effect sizes for these outcomes than the ITT analysis.

This consistency makes the results more reliable. However, the variance in effect sizes between the two analytical approaches for specific outcomes underscores the significance of accounting for participant adherence and attrition in intervention research. This variance emphasises that participant engagement and adherence factors may moderate the intervention's potential benefits.

4.1.4 Sample size and adherence for the intervention studies

4.1.4.1 Sample size.

The sample size is determined based on the study design, significance level, power, and effect size. The National Center for Complementary and Integrative Health (NCCIH) recommends determining the appropriate sample size for research based on practical factors such as participant availability, budgetary limitations, and the number of participants required to assess feasibility objectives effectively. In the case of qualitative research, a sample size of 30 or fewer may suffice to achieve data saturation. For quantitative investigations, a sample size of 30 participants per group (intervention and control) can be sufficient to establish feasibility (Whitehead et al., 2016). However, the researchers aimed for 50+ participants, where each of the ten care homes would deliver at least five participants. This follows standard sample size rules of thumb, where 12 to 70 participants per treatment arm are recommended (Browne, 1995; Julious, 2005; Teare et al., 2014).

In the subsequent pilot RCT, a formal sample size calculation was performed with the G*power software. The statistical test (ANOVA: Repeated measures, within-between interaction) and the power of the analysis (A priori: compute required sample size) were selected, with α = .05 and power = .80. We used the Standardised Mean Difference (SMD) of (=.80) for the cortisol outcomes of the intervention studies (differences in pre- and post-intervention markers) from our previous systematic review (De Nys et al., 2022) to determine the effect size f for the planned pilot RCT. This revealed a required total sample size of n = 16. To account for a possible 20% attrition, group sample sizes were inflated to n = 20 or more if more participants opted into this aspect of the research.

For the mental health outcome (measured with HADS), which was of primary concern for the other PhD student of the project (EO), the total required sample size was calculated as n = 110, according to her preliminary systematic review (Ofosu et al., 2023). Accounting for possible attrition, the group sample sizes were inflated to n = 132.

However, the recruitment process for the pilot RCT fell short of the intended target of 132 participants, as only 34 participants were recruited. The research group initially planned to include two care homes. However, to recruit more residents, two additional care homes were included. The reason the intended sample size was not reached was mainly for two main reasons. Firstly, there was a pre-defined recruitment period to comply with the timely initiation of the intervention. Secondly, the study's eligibility criteria required participants to have the capacity to give informed consent, which was often unfeasible for individuals with progressed dementia. These factors limited the number of eligible participants. The pilot RCT's limited sample size resulted in potential limitations in detecting true treatment effects concerning the HADS outcomes. These limitations were adequately addressed in the manuscript's limitation section, further deeming it necessary that adequate statistical power for a full-scale RCT would require a minimum sample size of 132 participants.

4.1.4.2 Overall adherence to danceSing Care evaluation.

Based on data from a previous systematic review of the adherence to supervised technology-based exercise programmes for 12 weeks in older adults, the expected adherence range would fluctuate from 70% to 100% (Valenzuela et al., 2018). Session attendance forms were created for each care home with the names of residents who completed the baseline survey (for a template, see Appendix 4.5). ACs were asked to tick a box each time residents attended a session. Participating in the danceSing Care activities was not restricted to residents included in the feasibility study. Therefore, the attendance of other residents was recorded to indicate uptake, following the given personal consent.

Several efforts were made to keep the care staff engaged: (1) the principal researcher from the University of Stirling (AW) sent a weekly email reminder to care home staff so they would send through weekly updates on the attendance of participants, with information about reasons for deviation from the initial protocol (e.g., sessions were not delivered, reasons for residents' absence or withdrawal), (2) the danceSing Care marketing officer sent engaging emails to the care staff with updates about the danceSing Care evaluation over the ten care homes, (3) a danceSing Care Facebook group was made, where care staff could send through messages or videos about the programme (4) the ACs were given an induction at the start of the program, and a danceSing Care member-organised special session to the care homes throughout the intervention period.

Appendix 4.4: danceSing Care resources description

MUSIC AND SINGING PROGRAMME - session list

Our Music and Singing Programme is led by highly experienced danceSing Music Leader, Karol Fitzpatrick on piano. Upbeat and calming sessions, our chosen songs will stimulate memory and provide a range of tempi and mood. Our shorter session bites can be practised regularly and will help to improve breathing, posture, vocal control, concentration, and coordination.

Session	Duration	Overview	Dementia Friendly	Key Tags
GET STARTED SERIES - Sing along or listen to our bespoke musical arrangements to improve well-being.				
1	25-minutes	Sing along to ‘Yes Sir I Can Boogie’ and sit back and enjoy to ‘Moon River’.	Mild Moderate	Music, Singing, Calm, Relax, Upbeat
2	22-minutes	Sing along to ‘That’s The Way I Like It’ and sit back and enjoy ‘Somewhere Over The Rainbow’ and ‘Raindrops Keep Falling On My Head’.	Mild Moderate	Music, Singing, Calm, Relax, Upbeat

Session	Duration	Overview	Dementia Friendly	Key Tags
3	26-minutes	Sing along to ‘The Lion Sleeps Tonight’ and sit back and enjoy ‘Fields Of Gold’ and ‘What A Wonderful World’.	Mild Moderate	Music, Singing, Calm, Relax, Upbeat
4	7-minutes	Sing along or sit back and enjoy ‘Scarborough Fair’ and ‘Peace In My Soul’.	All Stages	Music, Singing, Calm, Relax
5	22-minutes	Sing Along to or sit back and enjoy “Amazing Grace” and “Somewhere Over The Rainbow” with accompanying grand piano and flute.	All Stages	Music, Singing, Calm, Relax
IRISH SERIES - Well known Irish songs to stimulate memory and offer a range of tempi and mood.				
1	19-minutes	Sing along to ‘I’ll Tell Me Ma’ and ‘The Wild Rover’.	All Stages	Music, Singing, Upbeat, Energise
2	21-minutes	Sing along to ‘Molly Malone’ and ‘Danny Boy’.	All Stages	Music, Singing, Calm, Relax
FESTIVE SERIES - Sing along or listen to our favourite selection of magical Christmas Carols.				

Session	Duration	Overview	Dementia Friendly	Key Tags
1	20-minutes	Sing along to ‘Winter Wonderland’	All Stages	Music, Singing, Upbeat, Energise
2	25-minutes	Sing along to ‘White Christmas’	All Stages	Music, Singing, Calm, Relax
BITESIZE SESSIONS - Selection of shorter bitesize sessions including Feel-good, Ballet & Irish (approx. 5-mins long).				
1	5-minutes	GENERAL Sing along bite Voice Strengthening Exercise	Mild Moderate	Music, Singing, Calm, Relax
2	5-minutes	IRISH Sing along bite ‘Molly Malone’	All Stages	Music, Singing, Calm, Relax
3	6-minutes	IRISH Sing along bite ‘The Wild Rover’	All Stages	Music, Singing, Upbeat, Energise
4	6-minutes	IRISH Sing along bite ‘Danny Boy’	All Stages	Music, Singing, Calm, Relax

Session	Duration	Overview	Dementia Friendly	Key Tags
5	5-minutes	FESTIVE Sing along bite ‘White Christmas’	Mild Moderate	Music, Singing, Upbeat, Energise
6	5-minutes	FESTIVE Sing along bite ‘We Wish You A Merry Christmas’	Mild Moderate	Music, Singing, Upbeat, Energise

MOVEMENT AND FITNESS PROGRAMME - session list

Our Movement and Fitness Programme is led by highly experienced danceSing Founder Natalie Garry. Inspiring and motivational, our sessions will help prevent falls, improve posture, boost mood and circulation, increase strength and flexibility to help with everyday activities and promote independent living.

Session	Duration	Overview	Dementia Friendly	Key Tags
GET STARTED SERIES - Have fun moving and grooving to boost your well-being.				

Session	Duration	Overview	Dementia Friendly	Key Tags
1	18-minutes	Chair Fitness focusing on improving posture, strength, and flexibility, boosting cardiovascular health, and mobilising joints.	Mild Moderate	Chair, Dance, Calm, Relax, Upbeat, Circulation Falls, Energise
2	19-minutes	Chair Fitness focusing on improving posture, strength, and flexibility, boosting cardiovascular health, and mobilising joints.	Mild Moderate	Chair, Dance, Calm, Relax, Upbeat, Circulation Falls, Energise
3	18-minutes	Standing Fitness focusing on improving posture, strength, and flexibility, boosting cardiovascular health, and mobilising joints.	Mild Moderate	Standing, Dance, Calm, Relax, Upbeat, Circulation Falls, Energise
4	8-minutes	Chair Fitness Circulation Boost focusing on boosting cardiovascular health, mobilising joints, and improving posture, strength, and flexibility. Recommended daily.	Mild Moderate	Chair, Dance, Calm, Relax, Upbeat, Circulation Falls, Energise
5	21-minutes	Chair Fitness focusing on boosting circulation, cardiovascular health, mobilising joints, and improving posture, strength and flexible.	Mild Moderate	Chair, Dance, Calm, Relax, Upbeat, Circulation, Falls, Energise

Session	Duration	Overview	Dementia Friendly	Key Tags
6	11-minutes	Chair Fitness Circulation Boost focusing on cardiovascular health, mobilising joints, and improving posture, strength, and flexibility. Recommended daily.	All Stages	Chair, Dance, Calm, Relax, Circulation, Falls, Energise
7	11-minutes	Chair Fitness focusing on easing out the muscles and improving posture and flexibility. Recommended daily.	All Stages	Chair, Dance, Calm, Relax, Circulation, Falls
8	12-minutes	Chair Fitness focusing on moving gently, mobilising the joints, and improving posture and flexibility. Recommended daily.	All Stages	Chair, Dance, Calm, Relax, Circulation, Falls
FEEL-GOOD SERIES - Motivational feel-good sessions created to help enable independent living.				
1	21-minutes	Chair Fitness focussing on improving posture, boosting circulation, falls prevention, and increased strength for everyday activities.	Mild Moderate	Chair, Fitness, Upbeat, Circulation Falls, Energise
2	21-minutes	Standing Fitness for people steady on their feet. Focusing on maintaining and improving movement quality and agility while working on falls prevention, increasing strength and flexibility for everyday activities.	Mild Moderate	Standing, Fitness, Upbeat, Circulation Falls, Energise

Session	Duration	Overview	Dementia Friendly	Key Tags
3	12-minutes	Gentle Chair Fitness slower paced focussing on gentle movements to mobilise the body.	All Stages	Chair, Fitness, Upbeat, Circulation Falls, Energise
BALLET SERIES - Joyful and uplifting inspired by classical ballet to improve strength for everyday activities.				
1	22-minutes	Chair Fitness focussing on improving posture, boosting circulation, falls prevention, increased strength for everyday activities.	Mild Moderate	Chair, Fitness, Upbeat, Circulation Falls, Energise
2	19-minutes	Standing Fitness focussing on maintaining and improving movement quality and agility while working on falls prevention, increasing strength and flexibility for everyday activities.	Mild Moderate	Standing, Fitness, Upbeat, Circulation Falls, Energise
3	13-minutes	Chair Relaxation focussing on breath work and gentle movement to mobilise the body leaving you feeling calm and relaxed.	All Stages	Chair, Fitness, Calm, Relax, Circulation, Falls
FESTIVE SERIES - Festive fun to improve posture and circulation, prevent falls, increase strength and flexibility.				
1	18-minutes	Chair Fitness focusing on improving posture, boosting circulation, falls prevention, and increased strength and flexibility for everyday activities.	All Stages	Chair, Fitness, Upbeat, Circulation Falls, Energise

Session	Duration	Overview	Dementia Friendly	Key Tags
BITESIZE SESSIONS - Selection of shorter bitesize sessions including Feel-good, Ballet & Irish (max. 5-mins long).				
1	4-minutes	FEEL-GOOD Chair Bite ‘Don’t Worry Be Happy’	Mild Moderate	Chair, Fitness, Upbeat, Circulation Falls, Energise
2	4-minutes	FEEL-GOOD Chair Bite ‘Fragile’	All Stages	Chair, Fitness, Calm, Relax, Circulation, Falls
3	3-minutes	FEEL-GOOD Standing Bite ‘The Lion Sleeps Tonight’	All Stages	Standing, Fitness, Upbeat, Circulation Falls, Energise
4	4-minutes	BALLET Chair Bite Mobility Circulation	All Stages	Chair, Fitness, Calm, Relax, Circulation, Falls
5	7-minutes	BALLET Standing Bite Mobility Circulation	All Stages	Standing, Fitness, Upbeat, Circulation Falls, Energise
6	3-minutes	BALLET Chair Bite Posture and Breath Work	All Stages	Chair, Fitness, Upbeat, Circulation Falls, Energise

MEMORY LANE RADIO - show list

Take a trip down Memory Lane, unlocking memories through the magic of music and movement.

Session	Duration	Overview	Dementia Friendly	Key Tags
1	60-minutes	Let danceSing transport you through the decades (50s, 60s, 70s, & 80s) with a variety of CLASSICAL and POPULAR music.	All Stages	Radio, Music, Calm, Relax, Upbeat
2	30-minutes	Let danceSing take you on a musical trip down memory lane with their handpicked selection of 1950s classics.	All Stages	Radio, Music, Calm, Relax, Upbeat
2	30-minutes	Let danceSing take you on a musical trip down memory lane with their handpicked selection of 1960s classics.	All Stages	Radio, Music, Calm, Relax, Upbeat
3	30-minutes	Let danceSing take you on a musical trip down memory lane with their handpicked selection of JAZZY FESTIVE classics.	All Stages	Radio, Music, Calm, Relax, Upbeat
4	30-minutes	Let danceSing take you on a musical trip down memory lane with their handpicked selection of JAZZY FESTIVE classics.	All Stages	Radio, Music, Calm, Relax, Upbeat

Session	Duration	Overview	Dementia Friendly	Key Tags
5	30-minutes	Let danceSing take you on a musical trip down memory lane with their handpicked selection of TRADITIONAL FESTIVE classics.	All Stages	Radio, Music, Calm, Relax, Upbeat

MUSICAL CONCERTS - show list

Sit back, relax, and enjoy our magical danceSing Care musical concert.

Show	Duration	Overview	Dementia Friendly	Key Tags
1	20-minutes	POPULAR music medley performance of grand piano and flute covering a variety of popular uplifting music.	All Stages	Concert, Music, Singing, Calm, Relax, Upbeat
2	18-minutes	IRISH music medley performance of grand piano and flute covering a variety of popular uplifting music.	All Stages	Concert, Music, Singing, Calm, Relax, Upbeat

3	12-minutes	FESTIVE music medley performance of grand piano and flute covering a variety of popular uplifting music.	All Stages	Concert, Music, Singing, Calm, Relax, Upbeat

Appendix 4.5: Care home attendance sheet

Care home name: ________________

danceSing Care attendance: please tick the corresponding box each time a resident participating in the danceSing care Evaluation (i.e. they did the baseline survey) attended a **movement class** in the program and a circle for the **music only** class.

Please scan and send to us each Friday so we can keep a cumulative attendance record.

NAME	W1	W 2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○
	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○
	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○
	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○	☐ ☐ ☐ ○
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Appendix 4.6: Interview/Focus group Guide

Semi-structured interview with residents

General overview of participation/adherence

1. What did you think about the danceSing Care online activities?
2. Did you manage to take part in the 3 movement and 1 music sessions a week? If not, why?
3. Can you tell me about your typical music and movement session?
4. What do you think about the length of the sessions? (Probe- would you say sessions were too long or too short)
5. Did you complete most of the sessions or had to stop at any point?
6. What did you like about the danceSing Care activities?

   Follow up questions

   Did you prefer the movement or music activities? (depending on Q6 answer)

   Is there anything you think was missing from the danceSing Care sessions?

7. Was there anything you did not like?
8. What made you continue/stop to take part in the music and movement activities?

Residents' participation/benefits

9. Do you think the activities have improved your life in any way?

   In what ways?

10. Would you like to continue to take part in the danceSing Care activities? Why/why not?

    Ask about pain/comfort

    Self care /

    Perceived fear of falling/stable

    In the last month- in line with stress, HADS

    What other activities they engage in

    What do you remember most – music /type /intensity /

    Stress and sleep relationship

    Change in health/life status – follow up what has changed?

Social support

11. Do you feel part of the danceSing Care family?
12. Has engaging in the music and movement activities brought you closer to other residents and staff?

Semi-structured focus group with staff

Go round for everyone to introduce themselves, role and the care home they work with.

General overview of participation/adherence

1. Can you tell me what your involvement in this danceSing Care programme has been ? (considering we might have other care home staff joining the FG)

2. Did you manage engaging residents in the 3+1 sessions a week? If not, why not?- mechanism
3. Did residents complete sessions after stating? If not why?
4. Do you think the residents enjoyed taking part in the danceSing Care activities? Can you give some examples
5. Did you enjoy taking part in the danceSing Care activities?- outcome
6. Did you prefer the music/movement or the singing activities?

Residents' and staff participation/benefits

7. What type of resident would you say came to a typical danceSing Care session?
8. Did some residents use the danceSing Care activities more than others? If so, why?
9. Did the class size grow or reduce? If so, why?
10. What do you think were the benefits of the danceSing Care activities for residents?
11. What were any benefits of the danceSing Care activities for you?
12. Would you like to carry on using the danceSing Care activities with residents? Why/why not?

Delivery of danceSing Care program

13. How did you find delivering the program?
14. What would you say helped with delivering the program?
15. Would you say delivering the programme came with some challenges?
    If so, in what ways?
16. If you could change something about this programme to make it work effectively in the care home, what would you change and why?

Social support

17. Do you feel part of danceSing Care family/champions?
18. Would you say delivering the danceSing Care activities has improved social connections between residents and staff?

Ask about what we should focus on for the staff?

Appendix 4.7: Weekly notes from care homes on delivery challenges

Weekly reports from care home staff through phone calls and emails					
Week 1	CH1 struggled to get residents to participate	CH2 recorded two drop outs. 1 relocation and 1 withdrawal	CH4- AC went on holiday and ran only one session	CH5 and CH6 had no assigned ACs	
Week 2	CH7 reported all residents have dementia and attention span is short making full participation difficult	CH3- COVID outbreak in the care home and Ac is on holiday.			
Week 3	CH3- COVID outbreak in home and one residents passed away	CH7-attendance forms not received	CH2- AC resigned and no new reassigned.	Less attention of ACs to weekly mails and reminders	Poor engagement on the social media platform for ACs

Week 4	CH5 recruited a new AC who is yet to start	CH3- COVID outbreak	CH8- COVID outbreak. Residents are isolating and not engaging in any social activities			
Week 5	CH9- AC is off sick. No sessions were run	CH8- COVID outbreak. Residents are isolating and not engaging in any social activities	CH3- one resident hospitalised	CH7- AC reported intervention has been delivered for only 2 weeks. AC was reminded of attendance forms	CH1- AC was on holidays so sessions were not delivered	
Week 6	CH8- COVID outbreak. Residents are isolating and not engaging in any social activities	CH1- AC was on holidays so sessions were not delivered	CH2- New AC starting next week.	CH6- New Ac starting in 2 weeks.	CH9-AC off sick with COVID	CH4- AC on holidays and delivery of sessions taken over by carer.

Week 7	CH4- AC on holidays and delivery of sessions taken over by carer.	CH10- One resident hospitalised	CH7, CH5, CH6 have not provided any attendance data- no sessions delivered		
Week 8	CH5- Residents struggle with the movement sessions				
Week 9	CH7- No response to follow up calls	CH2- New AC was off due to family issues. Care staff were unable to give any updates			
Week 10	CH7- AC is off on holidays	CH10: AC unable to join Facebook page.	CH2- Care home staff reported sessions have stopped due to staff shortage.	CH8 - no sessions delivered due to COVID. AC reported sessions were difficult to	CH1- attendance is better now since faulty display screen has been repaired

				follow (too fast) for residents.
Week 11 and 12	Final phone call follow ups and email reminders for attendance sheets made to all care homes	CH5, CH6 and CH7 did not engage in the intervention		

Note. CH: Care home, AC: Activity Coordinator

Appendix 5.1: TiDieR checklist

TiDieR Checklist requirement		Protocol description
1.	Brief description of the intervention	danceSing Care programme: digital music and movement resources to improve multidimensional health markers in older adults in care homes
2.	Rationale and theory of the elements essential to the intervention	• Physical activity interventions, including multi-component (chair-based) exercises or dancing, and music therapies have been shown to improve multidimensional health markers in older adults • Increasingly, innovative digital resources have been developed to influence physical activity in care homes
3.	Materials	For the participant and AC: • Information folder about the danceSing Care evaluation For the AC: • Training day and protocol documentation, including how the danceSing Care programme works • Personal username and password to enter the digital danceSing Care resources
4	Procedures	• Randomisation to intervention or waitlist group (1:1)

		• Participants were contacted before the pre-intervention testing to inform them of group allocation • Intervention participants received the intervention from week 1 to week 12
5.	Who provided	• All sessions were delivered by the AC of the care home • All ACs received an initial training session on how to engage participants in the programme during the trial and how to work with the digital resources
6	Mode of delivery	All sessions were group-based. Digital resources were provided on a big screen, under the supervision of the AC of the care home
7.	Location of delivery	• AC training sessions took place at the care homes • danceSing Care session took place in a communal room in the care home
8.	Intervention duration, intensity and dose	• One music and up to 2 movement sessions each week for 12 weeks • The sessions were of low-to-moderate intensity, at least 20 minutes, with a short warming-up and cooling-down part
9.	Tailoring	• The sessions are labelled by a dementia friendly-tag, ‘all stages’ or ‘mild-to-moderate’ • Movement sessions are labelled with tags like ‘chair fitness’ and ‘standing fitness’ and instructions are provided to adapt a standing or sitting posture during the sessions.

		• The music and sing-along sessions are tailored to the music preferences of older adults
10.	Modifications	Adaptations to the programme were made after the feasibility study (E F Ofosu et al., 2023) – reduction in the number of sessions as noted above
11.	How well planned	• Attendance and adherence registers were given to the ACs to be returned to the researchers every week • Researchers contacted the AC if the files were not sent through in time or if the attendance or adherence was not as expected
12	Delivered as planned	The intervention was delivered as planned in the intervention group

Appendix 5.2 Semi-structured interview guide

Semi-structured interview with residents

General overview of participation/adherence

1. What did you think about the danceSing Care online activities?

2. What did you like about the danceSing Care activities?

Follow up questions

- Did you prefer the movement or music activities?

- Is there anything you think was missing from the danceSing Care activities?

3. Was there anything you did not like?

4. What would you say there was anything that made participation easier or difficult?

5. Would you like to continue participating in the danceSing Care activities?

Follow up question

- Why/why not?

- Is there anything that would make this easier/difficult?

6. If you were in the control group, how did you feel about being on the waitlist for 12 weeks before participating in the music and movement sessions?

7. What did you think of the survey/interview questions?

8. What did you think about the saliva testing and physical function testing (Elaborate on what the physical function was)

Residents' participation/benefits

9. Do you think the danceSing Care activities have impacted your well-being in any way?

In what ways?

Social support

10. Do you feel part of the danceSing Care family?

11. Has engaging in the music and movement activities brought you closer to other residents and staff?

Follow up

- In what ways?
- Or if not, why not?

Semi-structured interviews with staff

General overview of participation/adherence

1. Can you tell me what your involvement in the danceSing Care programme has been?

2. Did you manage to engage residents in the 2+1 sessions a week? If not, why not?

3. Did residents do complete sessions after starting? If not why not?

4. Do you think the residents enjoyed taking part in the danceSing Care activities?

Can you give some examples.

5. Did you think residents preferred the music or movement activities?

6. Was there anything you think they didn't like so much?

Residents' and staff participation/benefits

7. Do you think some residents were more involved in danceSing Care activities more than others? If so, why?

8. What do you think made it easy or difficult for residents to participate?

9. What do you think was the impact of the danceSing Care activities on residents' well-being?

10. How do you think residents in the waitlist control group felt about waiting for over 12 weeks before taking part in the danceSing Care activities?

11. Would you say facilitating the danceSing Care activities has had any effect on your well-being?

Follow up

- What effect and how?

12. Would you like to continue using the danceSing Care activities with residents? Why/why not?

Delivery of danceSing Care programme

13. How did you find delivering the programme?

Follow up

- Would you say delivering the programme came with some challenges?

If so, in what ways ?

- What circumstances in the care home made delivery of the programme challenging?

14. What would you say helped with delivering the programme?

15. If you could change something about this programme to make it work effectively in the care home, what would you change and why?

Social support/well-being

16. Do you feel part of danceSing Care family/champions?

17. Would you say delivering the danceSing Care activities has improved social connections between residents and staff? If so, how/if not, why not?

Appendix 5.3: Per protocol analysis of all outcome variables for participants with complete data (n = 27)

Variables	n	Baseline mean	Post-intervention mean	Mean difference	95% CI	p	Effect size (d)
Cortisol (ug/dL)	18	0.30	0.40	-0.10	[-.34, .15]	.41	-0.20
DHEA (pg/mL)	18	1455.40	2359.21	-903.81	[1267.26, -540.36]	<.001*	-1.24
Cortisol: DHEA	18	0.00028	0.00029	0.00001	[-.00011, .00018]	.61	0.12
HADS-Anxiety (0-21)	27	6.30	4.41	1.89	[.53, 3.25]	.01*	0.55
FES (0-21)	27	5.56	3.26	2.30	[.09, 4.50]	.04*	0.41
Dartmouth COOP (6-30)	27	15.96	14.56	1.41	[-.52, 3.34]	.15	0.29
HADS-Depression (0-21)	27	6.30	5.78	0.52	[-.80, 1.83]	.43	0.16
Brief UCLA loneliness (6-24)	26	12.50	10.42	2.08	[.41, 3.75]	.02*	0.50

PSS (0-40)	27	12.70	10.96	1.74	[-1.08, 4.56]	.22	0.24
STT (9-36)	27	30.26	31.47	-1.21	[-3.53, 1.11]	.29	-0.21
SPPB total score (0-12)	24	4.83	4.83	0.00	[-.92, .92]	1.00	0.00
SPPB balance (0-4)	24	1.96	1.75	0.21	[-.46, .88]	.53	0.13
SPPB gait speed (sec) (0-4)	24	2.17	2.42	0.25	[.56, .06]	.11	-0.34
SPPB chair stand (0-4)	24	0.71	0.67	0.04	[-.32, .40]	.81	0.05
Handgrip strength (kg)	24	0.96	0.92	0.04	[-.11, .19]	.58	0.12
Frailty total score (0-5)	24	2.67	2.67	0.00	[-.25, .25]	1.00	0.00

Note: FES: Falls Efficacy Scale International (7-item), Dartmouth COOP: Dartmouth Cooperative Functional Assessment Charts measure of health-related quality of life, HADS: Hospital Anxiety and Depression Scale, UCLA: University of California, Los Angeles, PSS: Perceived Stress Scale, STT: National Sleep Foundation Sleep Satisfaction Tool. * significance $p < 0.05$

Appendix 5.4 Intervention fidelity and attendance of participants

	Number Sessions Offered Per Week															
Care Home	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Total**	**% Sessions Offered**	**Average sessions per week**	**% Attendance of participants**
1	3	3	3	4	2	3	3	2	3	2	0	0	28	78%	2	82%
2	2	0	2	2	2	4	0	2	1	2	2	2	21	58%	2	60%
3	4	3	3	3	3	3	3	4	3	4	6	4	43	119%	4	89%
4	2	3	3	3	3	3	3	3	3	3	3	3	35	97%	3	56%

Note: Care home 1 = Heatherfield, 2 = Larkfield View, 3 = Beechwood, and 4 = Almond View care home.

Appendix 5.5 Correlation matrix of change scores

Change in:	FES	COOP	Anxiety	Depression	UCLA	PSS	SST	Frailty
COOP	0.61***	1						
Anxiety	0.32	0.62***	1					
Depression	0.33#	0.31#	0.31#	1				
UCLA	0.57***	0.62***	0.51***	0.47**	1			
PSS	0.02	0.34#	0.47**	0.18	0.36*	1		
SST	-0.33#	-0.38*	-0.24	-0.34 #	-0.30#	-0.36*	1	
Frailty	-0.05	-0.05	-0.07	0.17	0.14	-0.22	0.39*	1
SPPB	0.09	0.14	0.39*	0.31	0.03	0.21	-0.10	-0.17

Note. ***significant at <.001 (2-tailed) **significant at < .01 level (2-tailed) *significant at <.05 level (2-tailed) #non-significant trend 0.05-0.09.