RESISTANCE TRAINING FOR FRAIL AND PRE-FRAIL OLDER ADULTS: FEASIBILITY, AND IMPACT ON MULTIDIMENSIONAL HEALTH

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in fulfilment of the requirements for the degree of
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Declaration

I, Bridgitte Swales, hereby declare that the work presented in this thesis has not been submitted for any other degree or professional qualification, and that it is the result of my own independent work. The sources used in the preparation of this thesis have been properly acknowledged and referenced in accordance with the guidelines of the University of Stirling. Parts of this work have been published in The Journal of Aging and Physical Activity, and BMC Geriatrics.

The thesis document was composed by me and under the supervision of Professor Anna Whittaker and Dr Gemma Ryde, with the following exception: Dr Iain Fletcher provided advice for data analysis in Chapter 4, The reliability and suitability of strength assessments in frail and pre-frail older adults: recommendations for strength testing in older populations.

HUR Ltd. provided loan of the equipment and technical support during the studies. HUR Ltd. had no role in data analysis or write up of this thesis and did not provide financial remuneration to any contributors. Professor Anna Whittaker presented research from this thesis at a UK conference (Global Ageing, Glasgow, 2023) sponsored by HUR Ltd. Bridgitte Swales presented research and data findings from this thesis at seminars supported by HUR Ltd. and SportsMed Products Ltd., (Dementia Care and Nursing Home Show, Birmingham, 2023; Care England, 2023). Professor Anna Whittaker is a Strategic Trustee for Christadelphian Care Homes, but this project began before she was recruited to this voluntary role. As the first author of this PhD thesis, I have no further conflicts of interest to declare.

COVID-19 Impact Statement

The pre-COVID research plan included a long-term follow-up study with the initial participants from Study 1, about one year after the end of the intervention. Participants, care and well-being staff were to be interviewed using a semi-structured format, and participants to be assessed using a modified version of the original testing battery. The planned study was to utilise a prospective, cohort study design, and was designed to increase the overall effectiveness of the intervention trials by extending the results obtained and allowing a deeper understanding of the findings. It aimed to investigate the acceptability, practicality, and demand for resistance training in a care home setting over a long-term period (> 1 year) and assess the longer-term impact on the study participants' health and well-being.

The researcher designed the long-term follow-up study to assess the longer-term impact of a resistance training intervention on health and well-being and examine the reasons influencing longer-term adherence. The planned sample size was 22, to include all participants from both the frail and pre-frail studies (Chapter Two and Three, respectively). The aims of the long-term follow-up study were to be achieved by a shortened re-assessment of secondary dependent variables and semi-structured interviews with participants, care team and well-being team staff. The proposed study timeline spanned six weeks: weeks one-two for study recruitment (distribution of Participant Information Sheets, meetings with interested participants, informed consent and scheduling follow-up testing); weeks three-four for Assessment Session One comprising lower limb maximal strength measures using HUR machines, and cognitive and emotional measures using two, short standardised questionnaires (Standardized Mini-Mental State Examination, SMMSE (Molloy et al., 1991), and Geriatric Depression Scale, GDS (Yesavage et al., 1982); and weeks five-six for Assessment Session Two to include functional capacity measures of grip strength, walking speed and balance in alignment with Fried Frailty criteria (Fried et al., 2001) and the Short Physical Performance Battery, SPPB (Guralnik et al., 1994), and semi-structured interviews with participants, well-being team and care staff.

In accordance with research and ethical requirements the researcher designed and submitted proposed amendments. This included revisions to the protocol and supporting documentation including Participant Information Sheets, Case Report Forms, personal and nominated consultee forms and information sheets, and semi-structured interview questions. The proposed trial received ethical approval.

COVID-19 related disruption significantly impacted this study. Measures and restrictions were in place within the residential care home (2020-2021), and it was not possible to access the site for research purposes. To mitigate disruption to the PhD and ensure timely completion, a reliability analysis of the combined strength assessment data collected in the initial trials with frail and pre-frail participants (Chapter Two and Three) was undertaken. This is reported in Chapter Four. As reliable testing protocols and equipment are required to ensure accurate evaluation and confident detection of meaningful changes in force production, this new direction was of high value. It was particularly important, as reliability for muscle strength measures and recommendations for maximal strength testing protocols had not been clearly defined in frail and pre-frail older adults in residential care.

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Abstract

This thesis investigated the feasibility and impact of a resistance training (RT) intervention on multidimensional health and physical function in frail and pre-frail older adults living in residential care. It also examined the reliability of maximal strength measures in this population. Chapter One introduces the literature on ageing and multidimensional health relating to the prevalence, causes and consequences of frailty. RT is offered as a potent strategy for lifelong health. Chapter Two describes a comprehensive feasibility trial evaluating a RT intervention with frail older adults in a residential care home. Chapter Three presents the feasibility and impact of a RT intervention with pre-frail care home and supported living residents. Chapter Four is an evaluation of the reliability of maximal handgrip and lower limb strength assessments across both frail and pre-frail older adults. Chapter Five is an overall Discussion summarising and critically appraising the findings, including strengths and limitations, practical implications, and recommendations for future research. This thesis makes several original contributions to knowledge. First, that RT interventions assessing measures of multidimensional health and physical function with frail and pre-frail older adults in residential care are feasible. Second, that RT can positively impact strength and functional ability, and perceived changes in mood, vitality, and movement confidence. Third, that maximal strength testing with frail and pre-frail older adults with no prior experience is both reliable and appropriate and identifies clear recommendations for strength testing with this population group. However, limitations and suggested revisions identified in the feasibility trials would need further consideration before progression to definitive Randomised Controlled Trials (RCTs). The thesis supports a multidimensional health approach to RT research with frail and pre-frail older adults and confirms that frailty is not a barrier to RT, and that structured progressive RT can improve physical function and quality of life in ageing.

Publications Arising From This Thesis

Peer-reviewed Articles

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

Swales, B., Ryde, G. C., & Whittaker, A. C. (2024). A mixed methods feasibility study of machine-based resistance training with prefrail older adults in residential care: The Keeping Active in Residential Elderly trial II. *Journal of Aging and Physical Activity*, 32(2), 244-263. https://doi.org/10.1123/japa.2022-0170

Swales, B., Ryde, G.C., Fletcher, I., & Whittaker, A.C. (2023). The reliability and suitability of strength assessments in frail and pre-frail older adults: Recommendations for strength testing in older populations. *BMC Geriatrics 23*, 820. https://doi.org/10.1186/s12877-023-04552-3

Conference Presentations

Work within this thesis has also been presented as published abstracts, conference talks and posters, listed below:

Swales, B. (2023) 'Strong for life: healthy ageing and strength' webinar [Presentation]. *Invited talk for Care England in association with SportsMed Ltd., December 2023.* Care England: https://www.careengland.org.uk/events/strong-for-life-healthy-ageing-and-strength/

Swales, B., Ryde, G.C., Fletcher, I., & Whittaker, A.C. (2022) Practice makes perfect: recommendations for reliable strength testing in older frail populations [Poster Presentation]. *SPARC, Virtual Conference, Nov 2022, Edinburgh, UK.*

Swales, B., Ryde, G.C., & Whittaker, A.C. (2022). Keeping Active in Residential Elderly 2 (KARE2): Personalised progressive resistance training in pre-frail older adults improves multi-dimensional health. *Psychosomatic Medicine*, 83, Abstract.

Swales, B., Ryde, G. C., & Whittaker, A. C. (2022) Keeping Active in Residential Elderly 2 (KARE 2): Personalised progressive resistance training in pre-frail older adults improves multi-dimensional health. *Poster presentation given at "Embracing Heterogeneity: Towards a More Inclusive, and Patient-Tailored Clinical Care" the 79th Annual Meeting of the American Psychosomatic Society, March 2022, Long Beach, C.A.*

Whittaker, A.C., Ryde, G., and **Swales, B.** (2022) 'A physical activity intervention designed to improve multidimensional health and functional capacity of frail older adults in residential care: a randomised controlled feasibility study'. *Poster presentation to be given at "An Eco-system Approach to Health-enhancing Physical Activity Promotion" the 11th Conference of HEPA Europe Network, 31st Aug-2nd September 2022, Nice, France.*

Whittaker, A.C. & **Swales, B.** (2021) Keeping Active in Residential Elderly (KARE): the feasibility and impact of a specialized strength training intervention to improve multidimensional healthy ageing in frail older adults in residential care. *International Journal of Behavioral Medicine, Abstract. Virtual conference, June 2021, Glasgow, UK.*

Swales, B. (2021) 'Strong for life: healthy ageing and strength' seminar [Presentation]. *Invited talk at Dementia, Care and Nursing Home Expo, September 2021, Birmingham, UK.*

Whittaker, A.C. & **Swales, B.** (2021) Keeping Active in Residential Elderly (KARE): the feasibility and impact of a specialized strength training intervention to improve multidimensional healthy ageing in frail older adults in residential care. *International Congress of Behavioral Medicine, June 2021. Conference moved from 2020 to online 2021. Glasgow, UK.*

Whittaker, A.C. & **Swales, B.** (2020) Keeping Active in Residential Elderly (KARE): Preliminary findings of a feasibility study of an adapted physical activity intervention to improve multidimensional health in frail older adults in residential care [Poster Presentation]. *Poster to be presented American Psychosomatic Society, March 2020 (Conference cancelled),*

Long Beach, USA.

Whittaker, A.C. & **Swales, B**. (2020 cancelled). Keeping Active in Residential Elderly (KARE): Preliminary findings of a feasibility study of an adapted physical activity intervention to improve multidimensional health in frail older adults in residential care. *Psychosomatic Medicine*, 82, A33. Abstract.

Swales, B., Doody, P., Lord, J., & Whittaker, A.C. (2019) *Keeping Active in Residential Elderly (KARE):* Preliminary findings of feasibility and impact of a resistance training intervention, aimed at improving health and functional capacity of frail older adults in residential care [Poster Presentation]. *November 2019, SPARC, Edinburgh.*

Other Research Activities

During this thesis period the candidate has also contributed to other research including journal articles, conference posters and lay-friendly articles, listed below:

Swales, B. & Whittaker, A.C. (2022, September 30) *Lifting weights once a week linked to reduced risk of premature death – new study.* The Conversation. https://theconversation.com/lifting-weights-once-a-week-linked-to-reduced-risk-of-premature-death-new-study-191462

Doody, P., Asamane, E. A., Aunger, J. A., **Swales, B.,** Lord, J. M., Greig, C. A., & Whittaker, A. C. (2022). The prevalence of frailty and pre-frailty among geriatric hospital inpatients and its association with economic prosperity and healthcare expenditure: A systematic review and meta-analysis of 467,779 geriatric hospital inpatients. *Ageing Research Reviews, 80*, 101666. https://doi.org/10.1016/j.arr.2022.101666

Tomaz, S. A., Coffee, P., Ryde, G. C., **Swales, B.,** Neely, K. C., Connelly, J., Kirkland, A., McCabe, L., Watchman, K., Andreis, F., Martin, J. G., Pina, I., & Whittaker, A. C. (2021). Loneliness, wellbeing, and social activity in Scottish older adults resulting from social distancing

during the COVID-19 pandemic. *International Journal of Environmental Research and Public Health,* 18(9), 4517. https://doi.org/10.3390/ijerph18094517

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Doody, P., Asamane, E.A., Aunger, J.A., **Swales, B.,** Lord, J.M., Greig, C.A., & Whittaker, A.C. (2021). Frailty prevalence among geriatric hospital inpatients, and its association with economic indicators: A systematic review and meta-analysis of 467,779 inpatients. *Irish Gerontological Society Annual Scientific Conference Website* Abstract. Virtual conference, Nov 2021.

Whittaker, A.C., Tomaz, S.A., Ryde, G., Connelly, J., Coffee, P., Kirkland, A., McCabe, L., Watchman, K., Andreis, F., **Swales, B.,** Martin, J.G., Pina, I., & Neely, K. (2020). Loneliness, social support, and well-being in Scottish older adults as a result of social distancing during the Covid19 pandemic. *Psychosomatic Medicine*, 82(6), A1-A225. Abstract. Virtual conference, December 2020.

List of Abbreviations

1RM	One Repetition Maximum
ACSM	American College of Sports Medicine
ADL	Activities of Daily Living
ANOVA	Analysis of Variance
BMI	Body Mass Index
CMO	Chief Medical Officer
CONSORT	Consolidated Standards of Reporting Trials
CRP	C-reactive Protein
CV	Coefficient of Variation
DHEAS	Dehydroepiandrosterone sulphate
GDS	Geriatric Depression Scale
HADS	Hospital Anxiety Depression Scale
HPA	Hypothalamic-pituitary-adrenal
ICC	Intraclass Correlation Coefficient
IFN-γ	Interferon gamma
IGF-1	Insulin-like Growth Factor 1
IL-6	Interleukin-6
ISEL	Interpersonal Support Evaluation List
ITT	Intention to Treat
KARE	Keeping Active in Residential Elderly
MLTAQ	Minnesota Leisure Time Activity Questionnaire
MNA	Mini Nutritional Assessment
MVPA	Moderate-to-vigorous Physical Activity
NSCA	National Strength and Conditioning Association
OMNI-RES	OMNI-Resistance Exercise Scale
PA	Physical Activity
PIS	Participant Information Sheet
PSS	Perceived Stress Scale
RCT	Randomised Controlled Trial
RFD	Rate of Force Development

RFID	Radio-frequency Identification
RIR	Reps in Reserve
RPE	Rating of Perceived Exertion
RT	Resistance Training
SMMSE	Standardized Mini-Mental State Examination
SPIRIT	Standard Protocol Items: Recommendations for Interventional Trials
SPPB	Short Physical Performance Battery
TNF-α	Tumour Necrosis Factor Alpha
TUG	Timed Up and Go
WHO	World Health Organization

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Chapter 1: Introduction

This initial chapter discusses the literature on ageing and health, in relation to the prevalence, causes, and consequences of frailty in older adults. It considers the capacity for physical activity (PA) to positively impact health status in ageing and contribute to the maintenance of independence and quality of life. Resistance training (RT) is introduced as a robust strategy to support lifelong health, combat muscle strength loss, and slow the progression of or reverse physical frailty. This information will then be used to justify the overall aims of this PhD project at the end of this chapter.

1.1 Ageing, Health, and Frailty

1.1.1 Definitions of Health and Healthy Ageing

The World Health Organization Constitution defines health as “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (World Health Organization, 1946). As such it is recognised as a positive, multidimensional concept encompassing physical and cognitive ability, resilience, robustness, and well-being (Rozanski, 2023). Consequently healthspan (years lived in good health) is a complex construct (Kaeberlein, 2018) influenced by multiple factors. These include chronic conditions i.e., sarcopenia (loss of muscle mass and strength); the reversal or slowing of clinical syndromes i.e., frailty; policy decisions; and the promotion and support for capacity enhancing behaviours including PA and social interaction (Olshansky, 2018; Rozanski, 2023; Seals et al., 2016). Addressing healthspan is a challenging problem for governments, health organisations, individuals, and broader society, particularly when the economic cost of ill-health in older age is considered (UK Health Security Agency, 2019).

A focus on healthy ageing with investment and strategies to support the ageing population and enhance quality of life in older age is fundamental to positive societal change (World Health Organization, 2020b). Central to this is the maintenance of physical capacity to perform activities of daily living, and the ability to learn, contribute, build, and maintain relationships. This approach recognises the impact of an individual’s intrinsic capacity, their environment, and the interaction between the two, with intrinsic capacity seen as a multidimensional concept including physical movement, vitality, sensory, cognitive, and psychological components. Research indicates that significant negative change in intrinsic

capacity is associated with a loss of functional ability and increased levels of dependence (World Health Organization, 2020a). Other related terms have been used in the ageing literature and include active ageing, successful ageing, and healthy longevity (Pruchno, 2015; Rowe & Kahn, 1987; Whitson et al., 2018; Wong et al., 2023).

Healthy longevity is seen as a realistic and achievable target which requires investment in healthcare infrastructure, support systems, age-friendly cities and communities, and personal responsibility for PA and health (World Health Organization, 2020a). An overarching principle of healthy longevity is to facilitate and support older adults to reach their full potential to live life with robust multidimensional health, meaning, purpose and dignity (Wong, 2023).

1.1.2 Population Ageing and Healthspan

Ageing is the time-dependent deterioration that affects most living organisms and is characterized by a progressive decline of function and physiological integrity (Lopez-Otin et al., 2013). It is a distinctive, natural biological process and a predictor for impairments in function and mobility (McLeod et al., 2019). Further, it is linked to an increased vulnerability to multisystem dysfunction and dysregulation, and related to disease, disability, and mortality. Human ageing represents a complex interaction of interconnected cellular and molecular hallmarks of ageing including chronic inflammation (Lopez-Otin et al., 2013, 2023), health including homeostatic resilience (Lopez-Otin & Kroemer, 2021) and behavioural, psychological, and social factors such as well-being and social connectedness (Fernández-Ballesteros, 2019).

Increased population age is recognised as a defining global trend (United Nations, 2023) with 1.4 billion people expected to be aged 60 years or more by 2030, equating to 1 in 6 people worldwide. Projections for people over 80 years tell a similar story with numbers likely to triple between 2020 and 2050 to more than 426 million (World Health Organization, 2022). Even with recent deceleration of the increase in lifespan (Office for National Statistics, 2021), these remarkable changes bring many potential positive opportunities including options for individuals to continue to enjoy their careers or forge new ones, contribute to society, and participate in wider social networks of families and friends. Yet, these lifespan changes are not being matched by increases in healthspan (Whittaker et al., 2019) with the need to address this societal challenge.

1.1.3 Multidimensional Health

This thesis focuses on the concept of multidimensional health which is firmly related to healthspan and healthy longevity. It underlines the connections between biological hallmarks of

health (Lopez-Otin & Kroemer, 2021) and psychological, cognitive, and emotional health, social support, and physical function, and their combined impact on quality of life and well-being (Sacha et al., 2017).

Measures of robustness and physical resilience may allow early identification of impaired human functioning as a pre-cursor to increased vulnerability. In support of this, a key evidence-based recommendation from the Global Roadmap for Healthy Longevity (National Academy of Medicine, 2022) is to move health care systems to focus on multidimensional health. This will, in turn, improve and support health during ageing while appreciating the requirement for different or modified strategies for individuals at different life stages. While research indicates that the rate of ageing is likely determined by genetics and biochemical processes, socio-economic status, and environmental factors there is irrefutable evidence which supports the positive impact of healthy lifestyle practices, including PA, on physical function (Abud et al., 2022). These now form the evidence base for many UK and worldwide healthy ageing policies and recommendations (NIH National Institute on Aging, 2022).

The decline of physiological function with ageing is a primary barrier to increasing healthspan (Seal, 2016) and impacts negatively on functional capacity, chronic disease risk and quality of life. Specific changes in skeletal muscle strength and rate of force production, for example, can limit the ability to perform activities of daily living and compromise independent living (Inouye et al., 2007; McLeod et al., 2019; Seals & Melov, 2014).

1.1.4 Frailty

Frailty is a complex clinically significant multidimensional syndrome associated with a high risk of adverse outcomes such as falls, cognitive decline, disability, and death among older adults (Clegg et al., 2013; Fried et al., 2001). It is characterised by lower functional capacity, reduced physiological reserves, and increased vulnerability to stressors (Hewitt et al., 2019), and while it is distinct from other degenerative diseases of ageing it overlaps with related illnesses including depression, cognitive decline, and chronic inflammation (Hoogendijk et al., 2019). Evidence suggests that age-related changes in the immune, endocrine and neuromuscular systems, are fundamental to the development of frailty (Clegg & Young, 2011), and that cumulative deterioration contributes to a loss of homeostatic reserve and decline in physical resilience (Whitson et al., 2016). This in turn, creates potential for a relatively minor stressful event to cause a disproportionate negative change in health status, for example, from independent to dependent. Frailty has also been shown to be closely linked, but not

synonymous, with co-morbidity and disability (Fried et al., 2004; Theou et al., 2012), and these health conditions commonly co-occur. It is of note that Fried and Ferrucci (2016) were the first to expand the concept of frailty as a syndrome of 'accelerated ageing' and observe that clinical frailty is associated with the presence of multiple chronic diseases and physical health conditions. A recent review supports this concept and highlights the shared molecular mechanisms of ageing and geriatric syndromes (Franceschi et al., 2018).

Pre-frailty is broadly acknowledged as the early or intermediate stage of frailty and lies on the frailty continuum. It is a risk-state that may be apparent before the onset of clinically diagnosed frailty and, as such, represents an increased level of vulnerability of transition to frailty and associated poor clinical outcomes (Sacha et al., 2017; Sezgin et al., 2020). Research suggests that prefrail individuals are at more than twice the risk of develop frailty over the following three years than non-frail individuals (Fried et al., 2001). With many studies indicating that prefrailty predicts frailty, there is increasing interest in early identification and proactive intervention to halt or reverse progression, particularly as research suggests that prefrail individuals are at a critical timepoint and may respond better than those who have already moved into frailty (Bray et al., 2016; Kojima et al., 2019). As such further research into pre-frailty is essential to gain a better understanding of both treatment and prevention strategies (Fernandez-Garrido et al., 2014).

While the increasing prevalence of frailty is a global concern, the true scale of the problem is difficult to determine due to differences across measuring tools, countries, and settings (Collard et al., 2012; Gale et al., 2015). Consequently, studies using physical frailty measures in community dwelling older adults report European and global prevalence rates of 7.7% (Manfredi et al., 2019) and 12% (O'Caoimh et al., 2021), respectively, while pooled estimates of prevalence of frailty in nursing homes were reported as 52.3% (Kojima, 2015). A recent systematic review and meta-analysis found pooled prevalence of frailty, and pre-frailty, among geriatric hospital inpatients to be 47.4% and 25.8%, respectively (Doody et al., 2022). The prevalence of pre-frailty in community dwelling older adults is higher than that identified for frailty: Rasiah et al. (2020) reported figures between 35% to 60% in large cohort studies using physical frailty measures. An overall population level estimate of 46% was noted by O'Caoimh et al. (2021), with other global and European studies citing a weighted average prevalence of 44.2% and an overall prevalence of 42.9%, respectively (Collard et al., 2012; Manfredi et al., 2019). Given these figures, the proportion of older people living with frailty or pre-frailty is considerable and pressing, particularly given that a significant proportion of those with pre-frailty

are at high risk of progression to a future frail state (Fernandez-Garrido et al., 2014; Harrison et al., 2015; Xue, 2011).

1.1.5 Measures of Frailty

Several different measures and models of frailty exist, with most classifications utilising one of two broad models: a phenotype model (Fried et al., 2001) or a cumulative deficit model (Rockwood, 2016). The frailty phenotype of older adults is clinically recognisable and includes sarcopenia, fatigue, falls risk and poor health. One of the most widely cited is the Fried frailty phenotype (Fried et al., 2001) which proposes that frailty be based on five physical characteristics: unintentional weight loss ($\geq$10lbs in the past year), self-reported exhaustion, weakness (grip strength), slow walking speed, and low levels of PA. Older adults can be classified into different frailty states using the presentation of criteria from robust/non-frail (zero), pre-frail (one or two) to frail (three or more). Recent research suggests that it is possible to halt and even reverse progression between states (Travers et al., 2019) with pre-frail status being notably malleable.

The Frailty Index (Rockwood et al., 2005) is a well-recognised cumulative deficit model whereby a frailty index score is calculated by counting the presence or absence of signs, symptoms, diseases and disabilities (deficits). The number of deficits is divided by the total number of measures to give an individual Frailty Index, with more deficits indicating a higher likelihood of frailty. Previous research has proposed the Frailty Index to be a more comprehensive and sensitive tool (Cesari et al., 2014), more predictive of mortality (Kojima et al., 2018) and potentially more useful to track changes in frailty and health status (Kaskirbayeva et al., 2023). While there is also some support for the use of individual frailty markers e.g., grip strength, or a dual-trait measure (grip strength and gait-speed) in primary care settings to reduce time and practitioner burden (Lee et al., 2017), the five Fried frailty phenotype elements have been extensively tested for validity and continue to be widely utilised in frailty research. A recent review by Buta et al. (2016) found that the Physical Frailty Phenotype (Fried et al., 2001) was the most commonly used in the research literature and encouraged careful consideration in the selection of a frailty instrument based on context and intended purpose.

Advancing age only partly explains transitions in physical frailty status and more research is needed to gain a better understanding of the complex relationships between ageing, multidimensional health status and trajectories of frailty. While frailty onset, for example, may start before age 65 and frailty seems to increase steadily with age, not all adults will develop the

syndrome, even those grouped among the oldest-old (≥ 85 years) (Dent, Martin, et al., 2019). Further, an investigation of multidimensional predictors of physical frailty in 4638 older adults aged 65-89 years from the English Longitudinal Study of Ageing identified multiple physical, psychological, and social conditions which can act as predictors, mediators, or moderators of physiological decline (Ding et al., 2017). As such, ageing represents both a certain and a unique experience for each one of us. Advances in the science of ageing biology, and a growing understanding of multidimensional health, may bring an opportunity to better understand these interactions and develop possible targets for improving healthy longevity.

1.2 Multidimensional Health, Ageing and Physical Activity

1.2.1 PA and Health

Collectively, research indicates that age-related changes to physiological, psychological, emotional, social, immunological and nutritional function can negatively impact on quality of life and increase the risk of disability, morbidity, and mortality. Therefore, the importance of supporting and enhancing healthspan and healthy longevity for the global population is becoming increasingly clear. A logical route path to achieve this would involve a lifelong investment in multidimensional health and focus on interventions that have the capacity for positive impact across the range of these health outcomes.

It is now well established that regular PA has a strongly protective effect on health at all ages and stages of life (Chodzko-Zajko et al., 2009; Davies et al., 2019; Piercy & Troiano, 2018; World Health Organization, 2020b). Scientific literature supports a number of PA-related health benefits for adults of all ages that include lower risk of all-cause mortality and cardiometabolic conditions, and some types of cancer (including bladder, stomach and lung cancers); improved brain health including reduced risk of dementia, improved cognitive function, reduced feelings of anxiety and depression; and reduced risk of excessive weight gain (American College of Sports Medicine, 2018; Lear et al., 2017; Zhao et al., 2020). Regarding older adults, recent expert consensus guidelines state that in the presence of adequate exercise/PA, changes in muscular and aerobic capacity with age are substantially attenuated (Izquierdo et al., 2021). Consequently, regular PA is now recognised as a robust strategy to preserve function with advancing age, compress morbidity and disability and extend healthspan. Research suggests that it may be the default position for the maintenance of physiological function throughout the life course (Harridge & Lazarus, 2017). Further, it is important to recognise that a growing body

of evidence supports positive effects of regular PA on cognitive function, mental health and well-being, and social connectedness (Davies et al., 2019; Piercy & Troiano, 2018; World Health Organization, 2020b).

The UK PA guidelines (2019) for adults and older adults proposed several core elements to maintain and improve health and physical function. These include activities to increase or maintain muscle and bone strength (resistance exercise training), cardiovascular fitness (aerobic exercise training), and balance and coordination. UK PA recommendations propose that each week adults should accumulate at least 150 min of moderate intensity activity, or 75 min of vigorous activity, or a combination of moderate and vigorous; and muscle strengthening activities on at least two days per week. Older adults are advised to focus on multi-component strength and balance activities, including flexibility.

PA levels vary across age and stage of life and by sex, with activity levels tending to decline with age and particularly at older ages. Scottish Health Survey data (2021) reported that young adults were more likely than older adults to have met the moderate-to-vigorous PA (MVPA) guidelines (74-76% of those aged 16-54, compared with 66%, 61% and 44% for those aged 55-64, 65-74 and 75 and over, respectively). Additionally, 72% of men aged 55-64 met the guidelines, compared with only 61% of women. Research also indicated that adults with a chronic health condition or disability are twice as likely to not achieve PA health-related targets (Smith et al., 2018).

Inadequate PA is a substantial health risk factor and public health burden. An analysis of burden of disease and life expectancy estimated that physical inactivity, defined as an activity level insufficient to meet current guidelines, worldwide was responsible for between 6-10% of the major non-communicable diseases of coronary heart disease, type 2 diabetes and breast and colon cancer, and for 9% of premature mortality (Lee et al., 2012). The latest UK Government guidance reported that inactivity is associated with 1 in 6 deaths in the UK and is estimated to cost the UK £7.4 billion annually (including £0.9 billion to the NHS alone) (Department of Health and Social Care, 2022). This research emphasises the broad health and economic value of attempting to increase PA.

1.2.2 Ageing, Physical Function and PA

Ageing is associated with a progressive decline in physical function and capacity. This is consistently observed in age-related decreases in levels of health-related physical fitness measures including muscular strength and endurance, cardiorespiratory fitness, mobility,

balance, and coordination (American College of Sports Medicine, 2018). Compromised physical function can subsequently negatively impact on the ability to carry out activities of daily living (ADL) and is linked with multiple adverse health outcomes including depression, anxiety, reduction in quality of life, increased risk of future age-related disease, falls, loss of independence and disability (Lazarus et al., 2019; Payette et al., 2011; Trombetti et al., 2016).

Research suggests that declines in key physiological measures, including aerobic fitness and muscle strength, follow a non-linear downward trend each decade from age 30 (Harridge & Lazarus, 2017). For example, in relation to peak $V0_2$ (a measure of aerobic fitness) in healthy adults, this has been estimated to be between 3-6% in the third and fourth decades and accelerating to greater than 20% after age 70 (Fleg et al., 2005). However, as noted by Harridge and Lazarus (2017), the relationship between human ageing and physiological function is complex with no one functional value or index capable of reliably relating age and physical status.

Age-related changes in physical function have been identified across several different gait parameters including walking speed, stride length, cadence and step width (Prince et al., 1997). While walking speed at usual pace is relatively stable until the sixth decade, with the critical age for change being around 70 years, it does decline with increasing age and there is also growing evidence that a faster rate of decline is related to worse outcomes (Ferrucci et al., 2016). A pooled analysis of 9 cohort studies comprising individual data from 34,485 community dwelling older adults aged 65 years or older followed up for 6 to 21 years also found gait speed was associated with survival, with survival increasing across the full range of gait speeds, with significant increments per 0.1 m/s (Studenski et al., 2011). Further, walking speed has been proposed as a ‘vital sign’ to provide important information on physical function and mobility, and a powerful predictor of mortality and future cardiovascular events (Franklin et al., 2015; Middleton et al., 2015). Walking speed is a widely used performance-based indicator of mobility either as an independent measure or as part of a mobility related functional test i.e., Short Physical Performance Battery (SPPB) (Guralnik et al., 1994) or Timed-Up-and-Go test (TUG) (Podsiadlo & Richardson, 1991).

Regular PA has a positive impact on physical function and capacity for all age groups. This is routinely reported across health-related physical fitness measures (American College of Sports Medicine, 2018). There is no minimum amount of PA required to achieve health benefits and improvements in physical function: this is reinforced by the assertion that ‘any activity is better than none, and more is better still’ (Davies et al., 2019). Research studies consistently

report that regular PA has cardioprotective effects across all ages, sex, and race (Lavie et al., 2019). The potential physiological benefits of PA include reduced blood pressure (BP), reduced systemic inflammation and visceral adiposity; improved mitochondrial density, insulin sensitivity, capillary density and heart rate variability; and reduced risk of developing hypertension, depression, metabolic syndrome and diabetes (Piercy & Troiano, 2018). PA also positively impacts musculoskeletal health status including articular cartilage, tendon, and bone health (Maestroni et al., 2020).

Older adults who are habitually physically active remain at higher levels of physiological function across multiple systems that typically decline with age compared to their sedentary peers (Seals et al., 2016). This indicates that regular PA, as a lifestyle intervention, may be capable of moderating ageing across multiple organs and tissues, preserving function and supporting healthy longevity. Previous studies have also shown that regular PA can help offset and manage symptoms associated with age-related chronic disease (Marzetti et al., 2017; McLeod et al., 2019). Izquierdo et al. (2021) propose that PA for older adults can operate both as preventative medicine to support the maintenance of effective but declining function, and as a therapeutic agent for disease and dysfunction associated with inadequate levels of PA. Regarding PA, frailty and physical function, a recent systematic review and meta-analysis found that a higher level of PA was significantly related to decreased odds of developing frailty (Zhao et al., 2022).

The UK PA guidelines emphasise the importance of PA for older adults to support health, independence and physical function (Davies et al., 2019) and reiterate that habitual PA limits age-associated decline in functional status. Regular PA additionally positively supports quality of life by reducing the fear and risk of falls and improving movement confidence in both healthy and frail older adults (Chodzko-Zajko et al., 2009). Of note is a meta-analysis by Falck et al. (2019) which found that physical exercise had a significant benefit for both physical and cognitive function in older adults and identified a significant association between improvements in both outcomes. The findings indicated that studies with large effects on physical function tended to report large effects on cognitive function.

1.2.3 Ageing, Strength, and PA

A primary issue with ageing and compromised physical function is the loss of muscle mass and strength. Strength is defined as the ability to exert force against an external resistance (Stone, 1993) and is underpinned by a combination of neurological and morphological factors

including motor unit recruitment and muscle cross-sectional area, respectively (Suchomel et al., 2018). Age-related losses in muscle mass, strength and function are related to changes across both factors with research consistently identifying evidence of a decrease in cross-sectional area (McPhee et al., 2018), muscle density (Larsson et al., 2019), muscle quality (McGregor et al., 2014), tendon compliance, an increase in intramuscular fat (Pinel et al., 2021; Visser et al., 2005) and a gradual, selective denervation of muscle fibres (Aagaard et al., 2010). Research evidence suggests that chronic inflammation, declining hormone levels, impaired muscle mitochondrial function, and impaired muscle stem cell function may all contribute to a progressive decline in muscle mass and strength (Aagaard et al., 2010; McCormick & Vasilaki, 2018; Wilson et al., 2017).

Low levels of muscle mass, strength and physical performance are key parameters of sarcopenia and present as compromised functional ability, mobility and movement confidence in older adults (Visser et al., 2005). Sarcopenia is defined as a progressive and generalised skeletal muscle disorder that is associated with increased likelihood of adverse outcomes including falls, fractures, physical disability and mortality (Cruz-Jentoft et al., 2019).The European Working Group on Sarcopenia in Older People recently proposed a focus on muscle strength loss as the principal determinant of risk, recognising that strength is better than mass in predicting negative health outcomes (Cruz-Jentoft et al., 2019). While there is some overlap between sarcopenia and frailty (most older adults with frailty are also sarcopenic), not all older adults with sarcopenia are frail (Sacha et al., 2017). Prevalence of sarcopenia increases with age with reported figures ranging from 5.3% in 499,046 men and women aged 40-70 years (UK Biobank data) (Dodds et al., 2020) to 21% of 719 participants measured at baseline in the Newcastle 85+ study (mean age 85.5 years) (Dodds et al., 2017).

Bone mineral content and microarchitecture of bone also change with ageing, and there is a recognised mechanistic interrelationship between muscle and bone (Edwards et al., 2015). Osteoporosis is a skeletal disease of ageing and characterised by low bone mass and deterioration of bone tissue, leading to enhanced bone fragility and susceptibility to fracture (Kanis et al., 1994). It is also associated with chronic pain, impaired physical function and loss of independence. A recent study exploring the relationship between sarcopenia, osteoporosis and frailty in 405 community dwelling older adults found that the presence of coexisting sarcopenia and osteoporosis (‘osteosarcopenia’) were highly associated with frailty, highlighting the potential adverse outcomes of musculoskeletal ageing (Laskou et al., 2022).

As regards changes to strength, between the ages of 25 and 85 years there is a decline of approximately 50% (Skelton & Mavroeidi, 2018a) with small, reported changes between 30 and 40 years, but pronounced changes after 50 years, with more than 15% loss each decade (Francis, Lyons, et al., 2017). These declining levels of muscle and bone strength can negatively impact balance, stability, gait and mobility (Curtis et al., 2015). Physical mobility is a key issue in maintaining independence and quality of life (Rantakokko et al., 2013) and can be defined as the ability to move by changing body position or location, or by transferring from one place to another, and the ease by which this is accomplished (World Health Organization, 2001). Mobility limitations can be identified as problems with daily activities such as walking or climbing a single set of stairs and are often linked to early phases of functional decline and strength loss. Impaired mobility is reported to be prevalent in about 30% of older adults and associated with negative health outcomes such as dependency in ADL, increased risk of falls, and is predictive of entry into nursing or care facilities (Musich et al., 2018). A longitudinal study with community dwelling older adults aged 70-85 years also indicated that declining physical performance measures of mobility contribute to an increased fear of falls and a deterioration in quality of life (Trombetti et al., 2016). There are multiple risk factors for impaired mobility, such as unsteady or slow walking gait speed, injuries, falls, cognitive impairment, and psychosocial factors, including social support (Buchman et al., 2011; Daley & Spinks, 2000; Rantakokko et al., 2013).

Given the changes in muscle and bone in ageing and resulting physical function effects which impact on mobility and independence in later life, these are important issues to address when seeking to improve health and well-being among older adults.

Consequently, PA that improves strength, muscle mass, mobility and balance has been highlighted as particularly important across all ability levels including active older adults, those in transition to frailty (pre-frailty) and frail older adults. Robust evidence also indicates an inverse dose-response relationship between MVPA and risk of functional limitations, and consistently shows improvements in function with aerobic, muscle strengthening and multi-component PA regardless of frailty or existing chronic disease (Powell et al., 2018). In relation to older adults with existing limitations, the Lifestyle Interventions and Independence for Elders study found that a long-term structured moderate intensity PA programme designed to improve lower limb strength, function and balance reduced the risk of developing major mobility disability by 18% among at-risk older adults (Pahor et al., 2014). Interestingly, analysis of a sub-group with lower physical function (scoring <8 on the SPPB) indicated stronger effects, but otherwise the effects of PA did not differ by age or sex. A more recent study, the Retirement in Action trial, also found

that a long-term PA and behavioural maintenance programme could significantly improve muscle lower limb strength and balance for at-risk older adults in a UK-based community setting (Stathi, Greaves, et al., 2022).

PA interventions have been shown to positively impact measures of strength and physical function including gait speed, sit-to-stand, balance and TUG tests (Cadore et al., 2014; Chase et al., 2017; Papa et al., 2017). A systematic review and meta-analysis which aimed to determine the effects of different PA interventions including strength, balance and multi-modal designs, on healthy older adults habitual and fast-gait speed found a substantial and clinically meaningful increase of 0.1 m/s or 8.4% with a large effect size (0.84) across all types of PA combined (Hortobagyi et al., 2015). While additional analysis did reveal that RT was slightly more effective, the overall findings suggest that a range of different modes of PA can improve key measures of strength and physical function in older adults and gives more scope for individual preference as regards PA prescription.

Overall, the physical benefits of PA for older adults shows the great scope for PA as a successful intervention. The next sections discuss its potential for impacting on psychosocial, cognitive and biological outcomes.

1.2.4 Ageing, Mental Health and Well-being, and PA

Mental health is a state of mental well-being that enables people to cope with the stresses of life, realize their abilities, learn well and work well, and contribute to their community (World Health Organization, 2021). Factors associated with mental well-being include life satisfaction, optimism, and life purpose with high levels of mental well-being consistently linked to improvements in health and longevity (van Agteren et al., 2021). Research suggests that positive psychological well-being has a favourable effect on mortality in both healthy and diseased populations (Chida & Steptoe, 2008) with studies among older age-groups indicating that happy older people live longer and enjoy more years in good health (Chei et al., 2018).

The link between mental well-being, physical health and function becomes increasingly important with ageing, not least due to the increased likelihood of chronic disease and disability with mental ill-health. Research indicates that poor mental well-being and negative psychological traits including depression are associated with increased risk of cardiovascular disease (CVD), diabetes, and disability in older adults (Kubzansky et al., 2018; Penninx et al., 1999). Several studies also suggest that there may be a bidirectional relationship between chronic physical illness and psychological well-being such that chronic disease state and declining physical

health increase the likelihood of poor mental well-being and vice versa (Almeida et al., 2009; Pan et al., 2012). Interestingly, a three-year follow-up of data from 1741 men and women aged 68-82 years participating in the NuAge five-year observational study showed that a significant decline in physical health was paralleled by a subtle but not clinically significant decline in psychological health (Payette et al., 2011). The researchers also highlighted that the effect of age on rate of decline in physical function was confounded by individual characteristics, including depressive and cognitive status, and indicated the important role of modifiable lifestyle factors in the quality of ageing.

Age-related change in mental health is not inevitable and variation in mental health status can occur at any stage of the life course. However, specifically in older age, circumstances and experiences can alter across multiple domains which individually or collectively can impact on mental well-being: changes to financial resources; social and personal relationships including bereavement and loss of loved ones; social status, role and retirement; and self-perception of ageing (Donovan & Blazer, 2020; Steptoe et al., 2015).

Depression in older adults is a global health concern. It is the most prevalent mental illness among older adults (Polacsek et al., 2019) and is linked with high use of health and social care support, poorer outcomes for physical health, emotional suffering, morbidity and mortality (Vieira et al., 2014). It is a complex disorder proposed to be an interaction of biological, psychological and social factors which may include cardiac and cerebrovascular disease, lack of social support, loneliness, functional decline and disability (Daskalopoulou et al., 2016).

Some variability exists in relation to estimates of the prevalence of later-life depression (Zenebe et al., 2021). A recent systematic review and meta-analysis evaluating the global prevalence of depression analysed 48 studies involving 72,878 older adults ($\geq$60 years) and reported a value of 28.4% (Hu et al., 2022). Other recent work found the overall pooled value to be 13.3%, 95% CI [8.4, 20.3] with 11.9% [7.6, 18.6] and 9.7% [5.2, 17.3] in older women and men, respectively (Abdoli et al., 2022). However, in a systematic review and meta-analysis of depression in later-life age groups (75+) (Luppa et al., 2012) reported pooled prevalence of major depression as 7.2%, 95% CI [4.4, 10.6] and 17.1% [9.7, 26.1] for depressive disorders with substantial rate increases of 20-25% and 30-50% in the highest age groups, 85-89 and 90+ years, respectively. Notwithstanding the differences in reported values, symptoms of depression are often overlooked and unaddressed in older adults due to diagnostic issues, co-occurrence with other mental health problems, including anxiety, and stigma around mental illness (Polacsek et al., 2019).

Anxiety disorders are also a major cause of burden of disease (American Psychiatric Association, 2013). They are associated with increased sleep disturbance, decreased cognitive functioning, lower quality of life, depression, disability and mortality (Wolitzky-Taylor et al., 2010). General anxiety disorder is one of the most common anxiety disorders in older adults and often presents as illness or health anxiety (Goncalves & Byrne, 2012). Anxiety disorders are increasingly commonplace with reported prevalence rates ranging from 10.2-17.2% in community dwelling older adults (Beekman et al., 1998; Canuto et al., 2018; Maatouk et al., 2016) and from 1.0-28.0% in clinical settings (Bryant et al., 2008; Remes et al., 2016). However, as with depression, many more cases may go undiagnosed due to lack of awareness, stigma and misconceptions about mental health with accurate diagnosis further complicated by cognitive decline and medical comorbidity (Wolitzky-Taylor et al., 2010). It is also possible that both older adults and clinicians interpret symptoms as an accepted part of the normal ageing process (Witlox et al., 2021). Risk factors associated with an increased likelihood of anxiety in later-life include having several chronic medical conditions; being female; being single or widowed; low educational achievement; poor self-rated health; and physical limitations in ADL (Wolitzky-Taylor et al., 2010).

While research indicates that anxiety is more prevalent than depression (Bryant et al., 2013), co-occurrence of anxiety and depression is also widely reported in older adults. Research indicates that up to 90% of those diagnosed with anxiety will also present with symptoms of depression (Moller et al., 2016) and that 60.4% of those with clinically relevant anxiety symptoms will also have a depression diagnosis (Schoevers et al., 2003). Mixed anxiety-depressive disorder is associated with greater functional disability, a poorer prognosis and a more persistent illness course than those with a single disorder (Dong et al., 2020; Schoevers et al., 2003). Older adults with co-morbid depression and anxiety also report an increased negative impact on loneliness and social relationships (Curran et al., 2020). Taken together, this research on mental health in ageing emphasises the necessity of measuring and addressing mental health issues among older adults.

The link between PA and mental health is becoming increasingly clear. Considerable evidence has accumulated to show that PA is positively associated with numerous aspects of mental health including measures of well-being, mood, happiness, self-esteem and overall quality of life (Biddle, 2016; Bize et al., 2007; Powell et al., 2018; Richards et al., 2015). National and global PA Guidelines are now acknowledging the beneficial link between regular PA and mental health and well-being across the life course (Davies et al., 2019; Powell et al., 2018;

World Health Organization, 2020b). In relation to older adults, the effect appears reliable across a range of different modes of PA, including muscle strengthening, balance, walking and Tai Chi, and locations, including both community-based and care settings (Park et al., 2014; Windle et al., 2010). While there is some indication that mind-body PA, such as Tai Chi or Yoga may offer stronger effects, there is yet no consensus (Miller et al., 2020). There is, however, growing evidence that light-to-moderate intensity PA, including outdoor walking, may lead to greater benefits for overall mental well-being in later life (S. T. Chen et al., 2021).

Existing research recognises that regular PA can reduce the risk of depression and reduce depressive symptoms with or without clinical depression across the lifespan (Cooney et al., 2013; Schuch et al., 2016). A recent systematic review and meta-analysis, which included the largest synthesis of the effect of exercise on major depressive disorder in adults, found moderate to large effects on depressive symptoms (Heissel et al., 2023). The findings strongly indicated that physical exercise is effective in treating depression and depressive symptoms and recognised its use as an evidence-based treatment. While Heissel et al. (2023) recommended aerobic activity, RT as a single intervention showed similar large effect sizes. Similarly a study by Bennie et al. (2019) investigating the association between aerobic and muscle-strengthening exercise with depressive symptom severity in 17,839 US adults aged 18-85 years found that while both single modes of exercise were associated with a low prevalence of depression, adults meeting a combination of MVPA and muscle strengthening exercise were associated with the lowest likelihood of reporting depressive symptoms. This emphasises the directives within the current PA guidelines.

PA in later life has been linked with protective factors such as resilience, purpose in life and positive perception of ageing and may be an appropriate non-pharmacological treatment or adjunct therapy for depression (Maier et al., 2021; Teychenne et al., 2020). A meta-analysis of prospective cohort studies reported that PA had a protective effect in older adults, regardless of sex or geographical region (Schuch et al., 2018). Research also indicates that the outcome effect of PA on depressive symptoms may be immediate and clinically relevant (Blake et al., 2009). Although the research on an optimal mode, dose or intensity remains undetermined and may require individualisation to increase efficacy, there is some evidence to indicate that the PA prescription may matter. In relation to duration and frequency, the UK recommendations propose that 30 min of moderate activity per day almost halve the odds of experiencing depression (Davies et al., 2019). International recommendations report that both aerobic and strengthening

types of PA have produced clinically meaningful improvements in depression, with a stronger response from higher intensities or volumes (Izquierdo et al., 2021).

Research suggests that PA and exercise may also have a role to play in the prevention and treatment of anxiety (Kandola et al., 2018; Stubbs et al., 2017). Studies have indicated similar effect sizes to other approaches including pharmacological strategies and suggest that PA may be both a more efficient and cost-effective strategy (Kandola et al., 2018). A recent systematic review and meta-analysis found PA interventions to be effective in managing anxiety in older adults, with differing magnitude of effects across different types, frequency and duration (Ofosu et al., 2023a). While current World Health Organization (WHO) PA recommendations appeared broadly appropriate, the evidence for an optimal prescription remains unclear. There is limited, and often equivocal, evidence to support the effectiveness of walking and mind-body activities such as Yoga and Tai Chi (Han et al., 2021; Leung et al., 2022). It is of note that analysis of data collected as part of a long prospective cohort study of community dwelling adults aged $\geq$ 50 years (The Irish Longitudinal Study on Ageing) showed that meeting WHO PA guidelines was associated with 17% (McDowell et al., 2018) and 13.5% (McDowell et al., 2020) lower odds of prevalent generalised anxiety disorder and lend support to the anxiolytic properties of PA for older adults.

1.2.5 Ageing, Social Support and PA

Social support is recognised as a powerful predictor of living a long and healthy life (Dykstra, 2015). Previous research has established that social support has an impact on older adults' multidimensional health status independent of potentially confounding factors including socioeconomic status (Hakulinen et al., 2016; White et al., 2009). Meaningful social support can offer a substantial positive contribution to emotional health and well-being, help protect against mental health disorders including depression and anxiety, enhance resilience to stress, and reduce medical morbidity and mortality (Cohen, 2004; Holt-Lunstad et al., 2010). A cohort of the oldest-old (85+ years) perceived social relationships as the most important condition for well-being and, as a result, successful ageing (von Faber et al., 2001). Further, both network size and contact frequency have been found to be positively and independently associated with higher subjective well-being and quality of life of older adults (Rafnsson et al., 2015).

Social support is reported to protect mental health directly via the benefits of social interaction and indirectly as a buffer against the impact of stress (Kelly et al., 2017). The stress buffering model suggests that social support is positively related to well-being such that high

levels of social support buffer against life stress (Cohen & Wills, 1985). Research by Heinze et al. (2015) found that the relationship between social support, general and emotional health remained consistent across the life course, but that sources of support did differ, with older adults identifying their friends/peers and community as more meaningful sources of support. It is reasonable to suggest that bereavement, loss of spouse and retirement will bring significant change to social support and networks for older adults, and that the ability to cope with stress will be influenced by this. This underlines the importance of measurement and intervention to improve social support-related factors in older age.

It is broadly established that social support is an important factor in PA behaviours and intervention success. Overall, there appears to be a positive relationship between adherence, attendance and social support in a PA setting. Group-based PA has been shown to provide social support and may also encourage more consistent participation and adherence (Harden et al., 2015). Connecting with other people during PA may be important for many different reasons. Exercise groups can encourage participation, build a sense of community and cohesion, and help establish supportive relationships. A sense of belonging may enhance the PA and positively impact on well-being and mood beyond the physiological impact. The literature does not yet provide a comprehensive explanation of the different types of social support seen and experienced by adults and older adults, and it is still unclear if and how PA with others is more beneficial than PA alone. However, there is some indication that social support may help individuals better cope with the perceived challenges of engaging with regular PA, and aspects of companionship, emotional and validation support may help to build exercise identity and subsequent motivation to be physically active (Golaszewski & Bartholomew, 2019).

Lindsay Smith et al. (2017) found social support specific to PA to be an important factor in assisting older adults to be physically active, particularly if this came from family members, and that support from friends was linked to leisure time PA. Overall, higher amounts of combined social support were found to be associated with higher levels of PA. The concept of ‘buddying up’ with a supportive partner has also been a successful strategy. However, a systematic review and meta-analysis of PA interventions found a positive effect for social functioning but no effect for some social health outcomes, including social support (Shvedko et al., 2018). The lack of sufficient evidence for social support was consistent with earlier reviews.

Despite a lack of definitive evidence, it is likely that social support has a role to play in PA engagement. Subsequently current UK PA guidelines highlight the associated health benefits of PA for older adults, including social functioning and reducing loneliness and social isolation, and

encourage daily PA for more social benefits (Davies et al., 2019). International recommendations suggest that PA interventions need to be better tailored to older adults by considering behavioural and social aspects and boosting social support to positively impact adherence and enjoyment (Izquierdo et al., 2021). Further, the inclusion of behaviour change strategies including social support through group interaction have shown to typically improve PA whereas insufficient social support has been recognised as an important motivation-related barrier (U.S. Department of Health and Human Services, 2023). This suggests that PA interventions with older people would be advised to consider the social context and impact of social support in their delivery.

1.2.6 Ageing, Cognitive Function and PA

Better psychological well-being has been linked with better cognitive function (Allerhand et al., 2014; Zhang et al., 2022). Data from a population-based cohort study of 11,234 community dwelling adults aged 50 or over who participated in the English Longitudinal Study of Ageing in 2002, indicated that high psychological well-being was robustly associated with better global cognitive function in older adults (Llewellyn et al., 2008).

Most older adults do exhibit a decline in cognitive ability, particularly episodic memory, and neurobiological changes including structural atrophy and altered brain activity during memory tasks (Deary et al., 2009). Longitudinal studies identify that the average onset is at approximately age 60 (Nyberg & Pudas, 2019) with a more marked decline often associated with neurodegenerative disease, such as Alzheimer's disease, and loss of independent status. However, age-related cognitive decline is not assured, and some older adults including those classified as 'super-agers', indicate robust measures across a range of functions including memory, attention, executive performance, and motivation (Garo-Pascual et al., 2023; Klinedinst et al., 2023). This suggests that a range of biological and environmental factors may interact to influence age-related cognitive decline.

Regular PA has been linked with improvements in cognitive function across the life course and proposed as a potential method to reduce the risk for cognitive decline (Chen & Nakagawa, 2023). This is particularly relevant given the high prevalence of cognitive impairment among older people (Wittenberg et al., 2020). Current UK, US and global PA guidelines promote the cognitive benefits of both regular, long-term PA and brief bouts for cognitively healthy adults and older adults (Davies et al., 2019; Powell et al., 2018; World Health Organization, 2020b).

Meta-analyses of prospective and longitudinal studies found that higher levels of PA are associated with a reduced risk of developing cognitive impairment including dementia and Alzheimer's disease (Blondell et al., 2014; Hamer & Chida, 2009). Figures cited for risk reduction for dementia ranged from 18-28%. Research also indicates that aerobic-based PA interventions may be beneficial for older adults with dementia (Groot et al., 2016). However, a Cochrane review did not find a relationship between PA or cardiorespiratory fitness and cognitive function in cognitively healthy older adults: the authors suggested that other factors may influence the relationship including lower baseline fitness, age and social network (Young et al., 2015). Findings from Sabia et al. (2017) also found no evidence for a neuroprotective effect for cognitive decline and dementia, using data from the Whitehall II study with PA assessed longitudinally seven times over 28 years. These mixed findings suggest that the relationship between PA and cognitive health is complex and may be influenced by modifying factors including socioeconomic status, cardiovascular risk factors and other health behaviours.

PA modality for older adults may be an additional influencing factor. PA interventions aimed at enhancing brain and cognitive function in older adults found association is supported across a range of different activities, including muscle strengthening (Liu-Ambrose et al., 2010), Tai Chi (Zheng et al., 2015) and walking (Oppezzo & Schwartz, 2014), and at different intensities. Chen and Nakagawa (2023) suggest that PA at different intensities may influence different biomarkers of brain health, such that aerobic activities and strength training primarily promote the release of growth factors while Tai Chi and Yoga are the primary activities that reduce inflammation and decrease oxidative stress. A meta-analysis of randomised controlled trials (RCTs) in adults aged 50 years or older found that a combination of aerobic and RT at moderate to vigorous intensity may be optimal, in line with current PA guidelines (Northey et al., 2018). Falck et al. (2019) add further support to these recommendations and assert that PA can reduce the risk of both cognitive and physical frailty. In relation to a potential dose-response association, analysis of data from a national sample of older adults aged 60-85 years found an inverted U-shaped relationship such that there may be an optimal range of MVPA to protect older adults from age-related cognitive decline (Loprinzi et al., 2018). This optimal dose might also explain the lack of consistent positive findings for PA and cognitive function outlined above.

1.2.7 Ageing, Stress and PA

Stress can exert a profound influence on individual well-being, health and function across the life course. It can affect health directly via neuroendocrine and autonomic responses, and

indirectly via changes to health behaviours, including eating and sleep patterns (O'Connor et al., 2021). Considerable evidence has established that chronic stress can have a detrimental effect on cardiovascular and endocrine systems, and may accelerate earlier onset of age-related chronic disease e.g., diabetes, hypertension and metabolic syndrome (Polsky et al., 2022). Research also indicates that stress can have a substantial effect on brain health: age-related changes in the regulation of the stress-response have been linked to later-life depression and anxiety, cognitive decline and cognition disorders (McEwen, 2006).

Reduced stress resistance is a part of the fundamental biological process of ageing. Ageing is broadly considered to compromise the body's ability to cope with both acute and chronic stress (Sapolsky, 1999) and age-related changes to the endocrine system are well documented. Hypothalamic dysfunction, for example, is an important mechanism involved in ageing and the development of age-related disease. During ageing, changes to the secretory patterns of hormones produced by the hypothalamic-pituitary-adrenal axis (HPA) and its sensitivity to negative feedback systems contribute to dysregulation and have been shown to have a significant negative impact on immune function. Importantly, excessive activation of the HPA axis can also contribute to hippocampal neuronal loss which may be a factor in cognitive impairment in older adults (Ouanes & Popp, 2019).

Chronically elevated psychosocial stress has also been linked to an acceleration of the ageing process via an accumulated burden of inflammation and oxidative stress (Lopez-Otin et al., 2013, 2023). Subsequently it has been proposed that stress and ageing may affect the body through several shared mechanisms, and demonstrate similar outcomes including changes in signalling proteins, thymic atrophy and telomere length (Polsky et al., 2022; Vitlic et al., 2014).

As potential biomarkers of ageing, Lara et al. (2015) highlighted the HPA axis, sex and growth hormones. Specifically, decreased levels of dehydroepiandrosterone (DHEAS), a sex steroid generally considered to have an immuno-enhancing ability, has been linked with increased mortality risk and physical frailty (Clegg, 2013). Research indicates that levels of DHEAS decline from the third decade onwards (Lazarus et al., 2019) with concentrations reported to be approximately 20% of peak values in men and 30% in women by age 70-80 years (van den Beld et al., 2018). This is often alongside either an unaltered or slight increase in cortisol levels (Moffat et al., 2020) which is generally considered to be immunosuppressive and anti-inflammatory. Subsequently this results in a higher cortisol:DHEAS ratio and this has been associated with mortality, dementia, metabolic syndrome, reduced immunity following physical stress, and has been reported to be an independent risk factor for sarcopenia in older adults

(Bauer, 2005; Yanagita et al., 2019). However, researchers and clinicians agree that further longitudinal research is needed to improve understanding of the relationships between cortisol, DHEAS, cortisol:DHEAS ratio and ageing and frailty (Lara et al., 2015). Thus far, the literature highlights the important detrimental impact of stress on health and healthy ageing, including effects on immunity, cognition, mental health, and increased risk of disease. The cortisol:DHEAS ratio is one pathway through which ageing and stress interact to affect health.

One of the wider benefits of PA for all age groups is as an effective stress management tool. Research indicates that PA may have a positive protective impact and a stress reducing or regulating effect (Hamer et al., 2012). Further, there is growing evidence to suggest that PA is associated with lower levels of perceived stress (Stults-Kolehmainen & Sinha, 2014), and it may have a regulating effect on physiological stress reactivity (Caplin et al., 2021). PA may influence measures of stress via different pathways including improved regulation of stress reactions via HPA axis and/or autonomic nervous system. Although an acute bout of exercise increases cortisol levels (Hill et al., 2008), longer term engagement in PA such as in a PA intervention has been related to lowered cortisol levels (De Nys et al., 2022). Further, PA can increase brain neurotransmitters including dopamine and serotonin; reduce negative effects of stress; and ease stress level and improve mood, often in relation to improvements in sleep and reduction in levels of anxiety and/or depression. Regular PA may also be able to buffer negative effects of stress on the immune response (Phillips et al., 2007) potentially through reducing the impact of psychological stress on cortisol levels (Heaney et al., 2014).

PA has a role in regulating psychological well-being in older adults and more time spent being physically active is associated with lower levels of perceived stress (McHugh & Lawlor, 2012). Recent systematic reviews and meta-analyses in older adults suggested that PA interventions could improve stress outcomes but identified a scarcity of quality RCTs to substantiate this (De Nys et al., 2022), and found that regular PA beneficially improved cortisol and/or DHEAS levels (De Nys et al., 2023). While there was some evidence to suggest that light-moderate PA, either aerobic or mind-body activity, may be beneficial, it was recommended that older adults choose any enjoyable PA that they would do regularly and maintain long-term.

Regarding a potential protective role of PA on managing daily life stress, evidence suggests that PA may boost older adults' ability to manage affective responses to stressors (Leger et al., 2023; Pauly et al., 2019). Further, investigation into the potential protective daily benefits of PA in older adults found that any amount of purposeful physical exercise lowered daily stress measures (Whitehead & Blaxton, 2017). Given the role of stress in the precipitation

of other mental ill health symptoms such as anxiety and depression (Schless et al., 1977), reducing stress is another mechanism by which PA can benefit overall mental health.

1.2.8 Ageing, Immunosenescence and Inflammation (Biomarkers), and PA

An effective immune system is vital to health across the life course. A decline in immune system function and age-related remodelling, termed 'immunosenescence', is an important driver of ageing and associated with an increased susceptibility to infections, reduced ability to respond to vaccines and increased risk of chronic inflammatory diseases (Lazarus et al., 2019; Phillips et al., 2007). Existing research has suggested that an age-related rise in basal inflammatory response leads to chronic, non-resolving low-grade inflammation or 'inflammageing' (Ferrucci & Fabbri, 2018; Franceschi et al., 2000). In a recent review Pilotto et al. (2020) noted that the presence of inflammageing and high levels of oxidative stress may compromise key regulatory mechanisms of ageing in frail older adults.

High levels of age-associated pro-inflammatory markers are found in most older adults, even in the absence of chronic disease, and chronic inflammation is increasingly recognised as a hallmark of ageing (Lopez-Otin et al., 2013, 2023). Inflammatory cytokines are a reliable measure of overall systemic inflammation. Age-related changes representative of inflammageing are indicated by elevated blood concentrations of pro-inflammatory cytokines and acute phase reactants e.g., interleukin-6 (IL-6) and C-reactive protein (CRP) and a reduced serum level of anti-inflammatory cytokines, including interleukin-10 (Bruunsgaard, 2002; Han & Meydani, 2000; Rohde et al., 1999). CRP is an accepted clinical measure of inflammation with elevated levels linked to poor cardiovascular prognosis including an increased risk of atherosclerosis (Baylis et al., 2013), and increasingly used as a marker for frailty diagnosis (Teissier et al., 2022). A recent review by Teissier et al. (2022) indicated that measures of CRP and IL-6 correlate well with chronological age, poor physical performance and increased mortality rate as reported in longitudinal studies.

Other biomarkers of ageing and inflammation include tumour necrosis factor alpha (TNF-α) and interferon gamma (IFN-γ). TNF-α is a pro-inflammatory cytokine and master regulator of the innate immune response, with increasing levels longitudinally associated with ageing, declining cognitive status and frailty. Emerging evidence suggests that it may also have a possible role in age-related neurodegenerative diseases including Alzheimer's disease (Lindbergh et al., 2020). IFN-γ is another pro-inflammatory cytokine critical for innate and

adaptive immunity with studies suggesting that a IFN-γ inducible inflammation cascade may contribute to cognitive dysfunction and depression in older adults (Oxenkrug, 2011).

Research indicates that typically elevated levels of inflammatory cytokines including TNF-α, TNF-β, and IL- 6 can blunt the insulin-like growth factor 1 (IGF-1)-mediated effects in skeletal muscle. This may also negatively impact on spinal motor neurons and axons (Aagaard et al., 2010) and contribute to dysregulated muscle homeostasis (Wilson et al., 2017). A growing body of research has identified an association between chronically elevated IL-6 and TNF-α with frailty, and the development of sarcopenia (Rong et al., 2018; Wilson et al., 2017).

A community-based prospective cohort study comprising 1554 older adults including 684 centenarians (100-104 years) and semi-supercentenarians (105 years or more) and their offspring from the Tokyo Centenarians Study and the Japanese Semi-supercentenarians Study found that low level inflammation, after chronological age, was the most important correlate of survival, capability and cognition (Arai et al., 2015). The researchers concluded that over all groups combined, the suppression of inflammation was the primary driver of healthy longevity. A growing evidence base also links chronic age-related inflammation to an increased risk of cognitive decline and dementia, with further potential to trigger neuroinflammatory changes and degeneration in limbic and associated brain structures (Sartori et al., 2012). Taken together these studies highlight the important role of inflammation in ageing, and its broad ranging impact from effects on immunity to cognition, mental health, physical function and frailty.

As touched on above, the immune system is directly influenced by PA. Large population-based cohort studies have consistently shown an association between regular PA and inflammation, such that more frequent and intense PA is linked with lower levels of measures of systemic inflammation (Beavers et al., 2010; Kasapis & Thompson, 2005). Regular bouts of MVPA have been shown to be protective against immune and inflammatory dysregulation and reduce the risk of the development of diseases associated with chronic inflammation including insulin resistance and atherosclerosis (Gleeson et al., 2011). PA interventions may also reduce the risk of infection, improve anti-viral immunity (Duggal et al., 2019) and may improve disease symptoms in inflammatory and autoimmune disorders including rheumatoid arthritis (Benatti & Pedersen, 2015). Maintenance of muscle tissue mass via strengthening exercise is of specific note as skeletal muscle tissue is now recognised as a major immune regulatory organ. RT at all ages has been shown to positively impact on immune function, markers of inflammation and improve indices of insulin sensitivity (McLeod et al., 2019).

Regular PA is associated with enhanced immunity in older adults. Accumulating evidence indicates that PA can regulate the immune system and moderate or delay the onset of immunosenescence. A review by Duggal et al. (2019) found that maintaining levels of PA has immune benefits for older adults including the reduction of chronic systemic inflammation and may subsequently reduce the risk of frailty and mortality. Regular PA has been shown to reduce levels of circulating IL-6 and TNFα independent of any reductions in adiposity (Simpson et al., 2012) suggesting that the mechanism of influence is not simply due to the reduction in inflammatory cytokine-producing adipose tissue. Assessment of the immune profiles of 125 older adults who maintained lifelong high levels of PA compared to more sedentary older adults found reduced evidence of a decline in thymic output and inflammaging, high serum levels of thymoprotective cytokines and lower IL-6 (Duggal et al., 2018). However, even high levels of lifelong PA did not protect against all aspects of immunosenescence, such as an increase in the frequency of CD8 memory T cells and accumulation of senescent T cells. A recent systematic review reported significant anti-inflammatory effects of physical exercise interventions in older adults (Bautmans et al., 2021). Findings indicated that while the anti-inflammatory effect differed with types and combinations of PA, lower measures of circulating levels of CRP, IL-6 and TNFα were consistently reported. A possible mechanism by which PA exerts this effect may be via an increased production and release of myokines from working skeletal muscle. However, literature regarding the impact of PA on frail, older adults was noted as being extremely scarce.

Regarding the required levels of PA to positively impact immune function, a cross-sectional study of 211 healthy older adults found that moderate levels of habitual PA (10-15,000 steps per day) were positively associated with measures of T-cell ageing (Bartlett & Duggal, 2020). While more moderate PA did not have the same broad effect as lifelong high levels of PA, it still indicated a beneficial and effective approach to optimising immune function in older adults. Earlier work by Phillips et al. (2007) also indicated that regular moderate aerobic exercise may positively impact immunity in older adults experiencing chronic psychological stress. Consequently, the mechanisms of influence on health by PA are again shown to be diverse and include direct physiological effects within the immune system and indirect effects potentially via influencing the response to stress.

1.2.9 Ageing, Nutrition/Diet and PA

Nutrition plays an important role in healthy ageing. Nutritional status can be a mediating factor in ageing and frailty and has been linked to measures of physical function, muscle

strength and mass, and chronic inflammation (Whittaker et al., 2019). Ageing can also negatively impact appetite and nutritional intake, which may predispose older adults to becoming undernourished or malnourished.

Nutrition is a feature of most measures of frailty and often a key part of multimodal interventions with energy and protein intake as the central determinants of nutritional status. Research indicates that maintaining a healthy body composition is foundational to optimal health across the life course, with excessive adiposity linked to increased risk of several chronic diseases including diabetes, cardiovascular disease and cancer (American College of Sports Medicine, 2018). However, as unintentional weight loss is a key feature of frailty in older adults, undernutrition and malnutrition (diet quality) are of primary interest in this context. A recent systematic review and meta-analysis of malnutrition risk of European older adults in community, residential and hospital settings reported pooled prevalence rates of 8.5%, 17.5% and 28.0%, respectively (Leij-Halfwerk et al., 2019).

Malnutrition has an important role in the pathogenesis of both frailty and sarcopenia, particularly in relation to protein intake (Cruz-Jentoft et al., 2017). Research suggests that healthy older adults often have a sub-optimal protein intake and that this may be worse for those with acute or chronic disease (Bauer et al., 2013; Clegg & Williams, 2018). Specifically, this mismatch between protein supply and demand, in association with a chronic disruption between protein synthesis and degradation, can accelerate skeletal muscle mass loss. This underpins the potential development of muscle weakness and dysfunction seen in sarcopenia and is related to progressive functional disability (Cruz-Jentoft, 2017). While the mechanisms that underpin the decline in food intake with ageing are not yet fully understood, research suggests that changes to the endocrine system, specifically factors involved in appetite regulation, may be implicated (Cruz-Jentoft et al. (2017). This may result in significant and clinically relevant changes to appetite (van den Beld et al., 2018) particularly in frail older adults (Clegg & Williams, 2018).

Research indicates that undernutrition and weight loss are commonly observed in older adults with progressive cognitive decline and Alzheimer's disease (Shlisky et al., 2017). Different diet strategies, including the Mediterranean diet, have been proposed to positively impact on brain structure and cognitive function, and may lower the risk of mild cognitive decline (Valls-Pedret et al., 2015). Although the findings are inconclusive, positive effects may be linked to decreases in oxidative stress and inflammation (Leitao et al., 2022; Samadi et al., 2019). Again, the body of research in this area indicates a bi-directional and complex relationship between nutritional status, and cognitive and physical health among older adults, with an associated

impact on physical function and independence, indicating a probable need for interventions in later life, particularly in the context of frailty.

There is a clear relationship between PA and nutrition in relation to functional and metabolic adaptations. As combined lifestyle factors, PA and healthy nutrition offer robust benefits to musculoskeletal health, body composition and reduced risk of metabolic disease across all ages and stages of life. Energy availability is also an important factor for multidimensional health and optimal function, and this requires consideration of energy intake in relation to energy demands (Hall et al., 2012).

Research suggests that a dual approach of PA and high-quality nutrition with optimal energy availability can positively impact measures of functional capacity, reduce the risk of frailty and disability, and contribute to ageing well (Izquierdo & Fiatarone Singh, 2023). However, research into nutritional supplementation has reported mixed findings. Thomas et al. (2016) found that protein supplementation did not significantly enhance the effects of progressive resistance exercise whereas Finger et al. (2015) did report changes in fat-free mass but no association with changes in muscle mass and strength. Further, a recent umbrella review found no overall evidence of benefit for additional nutritional supplementation with group-based PA interventions with community dwelling older adults (Neil-Sztramko et al., 2022). In contrast, in relation to preventing or offsetting sarcopenia, International Exercise Recommendations in Older Adults propose that the additive effect of protein supplementation in conjunction with resistance exercise could be beneficial, especially for frail older adults in residential care (Izquierdo et al., 2021).

Current consensus statements recommend a holistic approach including physical and nutritional intervention, particularly in aged care settings or for individuals with dementia (Izquierdo et al., 2021), and for those with complex geriatric syndromes, such as frailty or sarcopenia (Cruz-Jentoft et al., 2017). However, given the complexity of administering personalised dietary and PA interventions simultaneously in older adults (Lorbergs et al., 2022), particularly those in care home settings, this is beyond the scope of many trials and the present thesis.

1.3 Resistance Training for Lifelong Health

1.3.1 RT for Health

The health benefits of developing and maintaining muscle mass, strength and physical function are well established. Higher strength levels are associated with a significantly improved cardiometabolic risk factor profile, fewer CVD events, decreased injury rates, and lower risk of all-cause mortality (Garcia-Hermoso et al., 2018). Current UK and global PA guidelines give a strong recommendation that all adults should do muscle strengthening activities at moderate or greater intensity that involve all major muscle groups on two or more days of the week (Davies et al., 2019; World Health Organization, 2020b). RT is an efficient and effective strength-promoting activity and a robust countermeasure to muscle and strength loss (Phillips, 2010). It can be defined as a specialised method of physical conditioning whereby an individual is working against a wide range of resistive loads to enhance health, fitness and performance (Lloyd & Faigenbaum, 2015). RT also positively impacts other musculoskeletal tissues including articular cartilage, tendon and bone (Maestroni et al., 2020).

Adults of all ages and abilities who regularly engage in muscle strengthening activities reduce chronic disease risk, improve quality of life, and improve or maintain their physical functioning (Momma et al., 2022). A systematic review and pooled analysis found that participation in any strength promoting exercise was associated with a 23% reduction in all-cause mortality and a 31% reduction in cancer mortality (Stamatakis et al., 2018). Of note is the ability of RT to improve future health outcomes at life transitions, including menopause, onset/diagnosis of disease or following hospitalisation (Skelton & Mavroeidi, 2018a). RT can help with the management and treatment of many common health conditions including depression, anxiety, CVD, chronic lower back pain, osteoarthritis, and hypertension (Gordon et al., 2018; Gordon et al., 2017). Recent evidence indicates that regular RT is associated with positive changes in multiple health-related biomarkers including insulin sensitivity, body composition (including measures of visceral fat) and blood pressure (American College of Sports Medicine, 2018; Casonatto et al., 2016). Accordingly, RT is increasingly recommended for the prevention and management of type 2 diabetes and metabolic disorders (Qadir et al., 2021; Westcott, 2012). RT has also been shown to be a safe and effective way to improve physical function, muscle mass and strength, and quality of life in cardiac rehabilitation and cancer patients (Cormie et al., 2013; Kirkman et al., 2022).

Despite the unique physical and mental health benefits of engaging in regular RT, and a growing consensus that RT can be as effective as aerobic training in reducing chronic disease risk, the RT guidelines are often the 'forgotten' element': both less well known and less often achieved (Strain et al., 2016). This is especially true of older adults with the 2021 Health Survey for England reporting that only 17% of those aged 65 or over met the muscle strengthening guidelines (NHS Digital, 2023). Similarly, a recent publication, to which the candidate contributed, showed that only 12% of Scottish older adults surveyed during COVID met the guidelines of strength training at least twice a week (Tomaz et al., 2022).

1.3.2 RT for Older Adults

Although RT for older adults may often be overlooked, the benefits cannot be overstated. Robust evidence recognises the unique ability of RT to improve muscle strength, mass and function, and mitigate age-related declines in neuromuscular control, rate of force development (RFD), bone mineral density, and associated metabolic dysregulation (Fragala et al., 2019; McLeod et al., 2019). Studies consistently show that RT can positively impact mobility, physical function, mood, movement confidence, ability to carry out ADL, and preserve independence and quality of life for older adults. Notably, while lifelong RT is ideal, it is never too late to start.

In relation to muscle function, Aagaard et al. (2010) noted a 'marked juvenilization' such that measures of maximal strength, RFD and power in RT older trained adults were equivalent to those of adults approximately 20 years younger. Regarding changes in muscle mass, RT is a powerful stimulus for skeletal muscle hypertrophy across older age groups. A meta-analysis of 49 RCTs found a strong association between full body RT for an average of 20.5 weeks and increased lean body mass in older men and women (65.5 $\pm$ 6.5 years) (Peterson et al., 2011). Further, a recent systematic review and meta-analysis of RCTs found that RT produced substantial increases in muscle strength and whole-muscle hypertrophy for older adults aged 75 years or more (Grgic et al., 2020). Subgroup analysis that included the oldest-old (85+ years) also found a significant effect, with minimal reports of any adverse events from all training studies analysed. Interestingly, chronic inflammation, which is considered to contribute to loss of muscle mass, is also positively impacted by RT, such that both a single bout and long-term adherence reduce inflammatory reactivity and overall inflammation (as measured by TNF-α and CRP) (Phillips et al., 2010; Sardeli et al., 2018). These combined findings indicate that RT interventions can mitigate age-related loss of muscle mass and strength, even in the oldest-old, and that muscle disuse is a preventable and reversible condition.

In terms of functional ability, a Cochrane review found that progressive RT is an effective intervention for improving physical function in older adults (Liu & Latham, 2009). Benefits were reported across a range of functional measures including TUG test, timed chair rise and balance. Specific improvements in lower limb force generation have also been reported to positively impact balance, walking speed, stair climbing and functional mobility (Papa et al., 2017). This is of particular importance as research clearly indicates that preserving balance and physical function in older adults is integral to maintaining quality of life and mental well-being by reducing both the fear and the risk of falls, fractures, and physical limitations (Fragala et al., 2019; Skelton & Mavroeidi, 2018a).

With respect to mental health and well-being, RT interventions with older adults have been shown to improve overall mood (McLafferty et al., 2004), improve sleep quality (de Sa Souza et al., 2022), reduce trait anxiety (Cassilhas et al., 2010), improve symptoms of depression (Miller et al., 2020) and self-esteem (Dionigi & Cannon, 2009). In addition, recent meta-analyses found that RT improved overall cognitive function in cognitively healthy and cognitively impaired older adults (Coelho-Junior et al., 2022; Zhang et al., 2020).

There is a growing argument that RT is the leading treatment strategy to prevent functional decline in older adults such that it is equal, and in some circumstances superior, to other types of PA (McLeod et al., 2019) particularly if significant deficits in strength or balance are identified (Izquierdo et al., 2021). RT-induced benefits can also have direct effect on the management of chronic health conditions, including arthritis, and as a component of cardiac rehabilitation (Khadanga et al., 2019). Notable examples of this are current evidence-based recommendations which offer clear support of progressive RT as a safe and effective intervention for the treatment and prevention of sarcopenia, osteoporosis, and osteosarcopenia (Atlihan et al., 2021; N. Chen et al., 2021; Izquierdo et al., 2021).

1.3.3 RT for Frail Older Adults

An emerging body of research also now recognises RT as a primary countermeasure for physical frailty (Fragala et al., 2019; McLeod et al., 2019) with potential to reverse the loss of functional capacity and change the trajectory of disease (Bray et al., 2016; Coelho-Junior et al., 2021; Lopez et al., 2018).

Frailty is a manageable condition (Morley et al., 2013) and has consistently been shown to be responsive to RT intervention. Seminal research by Fiatarone et al. (1990) found that progressive RT led to highly significant and clinically meaningful change in muscle strength, size

and functional mobility in frail nonagenarians with reported improvements of 174% and 48% for mean strength and tandem gait speed, respectively. More recent findings have supported this original work. A systematic review by Lopez et al. (2018) found that RT alone or in combination with additional balance/gait training, led to increases of 6.6-37.0% in maximal strength, 3.4-7.5% in muscle mass, 8.2% muscle power and 4.7-58.1% in measures of functional capacity in frail older adults. Functional measures included gait speed, sit-to-stand test and SPPB. Similarly, a recent systematic review and meta-analysis of RCTs reported that RT during early stage frailty (pre-frailty) had positive effects across all measures of strength, physical function and body composition (Talar et al., 2021). Reported functional measures included gait speed and chair sit-to-stand which appear strongly related to increases in lower limb strength. These positive findings reiterate the need for an early, proactive approach with pre-frail older adults as research indicates that they may respond better than those who have already moved to a frail state (Faber et al., 2006; Kidd et al., 2019; Vermeiren et al., 2016). Further, an umbrella review by Jadczak et al. (2018), in agreement with a systematic review by Cadore et al. (2013), supported the importance of RT (either alone or as part of a multicomponent programme) to enhance strength gains in frail and pre-frail older adults. Overall, these combined outcomes demonstrate that RT is a safe and highly effective strategy to improve muscle strength and physical function in frail older adults.

Although research has not yet identified the optimal prescription to reverse frailty, structured RT is increasingly cited as being the likely best therapy (Bray et al., 2016). Of note in this respect, is a study by Tarazona-Santabalbina et al. (2016) which included RT as part of a supervised multi-component programme, and reported a reversal of frailty and improved cognitive, emotional and social networking in community dwelling frail, older adults. In line with this, current PA guidelines are increasingly acknowledging that the benefits of RT outweigh the risks for frail older adults (Izquierdo et al., 2021) and that it may be a viable strategy to reverse or slow frailty (Fragala et al., 2019). International recommendations are clear that the treatment for frailty should focus on improvements in physical function and that it is no longer justifiable to not prescribe physical exercise. Izquierdo et al. (2021) state that even extreme frailty is not a contraindication to high-intensity RT, rather that frailty is one of the most crucial reasons to prescribe regular training. Other international guidance for the management of frailty echo these statements with clinical practice guidelines recommending that first-line therapy for frailty should include a resistance-based training component (Dent, Morley, et al., 2019).

1.3.4 RT in Residential Care Homes

Residential care, sometimes called long-term care, is the provision of accommodation and personal care for older people who need extra support in their daily lives, due to an increased dependency (Age UK., 2022; Van Malderen et al., 2013). In the UK, provision is usually termed as through care homes (with carer support but limited nursing care) or nursing homes (with nursing care as well as personal care and support, and assistance with everyday activities). Residential care is the terminology regularly used in the USA, thus appears in many publications. There are 17,079 care homes in the UK, and an estimated 408,371 older adults currently live in residential care in the UK (Berg, 2023).

There is less available literature about RT interventions in care home settings, however, RT interventions can be adapted to accommodate frail, older adults in residential care and existing data, albeit limited, is encouraging. Overall, studies suggest that RT is positively associated with improvements in muscle mass, strength and functional capacity and that frail and functionally impaired older adults living in residential care facilities have the capacity for physical adaptation (Fragala et al., 2019). With regard to physical function, a systematic review by Valenzuela (2012) identified that progressive RT interventions had a positive effect on strength and functional measures in older adults (mean cohort age range 80-89 years) living in a nursing home. Significant improvements were reported in sit-to-stand time, gait speed and stair climbing despite older age, presence of chronic disease and functional disabilities. RT was found to be an effective means to preserve independence and improve the ability to complete ADL. A more recent systematic review and meta-analysis of RCT's also found exercise interventions, including RT studies, for older adults in residential care were associated with improved physical function and functional independence (Valenzuela et al., 2023). Interestingly the combined literature did not include any reported adverse events, thus supporting RT as both safe and effective with this population group.

Resistance training for frail older adults in residential care is regarded as one of the most important and effective interventions to positively impact on physical function, and a vital treatment for sarcopenia and frailty (Izquierdo & Fiatarone Singh, 2023). National Strength and Conditioning Association (NSCA) resistance training guidelines for older adults with frailty recommend a frequency of two-three times per week, with three sets of 8-12 repetitions at an intensity that starts at 20–30% of 1RM and progresses to 80% of 1RM (Fragala et al., 2019). American College of Sports Medicine (ACSM) also encourage progressive weight-training

programmes for older adults on two or more days of the week with one to three sets of 8-12 repetitions increasing from light/moderate intensity (5-6) to vigorous (7-8) on a 1-10 scale and including all major muscle groups (American College of Sports Medicine, 2018). Clear guidance should also be given to ensure that all exercises are performed with proper form and technique, and that these should be both confirmed before exercise progression and maintained during progression. ACSM special considerations for exercise programming for frailty and sarcopenia acknowledge that these participants need to increase muscular strength as a priority: muscle weakness will limit or even preclude engagement in traditional aerobic conditioning (American College of Sports Medicine, 2018). The priority for frail older adults, and particularly for those with no previous experience of resistance training, is to build movement skill and competency while progressively challenging strength: 'teach them to move well and get them stronger, repeat'.

International physical activity and exercise recommendations for older adults in long-term residential care acknowledge the medical complexity of this population and suggest that current guidance (including those cited above) may be more appropriate for healthy community dwelling older adults (de Souto Barreto et al., 2016). While keen to stress that recommendations are not a 'one-size-fits-all' approach, and encouraging a flexible format, the authors still strongly support the use of resistance training with those in residential care with particular emphasis on lower body strength, and before the introduction of balance and/or coordination training, particularly with vulnerable individuals. Specific recommendations are for one to two sets of exercises performed at 13-15 repetitions with the number of exercises performed to be limited by individual capacity, but ideally between 8-10.

While it is evident that resistance training prescription should be individualised and based on the intended outcome there is, as yet, no clear understanding of the optimal dose required to prevent or treat frailty such that pre-frail and frail older adults may require different prescriptions. Further research into this is warranted and would require resistance training interventions with differing levels of frailty i.e. frail or pre-frail, and training prescriptions.

Despite the mounting evidence that RT interventions are safe and effective for combatting frailty, older adults in residential care remain an often-overlooked group. This is potentially due to higher frailty levels, reduced physical independence and functional ability, and the perceived difficulty of providing a feasible RT intervention for individuals with a range of comorbidities and potential limitations. Additional barriers may include potential health and injury risks, adherence levels, and cognitive decline and compromised health status (Ferrucci et al.,

2004). Further, the ability to tolerate strength testing may be a concern. Safe and reliable testing protocols and equipment are required to ensure accurate evaluation and confidently detect meaningful changes in force production. However, despite being commonly used in rehabilitation and clinical research (Buckinx et al., 2019; Sarabon et al., 2021) and consistently shown to be clinically appropriate for older adults (Arnold et al., 2010), the appropriateness and reliability for maximal muscle strength measures has not been clearly defined in frail populations with no previous training or testing experience. Research also suggests that frail older adults may themselves be reticent to participate in RT interventions. This may be due to fear of falling, comorbidities, and injury risk, over-exertion, and changes to habitual routines (Finnegan et al., 2015; Franco et al., 2015). Consequently, research investigating progressive RT interventions in residential care homes is limited and focuses primarily on measures of functional ability.

Notably, what is not yet clear is the quantifiable impact of RT, particularly in a group setting, on multi-factorial health and well-being outcomes in frail and pre-frail older adults in residential care, from psychosocial variables through to cognitive, physical function, and emotional outcomes. Given the increased ageing of the population, and proportion of older adults living in residential care, research to assess the feasibility and impact of RT on measures of multidimensional health, well-being, and physical function is both timely and urgent.

1.4 Thesis Aims

Overall, the gaps highlighted in the background review indicated:

- Limited data on the impact of RT on strength and physical function for frail and pre-frail older adults in residential care;
- Limited data on the impact of RT on multidimensional health and well-being, inclusive of physiological, psychological, social, immunological, and cognitive health for frail and pre-frail older adults;
- No interventions that have evaluated the impact of individualised, progressive group-based RT on comprehensive multidimensional health and well-being measures with frail and pre-frail care home residents;
- Limited data on the reliability of maximal strength measures with frail and pre-frail older adults and;
- No standardised maximal strength testing protocols for frail and pre-frail older adults in residential care with no prior testing or training experience.

This thesis will address these gaps in the existing research through the following aims:

1. Assess the feasibility of future definitive randomised controlled trials (RCTs) using a RT intervention with (a) frail and (b) pre-frail older adults in residential care.
2. Perform limited efficacy testing on measures of multidimensional health from pre- to post-intervention compared to the wait-list control. These measures include physiological, psychological, cognitive, and emotional health measures, and functional capacity, and are intended as the primary dependent variables in the future definitive RCT.
3. Establish within-session reliability for muscle strength tests in frail and pre-frail older adults using lower limb isometric strength measures and handgrip strength.

The specific objectives arising from these aims are to (a) evaluate the experiences of the intended recipients, well-being team and care staff; (b) determine actual interest, use and adherence levels to the RT intervention; (c) evaluate the level of organisational change required including perceived fit into the existing culture and structure; (d) determine the practicality of the RT intervention with frail and pre-frail older adults in residential care; (e) evaluate the suitability and relevance of the selected measures of multidimensional health; (f) examine changes pre- to post-intervention compared to the wait-list control in measures of multidimensional health using mean differences, effect size and meaningful change; (g) quantify the repeatability of lower limb isometric strength measures and handgrip strength within one session; and (h) relate this to the feasibility and appropriateness of field-based maximal strength testing measures with frail and pre-frail older adults.

1.5 Thesis Outline

The remaining chapters of this thesis include three original research studies (Chapters Two, Three and Four) and a final chapter (Chapter Five) which provides an overall thesis discussion and conclusion based on these previous Chapters. The thesis proceeds as follows: Chapter Two describes a randomised controlled feasibility trial which evaluated a RT intervention with frail older adults in residential care; Chapter Three presents the findings of a randomised controlled feasibility study of RT with pre-frail older adults in residential care; Chapter Four examines the reliability and suitability of strength assessments in frail and pre-frail

older adults; and Chapter Five provides an overall discussion of the primary findings and original contribution to the current body of knowledge.

Preface to Chapters Two and Three

The research presented in this thesis was conducted in a single UK residential care home. This section gives further detail of the study site used for both trials and the reasons for conducting separate feasibility studies with frail and pre-frail older adults.

Trial Site

The trial site selected for the studies presented in this thesis was a care home in central Birmingham, UK, initially approached due to management support of healthy ageing and research initiatives, a dedicated well-being team and strong sense of community. It was based in a mid-ranking city ward for deprivation level, with a similar age profile and ethnic make-up as Birmingham as a whole: older adults over 65 years were 13.2% of the population with 48.6% of residents identifying their ethnic group within the “white” category (Office for National Statistics, 2023).

The care home was part of the Christadelphians Care Home group which had nine different UK locations, and was a unique facility which included residential, nursing and dementia care in one setting, allowing older adults with varying care needs to live together in a supportive community. It provided personal and nursing care for up to 68 people. Residents within the care home had differing abilities ranging from a requirement for daily support for personal care needs and with activities of daily living, to more comprehensive full-time support in the dementia unit. Residents living in the independent living apartments were often married couples and were supported with a daily check in telephone call from care team staff. Residential/respite care was also provided. Christian faith was of high importance to residents and they were supported to practice their faith with daily bible reading sessions and weekly services. The wellbeing team were integral to the development and provision of activities including local outings, hymn-singing, art class, films and music-and-movement class. During the studies included in this PhD thesis, the wellbeing team comprised three staff members (one full-time) and several volunteers. Their involvement and support of the resistance training interventions was voluntary and the researcher aimed to minimise any additional burden on their time.

The initial approach and discussion with the care home was facilitated by the Principal Investigator (PI), Professor Whittaker, in November 2018, through her role at the University of Birmingham and an on-site meeting was attended by the PI, the researcher and a representative of the equipment supplier to consider the proposal. The initial meeting was positive and included

discussion about when the project could start, where and when the equipment could be installed, and potential numbers of residents and staff involvement. The trial site was confirmed in January 2019 and, after further consultation with the equipment suppliers and the care home management team in relation to equipment location and space requirements, the equipment was installed in the main lounge in February 2019, prior to the first trial starting. The researcher had several on-site meetings with care staff, management and equipment suppliers throughout January and February, and worked to build trust and rapport with all parties in this time. This included time to discuss the possible benefits and disadvantages of locating the equipment in the residents' communal lounge space, demonstrating the equipment, and reassuring staff that both sessions and testing would not conflict with already scheduled activities.

Lessons Learned

The initial study protocol was designed for frail older adults with eligibility criteria requiring that participants had a frailty diagnosis according to the Fried frailty phenotype i.e., having at least three of the five Fried frailty phenotype criteria (adapted from Fried et al. (2001).

However, as the initial KARE trial progressed (Chapter 2) and following discussions with the PI, care home management and wellbeing staff, and conversations with care home residents, it became increasingly clear that it may be feasible to trial the RT intervention with a less frail (potentially classifiable as 'pre-frail') group. Indeed, some of the residents who consented to pre-screening but were then classified as pre-frail were disappointed not to be eligible for the intervention. Other than for these individuals who went through screening, while there was no objective measurement of frailty in the residential care home by care staff of all residents to see how many would be considered pre-frail, it was apparent that levels of physical function and capacity differed from those in the frail group simply by observing the physical capability i.e., gait speed and movement ability, as residents engaged in other wellbeing activities in the lounge. Additionally, some residents who had not initially expressed any interest in the study and new residents who moved into the expanding supported living accommodation/flats during the first trial, once they saw the first trial taking place, were keen to benefit from the use of the RT equipment and interested in being part of the research. Taken together, this gave us the idea of running a 'pre-frail' version of the intervention, and it seemed only ethical to be able to offer this to those potentially eligible residents if possible.

This was an important lesson to learn, not least as it reinforced the heterogeneity of older adults in residential care settings and a need to recognise individual capabilities and interests. It

highlighted that frailty exists on a continuum and that physical limitations are an integral part of recognising transitions and trajectories between frail states. It also indicated that it takes time for an intervention, particularly a RT one, to gain broader acceptability with older adults and care staff including time to build relationships and rapport with instructors, and acceptability of having the equipment in their living area and research taking place.

Subsequently the PI and researcher applied to the Research Ethics Committee for a substantial amendment to allow inclusion of individuals with a pre-frail diagnosis i.e., identified as pre-frail by scoring one or two on the Fried frailty phenotype criteria (adapted from (Fried et al., 2001)). Ethical approval was granted and the KARE Trial II was implemented as a separate study (as the initial trial was already underway) as documented in Chapter 3. The idea for this study was also included as part of the recommendations and future directions section in the publication (Swales et al., 2022), and Chapter 2. Specifically, it was noted that it would be interesting to examine the prevention of the progression to frailty and that the authors planned to test the feasibility of the intervention in pre-frail older adults in residential care.

Presentation of Findings

There are some minor differences in the order of presentation of information in the published papers (Chapters 2 and 3), including presentation/inclusion of quantitative and qualitative findings, and detail of adherence levels by group/individual. These were at the request of the journal and reviewers, and a requirement for acceptance for publication.

Chapter 2: A Randomised Controlled Feasibility Trial Evaluating a Resistance Training Intervention with Frail Older Adults in Residential Care: The Keeping Active in Residential Elderly (KARE) Trial

A version of this chapter is published as: **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

2.1 Abstract

Frailty is associated with negative health outcomes, disability, and mortality. Physical activity is an effective intervention to improve functional health status. However, the effect of resistance training (RT) on multidimensional health in frail older adults remains unclear. This randomised controlled trial (RCT) was conducted in a UK residential care home to assess feasibility with limited efficacy testing on health and functional outcomes, to inform a future definitive RCT. Eleven frail older adults (≥65 years) completed a 6-week machine-based RT protocol three times a week. Uptake and retention were greater than 80%. The measures and intervention were found to be acceptable and practicable. Analyses indicated large improvements in functional capacity, frailty and strength in the intervention group compared to controls. These findings support the feasibility of a definitive RCT and reinforce the value of RT in this population. This trial was registered with ClinicalTrials.gov: NCT03141879.

2.2 Introduction

Frailty is a clinically significant multidimensional syndrome associated with adverse outcomes such as falls, hospitalisation, disability, and mortality among older adults (Clegg et al., 2013; Fried et al., 2001; Xue, 2011). It is characterised by diminished strength, mobility, and functional capacity, and increases an individual's vulnerability to external stressors including infection or trauma (Hewitt et al., 2019; Morley et al., 2013). Despite no universally accepted definition of frailty (Fried et al., 2001; Theou et al., 2015) it is of increasing importance as the world's older population continues to grow (United Nations & Social Affairs, 2019), and a rising proportion are spending prolonged periods in ill health. Evidence suggests that healthspan (the period of life spent in good health) is not keeping pace with lifespan (Whittaker et al., 2019) .

Sustained ill health and loss of function in older age is not predetermined, and frailty is not an inevitable consequence of ageing. Frailty is a manageable condition (Morley et al., 2013) and has consistently been shown to be responsive to PA intervention. Being physically active is vitally important to optimise healthy ageing and improve function (Bherer et al., 2013; Lazarus & Harridge, 2018). Further, preserving balance and muscle and bone strength is integral to maintaining quality of life by reducing both the fear and the risk of falls, fractures, and frailty (Davies et al., 2019; Fragala et al., 2019; Skelton & Mavroeidi, 2018a). Robust evidence supports the beneficial effects of RT to improve muscle strength and function, and its ability to mitigate age-related declines in neuromuscular function, RFD, bone mineral density, and associated metabolic dysregulation (Fragala et al., 2019; McLeod et al., 2019).

However, despite the mounting evidence that RT interventions are effective for combatting age-related physical decline, older adults in residential care are an often-overlooked group. This is potentially due to higher frailty levels, reduced physical independence and functional ability, and the perceived difficulty of providing a feasible regimen of training for individuals with a range of comorbidities and limitations. Additional barriers may include the ability to tolerate testing and training, health and injury risks, adherence levels, and declines in cognitive function and health status (Ferrucci et al., 2004). Research also suggest that frail older adults may themselves be reticent to engage in PA due to fear of falling, comorbidities, injury risk, over-exertion, and changes to habitual routines (Finnegan et al., 2015; Franco et al., 2015).

Approaches to PA interventions in residential care have included multi-component exercise (Arrieta et al., 2018; Cadore et al., 2014; Lazowski et al., 1999), functional exercise (Peri et al., 2008), and combined resistance and weight-bearing exercise (Fien et al., 2016). The

most commonly utilised exercise protocol is multi-component training, with the inclusion of resistance, balance, aerobic and flexibility activity (Theou et al., 2011) and current guidelines suggest this may be the best strategy to improve gait, balance and strength, and reduce the risk of falls (Fragala et al., 2019). However, the generalisability of these recommendations to address wider health consequences of frail older adults is still to be established. Studies that reported positive changes in physical function included stepping reaction time and timed walking test (Lord et al., 2003); enhanced functional outcomes, muscle strength and power (Cadore et al., 2014); and significant improvement in strength, gait speed and lower limb function (Bastone Ade & Jacob Filho, 2004). Exercise interventions with progressive RT as the primary focus are less common in residential care settings and have tended to focus primarily on physical performance outcomes, for example, strength, walking speed, balance, and functional capacity (Hassan et al., 2016; Serra-Rexach et al., 2011).

Delivering strengthening exercise programmes as group-based activity might also be important in a residential care home setting. For example, one study conducting a group multi-component exercise intervention with community-dwelling frail older adults reported a reversal of frailty and improvements in cognitive, emotional, and social networking measures (Tarazona-Santabalbina et al., 2016). This underlines the positive impact that social support and group processes can have on the engagement with, and maintenance of, PA behaviour (Lindsay Smith et al., 2017; Shvedko et al., 2018). What is not yet clear is the impact of RT in a group setting, on multidimensional health and well-being and physical function in frail older adults in residential care. Consequently, research to assess the feasibility and impact of this is timely and urgent.

2.2.1 Aims and Objectives

The primary aim of this study was to assess the feasibility of a definitive, RCT using a RT intervention with frail older adults in residential care. The secondary aim was to perform limited efficacy testing on measures of multidimensional health from pre- to post-intervention compared to the wait-list control. These are intended as the primary dependent variables in the future definitive RCT and include physiological, psychological, cognitive, and emotional health measures, and functional capacity.

The specific objectives arising from these aims were to: (a) evaluate the experiences of the intended recipients, well-being team and care staff (acceptability); (b) determine actual interest, use and adherence levels to the RT intervention (demand); (c) evaluate the level of

organisational change required including perceived fit into the existing culture and structure (integration and adaptation); (d) determine the practicality of the RT intervention with frail older adults in residential care (practicality); (e) evaluate the suitability and relevance of the selected measures of multidimensional health and wellness (implementation and expansion); and (f) examine changes pre- to post-intervention compared to the wait-list control in measures of multidimensional health using mean differences, effect size and meaningful change (limited-efficacy testing). The feasibility aims and objectives were based on the research design framework proposed by Bowen et al. (2009). As this was a feasibility study there were no directional hypotheses.

This research has been reported in line with CONSORT 2010 guidelines for reporting randomised pilot and feasibility trials (Eldridge et al., 2016), Consensus on Exercise Reporting Template (Slade et al., 2016) and Standard Protocol Items: Recommendations for Interventional Trials (SPIRIT) Schematic Participant Timeline (Chan, Tetzlaff, Gotzsche, et al., 2013). Consort 2010 checklist is included as Appendix A (Table A.1.).

2.3 Method

2.3.1 Participants

The trial site was a care home in Birmingham, UK, initially approached due to management support of healthy ageing and research initiatives, a dedicated well-being team and strong sense of community. The care home provided personal and nursing care for up to 68 people with varying needs, and included a dementia unit, private rooms and independent living apartments. Initial recruitment of participants was made by either a direct approach from a staff member, introduction to a member of the research team, or by voluntary attendance at a short introductory talk given by the Principal Investigator and researcher in the care home (February 2019). The short introductory talk was advertised to all residents and staff via an in-house weekly newsletter to try to ensure engagement with as many potential participants as possible. Participants were screened against the following eligibility criteria: (a) resident in the care home; (b) age $\geq$ 65 years; (c) having at least three of the five Fried frailty phenotype criteria (Adapted from Fried et al. (2001)); (d) no severe sensory impairments that would profoundly impact upon their ability to participate; (e) ability to speak and read the English language; (f) not currently taking part in any other clinical trial which could potentially affect the results of this study; and (g) with a predicted life expectancy greater than the length of the trial.

2.3.2 Recruitment

All potential participants were offered a summary sheet about the study (a 2-page flyer based on the Participant Information Sheet (PIS) content). The summary sheet detailed the 'who, what, when, where and why' of the study including potential benefits and risks of taking part, research team contact details, and confidentiality and data protection. The summary sheet was produced on the advice of the well-being team who suggested that lengthy documentation may be off-putting for some residents, particularly those with any cognitive or sight impairment. All potential participants who expressed further interest in the study were given the full comprehensive PIS, in line with the published protocol (Doody et al., 2019).

Potential participants had 10 days to consider whether they would like to participate and were encouraged to meet with a member of the research team to discuss any queries. Following any further explanation, interested potential participants were provided with an informed consent form. The trial design was inclusive, including those who may have lacked capacity to provide informed consent, and documentation was in place for personal or nominated consultees. All participants had capacity and provided written informed consent before trial commencement and verbal consent before the start of their interview. All were free to withdraw from the study at any time.

2.3.3 Sample Size

A convenience sample of approximately 48 participants was suggested by Doody et al. (2019) in the published protocol. Actual sample size for this trial was adjusted following recruitment advice from care home staff, and in line with recommendations (Hertzog, 2008; O'Cathain et al., 2015). Specific guidance for mixed methods randomised feasibility trials is limited. Hertzog (2008) proposed that samples of 10-15 per group may be adequate depending on the nature of the decision based on the estimate, and that even a few cases will be informative for decisions into acceptability, practicality, and implementation. Sample sizes for qualitative feasibility trials are also typically small, between 5-20 individuals (O'Cathain et al., 2015). An additional week (labelled as week -3, on Table 2.1) was allocated for consent and eligibility screening prior to the baseline assessments to allow for broader recruitment. Following the initial level of interest generated by the introductory talk at the care home, and discussions with the well-being team, the researcher aimed for a sample of 20 participants.

2.3.4 Trial Design

Ethical approval for this study was provided by London Harrow Research Ethics Committee, REC: 17/LO/1316 Protocol: RG_17-108 IRAS: 219616. The full study protocol has been published elsewhere (Doody et al., 2019). Trial registration: ClinicalTrials.gov: NCT03141879. Registered 5 May 2017. The trial was conducted between February 2019 and July 2019. The study timeline is shown in Table 2.1 and represents the overall study duration.

All study participants completed initial screening (week -2) and baseline measures (weeks -1 and 0) prior to confirmation of group allocation. The six-week RT programme was scheduled weeks 1-6 for the intervention group, and weeks 9-14 for the wait-list control group. Both groups completed post-intervention testing weeks 7-8, with follow-up testing scheduled weeks 13-14 and weeks 15-16 for the intervention and wait-list control group, respectively. This staggered approach ensured that follow-up testing was completed six weeks after the end of the group exercise sessions. Participants were advised to avoid strenuous PA or RT for at least 24 hours prior to any measures of strength or functional capacity, or blood samples. Due to the comprehensive test battery, and to avoid participant fatigue, assessments were scheduled over multiple days/visits (see Table 2.2).

Table 2. 1.

Study Timeline

Week	Monday	Tuesday	Wednesday	Thursday	Friday
Week-3	Recruitment	Recruitment	Recruitment	Recruitment	Recruitment
Week-2	Consent and eligibility screen	Consent and eligibility screen	Consent and eligibility screen	Consent and eligibility screen	Consent and eligibility screen
Week-1	Baseline assessments	Baseline assessments	Baseline assessments	Baseline assessments	Baseline assessments
Week 0	Baseline assessments	Baseline assessments	Baseline assessments	Baseline assessments	Baseline assessments
Week 1	Exercise Session: 1	Rest	Exercise Session: 2	Rest	Exercise Session: 3
Week 2	Exercise Session: 4	Rest	Exercise Session: 5	Rest	Exercise Session: 6
Week 3	Exercise Session: 7	Rest	Exercise Session: 8	Rest	Exercise Session: 9
Week 4	Exercise Session: 10	Rest	Exercise Session: 11	Rest	Exercise Session: 12
Week 5	Exercise Session: 13	Rest	Exercise Session: 14	Rest	Exercise Session: 15
Week 6	Exercise Session: 16	Rest	Exercise Session: 17	Rest	Exercise Session: 18
Week 7	Post-intervention assessments	Post-intervention assessments	Post-intervention assessments	Post-intervention assessments	Post-intervention assessments
Week 8	Post-intervention assessments	Post-intervention assessments	Post-intervention assessments	Post-intervention assessments	Post-intervention assessments
Weeks 9-14	Wait-list control exercise sessions Mon-Wed-Fri				
Weeks 13-14	Follow-up assessments: Intervention group	Follow-up assessments: Intervention group	Follow-up assessments: Intervention group	Follow-up assessments: Intervention group	Follow-up assessments: Intervention group
Weeks 15-16	Follow-up assessments: wait-list control group	Follow-up assessments: wait-list control group	Follow-up assessments: wait-list control group	Follow-up assessments: wait-list control group	Follow-up assessments: wait-list control group

Table 2. 2.

Participant Timeline (Schedule of Enrolment, Interventions, and Assessments Based on SPIRIT [2013])

	Study Period													
	Enrolment	**Baseline**		**Intervention**	**Post-intervention**			**Intervention (wait-list control)**	**Follow-up (intervention group)**			**Follow-up (wait-list control)**		
		B1	**B2**		**P1**	**P2**	**P3**		**F1**	**F2**	**F3**	**F1**	**F2**	**F3**
Timepoint (weeks)	-2	-1	0	1-6	7	8	8	9-14	13	14	14	15	16	16
ENROLMENT														
Eligibility Screen	x													
Informed Consent	x													
Fried frailty phenotype	x				x				x			x		
SMMSE	x				x				x			x		
Allocation			x											
STUDY GROUPS														
Intervention				x										
Wait-list control								x						
ASSESSMENTS														
SPPB		x				x				x			x	
GDS		x			x				x			x		
ISEL-12		x			x				x			x		
Socio-demographics		x												
MNA		x				x				x			x	
Leg Strength/RFD			x		x					x			x	
HADS			x			x				x			x	
PSS			x			x				x			x	
Katz ADL			x			x				x			x	
Blood measures			x		x						x			x
Semi-structured interviews							x							
Focus Groups (staff)														x

Note. SMMSE = Standardized Mini-Mental State Examination; SPPB = Short Physical Performance Battery; GDS = Geriatric Depression Scale; ISEL = Interpersonal Support Evaluation List; MNA =Mini Nutritional Assessment; RFD = rate of force development; HADS = Hospital Anxiety and Depression Scale; PSS = Perceived Stress Scale; ADL = Activities of Daily Living.

2.3.5 Randomisation

The Principal Investigator conducted the randomisation and allocation independent of the identification, consent, screening, and baseline assessments. The researcher enrolled participants; conducted eligibility screening and baseline testing; and informed participants of group allocation. Permuted block randomisation (1:1) was used to randomise participants. Randomisation was conducted using a computer-generated random number generator (www.randomizer.org). Group allocation was not revealed until after consent, eligibility screening and baseline measures had been completed ensuring allocation concealment and minimising selection bias. Due to the nature of the intervention and the researcher's dual role (intervention delivery and tester) further blinding was not possible. Trial participants, care staff and well-being team members were also aware of group allocation. All post-intervention and follow-up testing were completed un-blinded by the researcher. Minimisation of conscious bias was upheld by strict adherence to standardised test protocols, timing of tests and consistency of encouragement across all assessments.

Important Changes to Trial Design After the Protocol was Published

The published protocol (Doody et al., 2019) advised the use of a concurrent control group design for the feasibility trial and utilisation of a wait-list control group within the subsequent future RCT. After discussion with the care home management, this was amended to a wait-list control to ensure that all participants would have access to potential beneficial effects of the intervention, as well as nullifying the negative psychological impact of being interested in exercise for better health and then being randomised to no treatment. Both groups had continued access to regular on-site well-being activities independent from this study. Utilisation of the wait-list control group allowed more insight into the acceptability and implementation of the proposed RCT. Due to the small size and the proposed number of covariates (frailty score and age) block randomisation was adopted rather than the stratified-block method in the published protocol. Stratified-block randomisation would be a consideration for a future RCT to control for baseline covariate imbalance, reduce bias in statistical analysis and increase the power of the study.

2.3.6 Measures

Feasibility Outcomes

The primary aim of the study was to assess the feasibility of conducting a definitive RCT. The feasibility outcome measures are defined in Table 2.3 and address all key focus areas for

feasibility trials (Bowen et al., 2009). All semi-structured interviews and focus groups were conducted by the researcher who had previous experience of interviewing and facilitating group discussions. The researcher had established professional relationships with all participants and staff throughout the study. Interviews took place either in the communal lounge area outside of scheduled activities or in participant's rooms to ensure a quiet, private space. Two separate focus groups were conducted in a private room. Audio was digitally recorded using IBM ThinkPad X1 Laptop (Lenovo, China), Voice Recorder App (Microsoft 2018) and iGOKU USB Microphone (iGOKU, China). The researcher also kept comprehensive written field notes and a reflexive diary. Full detail of data collection is given in the trial protocol (Doody et al., 2019).

Health and Functional Outcomes

Measures of multidimensional health are outlined in Table 2.2, Participants Timeline, and in the trial protocol (Doody et al., 2019). These measures were categorised into physiological, psychological, cognitive, and emotional health measures, social support, and functional capacity. Physiological measures were inflammatory cytokines, C-reactive protein, cortisol, and dehydroepiandrosterone-sulphate (DHEAS) from blood serum. Psychological and emotional measures comprised the Geriatric Depression Scale (GDS) (Yesavage et al., 1982), the Hospital Anxiety Depression Scale (HADS) (Zigmond & Snaith, 1983) and the Perceived Stress Scale (PSS) (Cohen et al., 1983) . The cognitive assessment comprised the Standardised Mini-Mental State Examination (SMMSE) (Molloy et al., 1991), and social support was measured through the Interpersonal Support Evaluation List (ISEL-12) (Cohen et al., 1985). Finally, functional capacity was assessed using the Activities of Daily Living (ADL) scale (Katz et al., 1970), the Short Physical Performance Battery (SPPB) (Guralnik et al., 1994) and leg strength. The Fried frailty phenotype (Fried et al., 2001) and SMMSE (Molloy et al., 1991) were also used as part of eligibility screening (see Table 2.2). Qualitative data for each participant were recorded on an individual Case Report Form.

Table 2. 3.

Feasibility Trial Outcomes, Objectives, and Assessments

Area of Focus	Objectives	Assessment or measure
1. Acceptability	• To assess screening and eligibility criteria • To evaluate recruitment, retention, and adherence rates • To evaluate participant experience, feedback, and perceived appropriateness • To investigate the views and opinions of management, care, and support staff	• Participant uptake analysis • Semi-structured interviews with participants • Focus groups with well-being team staff, care staff and management
2. Demand	• To determine level of interest, actual use, and adherence • To investigate staff opinion of trial suitability and proposed, definitive RCT	• Analysis of uptake rates • Exercise intervention adherence rates • Focus groups with well-being team staff, care staff and management
3. Implementation	• To determine factors affecting ease, difficulty, or quality of implementation in this setting • To evaluate the applicability of the selected measures of multidimensional health and wellness • To determine any logistical issues which may require consideration or amendment prior to RCT	• Semi-structured interviews with study participants • Focus group with well-being team staff, care staff and management
4. Practicality	• To determine time-cost, burden and benefit for researcher, participants, staff, and broader support team • To evaluate any practical constraints around required resources, time, or commitment • To assess the quality and suitability of the intervention in this setting	• Semi-structured interviews with study participants • Focus groups with well-being team staff, care staff and management
5. Integration	• To assess integration into the existing culture, protocols, and procedures within the care home • To investigate perceived fit and longer-term sustainability in this setting	• Focus groups with well-being team staff, care staff and management

6. Adaptation	• To evaluate the requirement for any modification or amendments to the existing intervention	• Focus groups with well-being team staff, care staff and management • Semi-structured interviews with study participants
7. Expansion	• To investigate any potential disruption, positive or negative effects on environment, organisation, or culture from potential programme expansion • To assess any budget and/or resource requirements for further expansion	• Focus groups with well-being team staff, care staff and management • Semi-structured interviews with study participants
8. Limited-efficacy testing	• To examine the potential positive meaningful impact of a moderately intensive 6-week resistance training intervention on markers of multidimensional health in frail, older adults • To assess the efficacy of the intervention on the health and functional variables (identified as primary dependent variables of a proposed future RCT)	• Analysis of the health and functional variables • Analysis of uptake and adherence rates • Analysis of the level of satisfaction with the interventions through interviews and focus groups

Note. RCT = Randomised controlled trial

Important Changes to Health and Functional Outcome Assessments After the Protocol was Published

The original protocol (Doody et al., 2019) specified assessment of leg strength and power output, and one repetition maximum (1RM) testing (Sheppard and Triplett (2016) p.453). The 1RM would be subsequently used for assignment of training loads. This testing methodology was amended due to consideration of safety, appropriateness, relevance, and validity (Conlon et al., 2018; Zourdos et al., 2016). Whilst maximal strength testing *per se* is safe and acceptable for older adults (Alcazar et al., 2018) the researcher used professional judgement to select a maximal isometric strength testing protocol for lower limb only, including knee extensors, knee flexors, hip adductors, and hip abductors. This was justified on the basis that Moir (2012) proposes isometric tests to require little movement skill, be relatively easy to

administer and provide additional RFD data. RFD has shown direct association with the ability to contract muscles rapidly and maximally, and is related to falls risk (Fragala et al., 2019). Further, guidelines advise that maximal strength testing may be contraindicative for adults with severe osteoporosis (American College of Sports Medicine, 2018) but acknowledge that no specific criteria are recommended.

Isometric maximal strength testing was performed using Performance Recorder Software Suite User Manual test protocol (13.8.2010) and HUR Rehab Line Equipment Measurement Instructions, and in line with previous research using HUR equipment (Mård et al., 2009). The Performance Recorder is a reliable tool to assess isometric strength, and to monitor change in strength over time (Neil et al., 2013). Subsequent discussions with the equipment manufacturers confirmed that the 1RM test data would be reliable as an outcome measure but not appropriate for accurate training load prescription (Newton et al., 2011).

Attendance and Adherence

Attendance was reported as a percentage of attended exercise sessions. Adherence to exercise prescription was measured and reported as the percentage of total repetitions completed at prescribed load. Exercise adherence data (including attendance, exercises performed, sets, reps and loads) was automatically recorded by the SmartTouch software (HUR Ltd., Finland) incorporated into the exercise machines and verified by the researcher. Any technical issues which compromised accurate record keeping using SmartTouch (HUR Ltd., Finland), including wi-fi connectivity or log-in and recognition problems, were reported and noted alongside attendance records to ensure data reliability.

2.3.7 Equipment

The RT intervention utilised specialised, pneumatic, strength training equipment with SmartTouch web-based software and radio-frequency identification (RFID) user log-in systems with smart cards from the premium line of HUR SmartTouch (4^{th} Generation) (HUR Ltd., Finland). The ergonomically designed machines were specially designed for use in active ageing programmes. The touch screens on each machine displayed participants names on log-in and sign-out, overall programme, sets, repetitions, and load.

All machines were set-up and used according to the manufacturer's guidelines. Range of motion limiters, seat heights and lever arm lengths were set, stored on individual RFID cards, and checked prior to each session. Participants were encouraged to work through full range of joint movement (unless limited by pain, or specific joint or medical problems) and with proper

technique including handgrip, body and limb positioning, breathing patterns, range of movement and speed. The researcher assisted with transferring from machines to any assisted walking devices; manually modified load, if required; offered feedback; and assisted with any technology issues, that is, card recognition or wi-fi connectivity. Participants with sight, hearing or movement limitations were supported with individual attention, as needed. All RFID cards were kept in a card storage box next to the machine compressor unit and only accessed by the researcher or the participant.

Five separate, free-standing machines were used: leg press, leg extension/leg curl, chest press, hip abduction/adduction, and optimal rhomboid. The leg extension/leg curl and hip abduction/adduction machines had dual functionality, and exercise programme prescription included all seven exercises. All machines (except for hip abduction/adduction) had unilateral and bilateral capability. The exercise equipment was installed in the main meeting room (lounge) at the care home with adequate space between machines to allow direct access from walking frames and wheelchairs.

Figure 2. 1

Photo of HUR Equipment and Study Participants in Lounge (own photo)

2.3.8 Delivery

All exercise sessions were supervised by the researcher who was a qualified strength and conditioning coach with over 25 years of experience. Programme-specific training with HUR equipment (including isometric strength testing with the Performance Recorder and HUR Labs Performance Recorder PC software [HUR Ltd., Finland]) was undertaken prior to programme commencement, with additional support available throughout the trial duration.

The sessions were run as a group-based activity with a total of five participants attending each time. Participants wore their usual day clothes. While no specific or structured motivation strategies were used, the researcher and care-home staff were supportive and encouraging throughout the intervention. Participants were actively encouraged to attend all scheduled assessment and exercise sessions. This could include a verbal reminder of the day/time of the session, and/or physical assistance in moving to the lounge. While adherence was keenly promoted, participants were assured that attendance and engagement were voluntary.

Important Changes to Equipment and Delivery After the Protocol was Published

The published protocol (Doody et al., 2019) proposed using six separate machines for all participants. However, current recommendations advise that the inclusion of specific exercises, and the volume of exercise per session, needs to be tailored to individual fitness and physical function (Fragala et al., 2019; Ribeiro et al., 2020). In alignment with this the researcher used professional judgement to make modifications, as required. This intervention was subsequently amended to include only five machines (seven exercises) by exclusion of the abdominal crunch machine, directly based on guidelines for any clinical diagnosis for osteoporosis or frailty (American College of Sports Medicine, 2018) and extensive strength and conditioning and biomechanics literature (McGill, 2006, 2010, 2015; Verkhoshansky & Siff, 2009) discouraging repetitive loaded spinal flexion patterns in deconditioned or weak individuals. Specific guidance for individuals with osteoporosis (Skelton & Mavroeidi, 2018a) further recommends spine-sparing exercises and an avoidance of repetitive, weighted, loaded flexion patterns.

The proposed intervention (Doody et al., 2019) was a group exercise circuit but was subsequently modified to allow individual progression through the training prescription if required, in line with UK CMO's recommendations (Davies et al., 2019).

2.3.9 Exercise Prescription

The RT intervention was based on published recommendations for strength training for older adults including, but not limited to, ACSM Guidelines for Exercise Testing and Prescription (American College of Sports Medicine, 2018), NSCA Programme Design for Resistance Training (2016) and UK CMO 2019 PA Guidelines for Older Adults (Davies et al., 2019), and NSCA Resistance Training for Older Adults (Fragala et al., 2019). These included detailed guidance on number and frequency of sessions, structure, duration, loading, sets, reps, total volume load, rest intervals and progression.

The sessions were performed three times per week for six weeks, on Monday, Wednesday, and Friday mornings (0930-1030) allowing a minimum of 48 hours recovery between sessions. All participants were scheduled to attend 18 sessions in total throughout the 6-week intervention. Once established, total session duration, was 35-40 min, including warm-up and cool-down. Initial sessions (Week 1) were slightly longer in duration (45-50 min) due to participant unfamiliarity with warm-up exercises, machines and log-in systems, individual machine set-up, and establishing appropriate individual starting loads.

The short warm-up routine (~5 mins) was completed immediately prior to the RT programme, either sitting or standing depending on the individual participant. It included a range of low-intensity, simple movement patterns primarily aimed at increasing blood flow, joint fluid viscosity and range of movement, including shoulder rolls, reaches and punching patterns, marching on the spot and calf raises. The sequencing of the exercises was not strictly standardised but did follow a basic progressive format with a focus on movement quality, posture, and technique. The warm-up time was also a time for social interaction and feedback between the researcher and the participants. Post-exercise session, participants were encouraged to perform ~ 5 mins of light stretching and similar mobility patterns to the warm-up.

All exercise sessions were supervised by the researcher ensuring high levels of fidelity around consistency of delivery, coaching technical guidance, motivation, and observation. The intervention was delivered as planned and the programme prescription is shown in Table 2.4. For the duration of the study intervention, study participants did not use the machines at other times. Although exercise selection was standardised, there was flexibility to individualise this design by order or movement pattern. The order could be influenced by practical issues of transferring between machines (requiring additional time and/or assistance from the researcher),

use by another group member or individual preference. Any consistent preferences or sequencing were recorded.

Table 2. 4.

Programme Prescription Including Sets, Reps, Inter-set Recovery Interval and Intensity (Load)

Exercise	Sets	Reps	Inter-set recovery (s)	Speed of movement	Load
Optimal Rhomboid	2	12	120	Concentric: as rapidly as possible while maintaining sound technique. Eccentric: controlled (1-2 sec)	Progression from 'light-moderate' intensity (RPE 5-6) to 'moderate-hard' (RPE 7-8) (Equivalent OMNI-RES 4-6 progressing to 6-8, with 2-4 RIR)
Hip Adduction	2	12	120		
Hip Abduction	2	12	120		
Chest Press	2	12	120		
Leg Extension	2	12	120		
Leg Curl	2	12	120		
Leg Press	2	12	120		

Note. RPE = Rating of Perceived Exertion, OMNI-RES = OMNI-Resistance Exercise Scale, RIR = Repetitions in Reserve

The starting loads for each participant were confirmed during the first exercise session and as part of initial familiarisation. As all participants were beginners with no prior experience of RT, initial loading was conservative and designed to improve confidence, orientation, and skill acquisition with secondary focus on progressive overload (Conlon et al., 2018). The OMNI resistance exercise scale (OMNI-RES) (Gearhart et al., 2009) and 'reps in reserve' (RIR) (Helms et al., 2016) were used to describe appropriate loading and progression. Whilst not a key criterion of the study, load progression was achieved by programmed micro-adjustments on each machine: when more than 14 repetitions of a given exercise could be completed with good form, the load was automatically increased by 5% for upper limb and 10% for lower limb on the subsequent training session (Sheppard & Triplett, 2016). All loads were modifiable manually by the participant or researcher intra-session, if required, and immediate feedback was given on the machine screen to confirm whether the volume load (reps x sets x load) had been achieved. Participants were encouraged to hit their targets and gradually increase loading, but the focus was on movement quality, consistency, and overall session enjoyment.

All participants were requested to follow the RT programme as prescribed and not make any substantial changes to any other physical activity for the duration of the intervention. There were no other non-exercise components in the study i.e., lifestyle coaching or specific education.

Important Changes to Exercise Prescription After the Protocol was Published

The original protocol (Doody et al., 2019) suggested three-four sessions per week totalling 21 sessions over six weeks with an alternating pattern of three sessions one week, and four sessions the next. Following discussions with the well-being team this was not considered feasible: the lounge area was often used for other routine activities, including religious services on Sundays, and a changing schedule would be disruptive to both staff and residents. It was also advised that a regular routine at a consistent timeslot would be more acceptable, minimise interference with other activities, and increase the likely adherence and successful implementation.

The original protocol (Doody et al., 2019) proposed that the prescription of training loads for the intervention would be based on percentages of 1RM tests on each machine. This is a traditional and accepted tool within Strength and Conditioning, but is not without flaws (Sheppard & Triplett, 2016), and a considerable time requirement. Deconditioned and inexperienced participants in any RT programme will benefit from an orientation phase with a progressive increase in training volume load (sets x reps x load) allowing time for musculotendinous adaptations before 1RM testing. 1RM testing for beginners with little/no experience of RT on each exercise may not be accurate and representative of actual strength levels. Initial increases in strength are often attributed to improvements in coordination and skill, rather than strength alone (Newton et al., 2011). Older adults may have existing health conditions including arthritis and joint pain or mild cognitive impairment and require a more subjective-feedback approach. Training loads were subsequently prescribed based on professional expertise and participants' subjective feedback.

Exercise prescription in the original protocol (Doody et al., 2019) proposed '2 sets of 5 reps at 80% 1RM (Repetition Maximum)'. This was modified to '2 sets of 12 reps at Rating of Perceived Exertion (RPE) light/moderate intensity' in line with current guidelines (Fragala et al., 2019). All exercises, sets, loads and reps were modifiable intra-sessions to allow for daily fluctuation and subjective feedback (Sheppard & Triplett, 2016; Verkhoshansky & Siff, 2009).

2.3.10 Data Analysis

All quantitative data from individual Case Report Forms were inputted into IBM SPSS Statistics for Windows, version 25.0 (IBM Corp., Armonk, N.Y., USA). Qualitative data from interviews and focus groups was transcribed verbatim into Microsoft Word and uploaded into NVivo (Version 12, QSR International Pty Ltd.) for thematic analysis. The researcher's reflective journal and additional field notes were also uploaded as supporting data.

Feasibility Outcome Measures

Thematic analysis (Braun & Clarke, 2006) was used to identify, analyse, organise, and communicate themes in the qualitative data. The researcher reviewed the audio recordings and field notes after each interview and documented additional reflections in a reflexive diary. After transcribing the interviews, the researcher read and re-read the transcripts alongside the supporting field notes and journal entries to ensure immersion in the data. Initial themes (codes) were developed deductively based on the feasibility outcomes, key areas of interest, interview questions, and used to build a coding framework in NVivo 12. Sub-themes were subsequently refined and developed inductively from analysis of theme frequencies, patterns, and occurrences in the data set. The researcher documented any initial observations to clarify coding decisions, keep track of evolving ideas and theories, and improve trustworthiness of the data by providing an audit trail (Nowell et al., 2017). Reviewing and refinement of themes, including any recoding and renaming, was completed by the authors before the final write-up and analysis.

Attendance and adherence data were analysed for both groups for the duration of their respective six-week exercise intervention (weeks 1-6 and weeks 9-14, as detailed in Table 2.1) to provide further insight into feasibility, demand, and acceptability with this population.

Health and Functional Outcome Measures

Limited efficacy testing was completed on all measures. Descriptive statistics were used to report participant characteristics, recruitment, adherence, and participation rates. Intention-to-treat analysis was applied for all variables where participant data was missing due to missing assessments or dropping out of the study: the last measure taken was carried forward. Intervention effect was calculated using mean difference (95% Confidence Intervals) pre- to post-intervention. Effect size evaluation was performed using Hedges' g and interpreted as small (d = 0.2), medium (d = 0.5), and large (d = 0.8) based on Cohen (1988). Analysis was pre- to post- intervention compared to the wait-list control. In line with recommendations from Schober

et al. (2018) evaluation of minimally clinically relevant changes and smallest meaningful change (Perera et al., 2006) were also reported if reliable thresholds were available.

2.4 Results

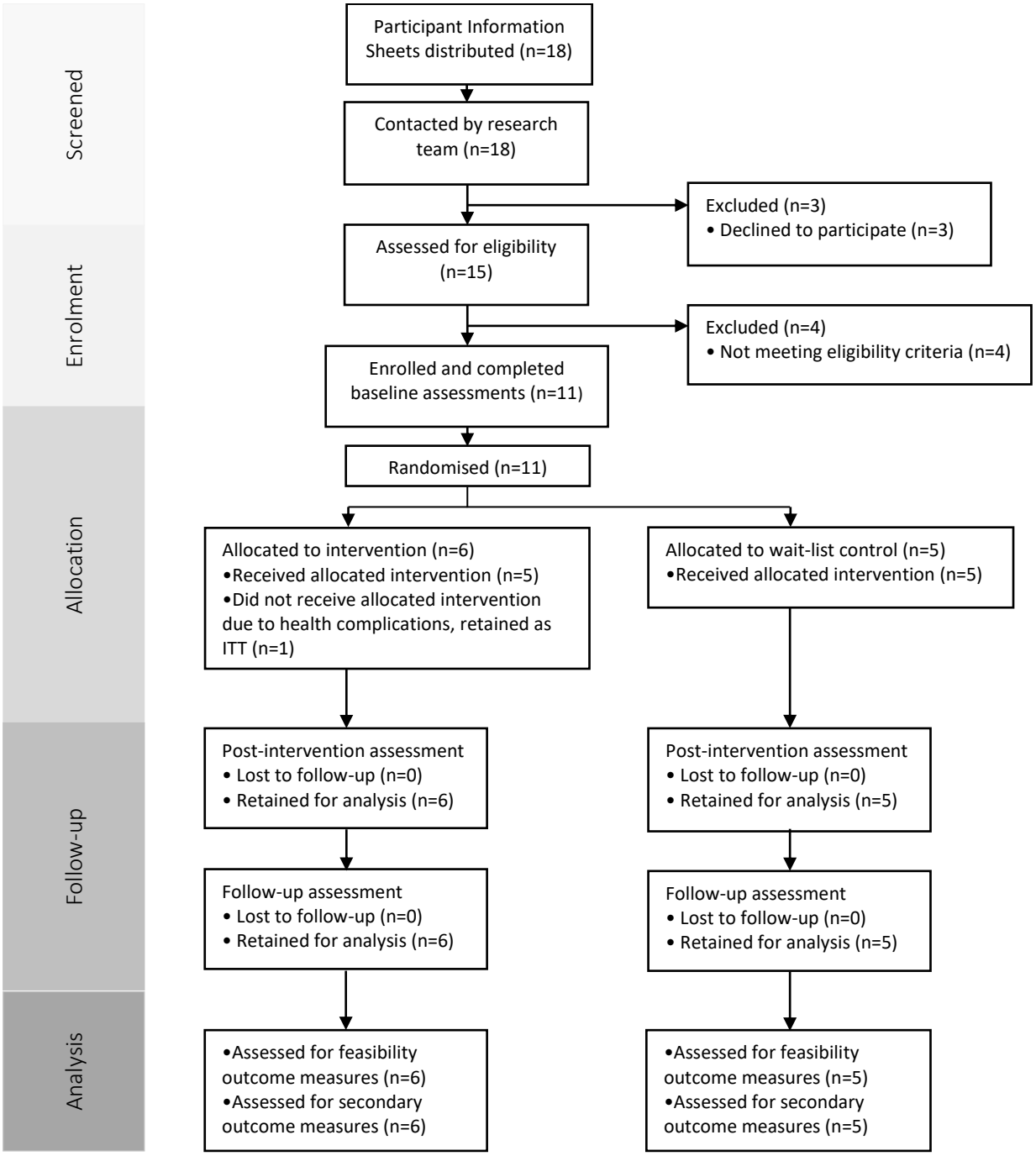
2.4.1 Participants

All those who requested further information and Participant Information Sheets were contacted (n=18), and 15 consented to eligibility screening giving an uptake of 83.3% (see Figure 2.1 CONSORT Diagram). Four were excluded through not meeting the Fried frailty criteria. All the eligible participants randomised to the study (n=11) completed the full baseline assessments. Six participants (54.5%) were allocated to the intervention group and five (45.5%) to the wait-list control group. One participant in the intervention group was unable to join the training intervention due to unrelated health complications and changes in medication but did not wish to withdraw. This participant remained positive that they would be able to re-join in due course and completed post- and follow-up assessments. Subsequently, all data were included in intention-to-treat analysis, (ITT). All participants (100%) were assessed for every feasibility and health and functional outcome.

Participants were mainly female (63%) with a mean age of 86.09 (7.18); the age range was 73-95 years. All participants were White British. Most participants had secondary or degree/diploma education (64%), had been resident at the care home for 54.00 (55.65, range: 5-156) months and reported on average 2.36 (1.36) medical conditions. Fried frailty score was 3.27 (± 0.47) with SPPB scores ranging from one to eight indicating the presence of frailty and functional limitations. The Katz ADL score was 5.18 (0.98) indicating partial dependency. Calculated gait speed from the SPPB walking test was 0.48 (0.21) $m \cdot s^{-1}$ suggesting increased likelihood of poor health and function, but the SMMSE score of 27.00 (4.17) indicated normal cognitive function. Baseline descriptive characteristics are summarised by group in Table 2.5. This also shows no significant socio-demographic or screening measure score differences between the intervention and control group, although cognitive function was marginally higher in the intervention group.

Figure 2. 2.

Consolidated Standards of Reporting Trials (CONSORT 2010) Participant Flow Diagram



Note. The figure is based on CONSORT extension for pilot and feasibility trials flow diagram (Eldridge et al., 2016). ITT = Intention to Treat

Table 2. 5.

Baseline Sociodemographic, Anthropometric, and Health-related Characteristics of Sample

Variable		Mean (*SD*) / n (%)		p
		Intervention (n=6)	Wait-list Control (n=5)	
Age (years)		85.83 (7.83)	86.40 (7.20)	.90
Range (years)		73-93	79-95	
Gender	Female	3 (50.0)	4 (80.0)	.30
BMI (kg/m^2)		25.22 (4.87)	27.83(1.75)	.29
Medical conditions		3.00 (1.55)	1.60 (0.55)	.09
Education	Primary	1 (16.7)	3 (60.0)	.27
	Secondary	4 (66.7)	2 (40.0)	
	Degree/Diploma	1 (16.7)	0 (0)	
Education years		10.67 (1.03)	9.40 (0.89)	.06
Occupation	Manual	2 (33.3)	2 (40.0)	.82
Marital status	Never	1 (16.7)	2 (40.0)	.33
	Married	2 (33.3)	0 (0.0)	
	Separated/divorced	0 (0.0)	1 (20.0)	
	Widowed	3 (50.0)	2 (40.0)	
Length of stay (months)		46.7 (57.5)	62.8 (58.6)	.66
Fried frailty score		3.33 (0.52)	3.20 (0.45)	.66
SPPB score		5.83 (1.94)	3.60 (3.13)	.18
SPPB Gait Speed (m·s^{-1})		0.55 (0.20)	0.39 (0.21)	.23
Katz ADL		5.50 (0.84)	4.80 (1.10)	.26
SMMSE		29.17 (1.17)	24.40 (5.13)	.05*

Note. * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$, differences indicated by independent t-tests, or chi-squared for categorical variables. ADL = Activities of Daily Living, BMI = Body Mass Index, SMMSE = Standardised Mini Mental State Examination, SPPB = Short Physical Performance Battery

The primary outcomes were concerned with feasibility; quantitative feasibility statistics are shown in Table 2.6. Overall uptake and retention were over 80%. Attendance and adherence, in the intervention but not the control group, were consistent with previous findings (Martin & Sinden, 2001) and exceeded 80% in all cases. Table 2.7 presents a breakdown of adherence by participant, detailing total reps, reps at prescribed load and those meeting the adherence criteria. Most striking are the differences in adherence criteria: in the intervention group, excluding ITT, completion in all cases was over 95% and met the adherence criteria, while the control group recorded less than 50% in all cases with none meeting the criteria. All participants engaged in interviews except one person from the control group due to illness. Interview duration ranged from 8-37 minutes. Separate care home management and well-being staff focus groups were both 36 minutes duration and included three participants per group.

Table 2. 6.

Overall Feasibility Statistics

Statistic	Group	Percentage
Study uptake	Both	83.3
Retention rate	Both	100.0
Session attendance[a]		
All allocated participants (n=6)	Intervention	82.4
Excluding ITT participant (n=5)	Intervention	98.9
All allocated participants (n=5)	Wait-list Control	34.4
Session adherence[b]		
All allocated participants (n=6)	Intervention	83.05
Excluding ITT participant (n=5)	Intervention	99.66
All allocated participants (n=5)	Wait-list Control	24.68

Note. ITT = Intention-to-Treat

[a]number of scheduled sessions attended, reported as a percentage of total available sessions. Intervention group = 18 total sessions (6 weeks, 3 days per week); control group = 12 total sessions (six scheduled sessions cancelled by facility due to room timetable clashes and norovirus outbreak containment procedures). [b] adherence to intervention exercise prescription (calculated as percentage of total reps completed at prescribed load)

Table 2. 7.

Session Adherence by Participant

Participant ID	Group	Adjusted reps (total reps - reps at < prescribed load)	Actual reps completed	Prescribed reps completed	Adherence criteria met
			(% of total prescription)		(Y/N)
01	Intervention	2972	98.28	98.28	Y
09	Intervention	3097	102.41	100.00	Y
10	Intervention	3565	117.89	100.00	Y
14	Intervention[a]	0	0.00	0.00	N
15	Intervention	3099	102.48	100.00	Y
17	Intervention	3911	129.33	100.00	Y
05	Wait-list Control	290	9.59	9.59	N
06	Wait-list Control	366	12.10	12.10	N
07	Wait-list Control	1116	36.90	36.90	N
11	Wait-list Control	1462	48.35	48.35	N
13	Wait-list Control	498	16.47	16.47	N

Note. Adjusted reps includes all optimally and overperformed reps only, as reported by the SmartTouch software, and in line with the progressive loading prescription. Any reps at less than prescribed load were not included. Adherence criteria is detailed in the published protocol (Doody et al., 2019). ITT = intention to treat; reps = repetition; Y = yes; N = no.

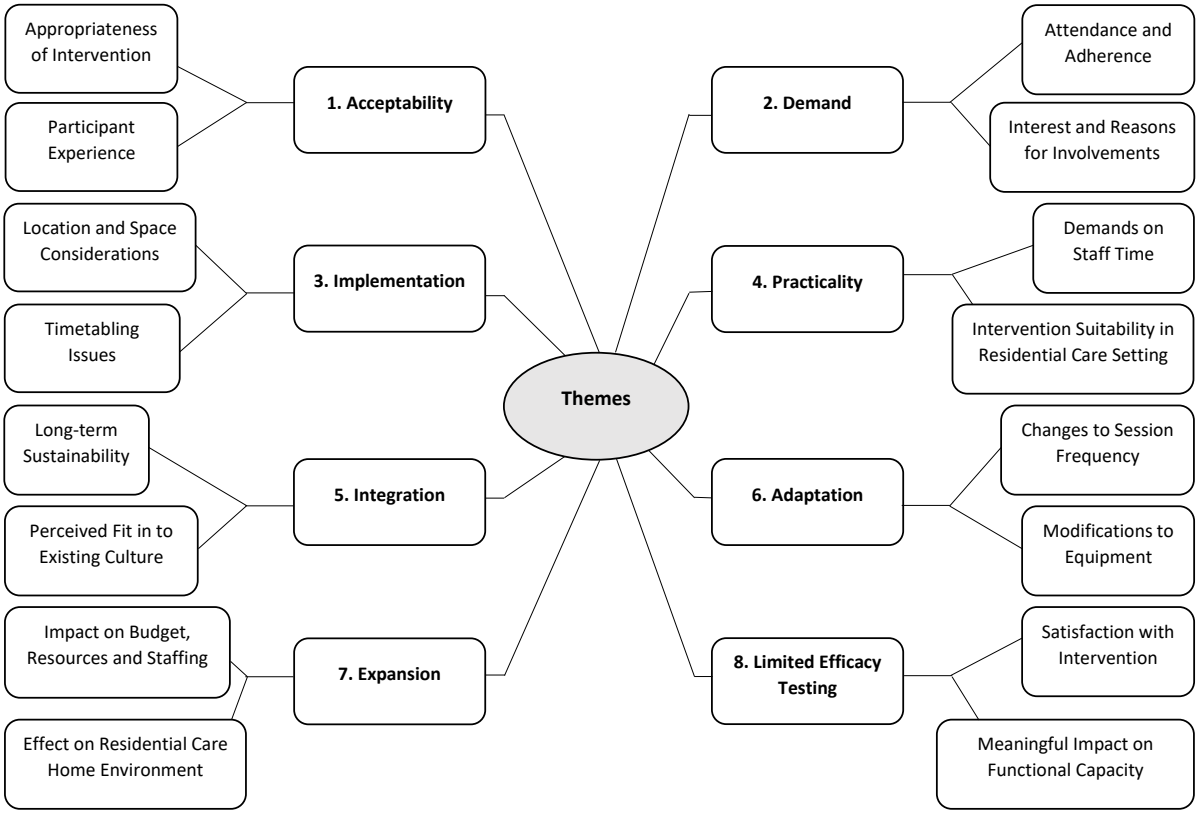
[a]Intention-to-Treat (ITT) participant

2.4.2 Feasibility Outcomes

Qualitative findings from the focus groups and interviews established several themes for each of the feasibility issues examined. These are outlined in Figure 2.2 for illustrative purposes.

Figure 2. 3.

Thematic Coding Structure Map



Note. Mind-map (NVivo 12) illustrating the feasibility outcomes and subsequent themes identified from the thematic analysis of the interviews and focus group discussions.

Acceptability

Two themes were identified: 'Appropriateness of Intervention' and 'Participant Experience.' As regards 'Appropriateness of Intervention,' discussions were focused on the suitability of the equipment and exercise prescription, the relevance of the assessments, and engagement with the research team. Staff explained that despite some initial reservations it had fitted in well with high levels of engagement and interest. Limited capacity to support more

residents, particularly those with cognitive impairment, was reported as the only negative feature. Comments from most participants were that the exercise prescription was “reasonable,” “manageable,” and “beneficial.” One participant, commenting on the suitability, said, “I’ve just been quite happy doing the exercises and coming along. I’ve felt it’s not been too hard, too onerous, too exacting. I can quite easily cope with it and I’ve found it quite pleasant” (Mary, participant, wait-list control). Opinion about the assessments, including the overall number, requirement for multiple re-assessments and some of the questionnaires, were more divergent. For example, whilst some participants spoke of enjoying the detail and “thought-provoking” nature of the questions, others said that they were “pretty useless,” “a bit out of this world” and lacking relevance.

Participants spoke positively about the practical relevance of the functional capacity tests, considered it to be “pretty obvious” that physical tests were going to be useful, and, despite it being a novel experience, took a keen interest in strength measures. Participants talked candidly about the new challenges: “getting on those machines…. grrr... and testing to your limits… phew, you know, and that’s coz I’m not used to it, you see” (William, participant, wait-list control).

In terms of ‘Participant Experience,’ most participants described their experience of the intervention as having been physically, mentally, and socially beneficial, and recognised that doing more exercise positively impacted general health. Participants spoke about improvements in leg strength, balance, and movement confidence. Feedback to staff from one participant’s family had been that of astonishment such were the improvements in walking speed and capacity on a family holiday. Commenting on their experience, one participant explained:

> *My balance. My walking. I do have a three-wheeler walker but even so when I first starting using it, I was zigzag on the corridor but now… and I can speed up my walking a little bit. Mentally it’s given me the confidence to do things that I couldn’t. (Betty, participant, intervention)*

Participants placed value on regular social interaction, involvement, and purpose. They spoke about enjoying talking to the researchers, the mental and physical stimulus of the intervention, and the opportunity to connect with fellow residents. One participant stated that “I think it has helped bring the five of us out that are residents in the home… I think it’s helped us relax and be able to communicate” (Betty, participant, intervention).

Demand

The feasibility outcome of Demand generated two themes of 'Attendance and Adherence' and 'Interest and Reasons for Involvement.' Regarding 'Attendance and Adherence,' participants suggested that three days a week was "not excessive" and "just about right." One participant with full attendance noted, "Well, I think this is the sort of thing, once you start you've got to keep it going. To be most effective" (James, participant, intervention). Staff members expressed surprise at the commitment and adherence of participants and explained that this was contrary to their initial expectations. Reflecting on why attendance had exceeded expectations, staff were candid about the need for routine, structure, consistency, and encouragement when working with older adults in residential care. Recorded levels of attendance and adherence were notably lower in the wait-list control group. Staff suggested that individual levels of motivation, group cohesion and physical proximity to the exercise equipment may have made a difference.

'Interest and Reasons for Involvement' was identified as a theme with several participants enthusiastically embracing the opportunity to take part. Participants spoke about enjoying the physical challenge, mental stimulation, self-reflection, and opportunity to benchmark their functional ability. For example, one participant said, with laughter:

> *I know I'm 80 and things do wear out but what's the point? If you've got the help to do something to improve your health both physically and mentally, and it's free, then why not benefit… make use of it? (Betty, participant, intervention)*

Staff discussed a "can-do attitude" towards research in the residential care home and were upbeat about the PA intervention and potential impact. Participants spoke about "being useful," "helpful," creating more knowledge and a feeling that others may benefit from the findings: "Does it mean that I'm helping people? Now, if I'm helping anybody, good, tick me off please, and I'll step into that one quite freely" (Joyce, participant, wait-list control).

Implementation

Two themes were developed here: 'Location and Space Considerations' and 'Timetabling Issues.' Regarding 'Timetabling Issues,' staff and participants felt that working within and respecting the existing daily routines of the care home had minimised any negative impact and meant that the intervention "fitted in" well. 'Location and Social Space Considerations' was a more contentious theme. Some staff members felt strongly that installing and using the exercise equipment in the lounge area was detrimental:

> *It restricts a lot of space and loads of people don't like it which then creates actually more negative feeling about it rather than creating a positive 'oh, I would get involved'… they don't want it in their space, it's getting in the way… in an ideal world I don't think anyone would want it there permanently. (Jessica, well-being team, staff member)*

Others maintained that any negative issues were minor with the benefits outweighing any perceived disadvantage. One staff member, for example, expressed an opinion that high visibility and accessibility had been advantageous:

> *I think a lot of it has been to do due with the fact that it is so visible. It's kept it in their thoughts… 'oh, yes we're doing that'…. and then other people have asked them questions and they like the fact that they can say, 'I'm involved in this that and the other'… and doing this… so helps to generate it because they've got a talking point whereas if it's away in a cupboard people aren't going to say, 'what's that all about?' because they don't see it. (Linda, care home management, staff member)*

Practicality

For Practicality, 'Demands on Staff Time' and 'Intervention Suitability in Residential Care Setting' themes emerged. 'Demands on Staff Time' was a theme for both staff and participants. Overall, staff felt positively about their time input and how it had changed over the project duration: more help was needed in the early stages including assistance with local knowledge, promotion, and recruitment whereas latter stages required less direct involvement. The need to request additional help from staff to access the equipment, for example, was a concern for some less able participants: "I was a bit concerned that two people had to lift me off that one machine, well helped with a lift up. I don't like to involve the staff, you see" (William, participant, wait-list control).

In terms of 'Intervention Suitability in Residential Care Setting,' it became clear that there were important practical considerations around scheduling and space demands. Staff pointed out that minimising changes to pre-existing schedules and creating a routine would be important for any future research. The demands on space in residential care homes was recognised as a practical issue of "impact" and "restriction", and experienced care staff saw this is a potential barrier: "They [care homes] weren't designed with certain things in mind as care has progressed

on so it's not just a problem in that room in this instance, it's a general problem" (Linda, care home management, staff member).

Integration

Regarding Integration, two themes were explored: 'Perceived Fit of Exercise into Existing Culture' and 'Long-term Sustainability.' For 'Perceived Fit into Existing Culture,' staff noted that exercise was already an accepted, regular, and popular feature on the well-being timetable in the form of a seated 'Music and Movement' class. However, it was discussed that although this was "fantastic" for frail and wheelchair-bound people the training intervention had been a "real outlet," and a good fit for those who wanted to participate in more challenging exercise options.

Under 'Long-term Sustainability,' staff remarked that there was additional demand for the equipment above and beyond the feasibility trial, and that even residents who were not involved in the trial had expressed interest. One staff member felt strongly that it was viable and would provide an opportunity to reinforce education surrounding long-term quality of life:

> *I have seen frail people become a lot better. And I think that the education… just because you're old, isn't an excuse for poor quality of life, because you can get better. You can improve your quality of life, until you die. (Lauren, well-being team, staff member)*

Most study participants were also supportive of long-term possibilities: "I think it's been a great idea and I only hope that they'll keep the equipment, quite frankly." (Arthur, participant, intervention)

Adaptation

Two key themes were established here: 'Changes to Session Frequency' and 'Modifications to Equipment.' While staff and participants were open to considering changes to the frequency of sessions there was overall support for the original format (three times per week). Some staff members talked positively about increasing the availability of sessions so long as this could be maintained within a regular structure and routine: "I think that people really like routine here and if you can build it into a routine, you could even get it more frequently really" (Jessica, well-being team, staff member).

Under 'Modifications to Equipment,' most staff comments were positive and included praise for the specific design functions for older people, ability to individualise loading and progression, and ease of installation. Feedback from participants was more nuanced: some

participants considered it lacked broader accessibility and had presented challenges including physically “getting on” to the machines.

Several participants were, however, undaunted by any additional physical demands. As one particularly upbeat interviewee laughingly explained:

> *Well, out of four machines there was one where… well I called it ‘The Beast’… because you had to put your legs under these rollers, and I did find that difficult, but we laughed about it, and I was helped. (Betty, participant, intervention)*

Expansion

Two key themes emerged from the feasibility outcome of Expansion ‘Impact on Budget, Resources and Staffing’ and ‘Effect on Residential Care Home Environment.’ Staff felt that any further expansion would be a “huge commitment and cost,” were concerned about “cost effectiveness” and whether use would be sustained long-term. Staff explained that the equipment alone would not be enough, and having a specialist, trained and motivating individual on-site with an ability to understand older people “makes a difference”:

> *I don’t think you could put it in a room aside from anything else. I think you’ve got to build something else in. So, whether you have a person who oversees the whole lot and spurs people on, it’s encouragement, I think, really. I think you’ve got to have that particular person who’s motivating enough to do it. (Susan, care home management, staff member)*

‘Effect on Residential Care Home Environment’ was identified as an issue for further expansion, especially in care facilities that were not purpose built, with the equipment viewed as “taking up a lot of space.” However, there were differing perspectives within the staff:

> *I find there to be a big benefit with exercise so I would outweigh the benefit with the fact that it is in the room because I know the benefit of exercise, I put a lot of stock into it. Yes, I would be quite happy to have it stay there regardless of the fact that it is in the way or not, but I understand that it might not be ideal, but I think it’s good. (Lauren, well-being team, staff member)*

Limited Efficacy Testing

Two key themes were established: ‘Meaningful Impact on Functional Capacity’ and ‘Satisfaction with Intervention.’ In terms of ‘Meaningful Impact on Functional Capacity’ it became clear that improvements in strength, walking speed, and balance were recognised and valued by both staff and participants. Participants described feeling “much firmer on my feet,” healthier, and strong enough to get out of chairs without using their arms:

> *Well, overall, I found it very beneficial physically and also mentally because I’ve been diagnosed with vascular dementia and having various buttons to press, when and whatever, I have found it very beneficial. But physically I am doing things that I haven’t been able to do, you know. (Betty, participant, intervention)*

However, some participants were more reserved with their judgements, and felt that it had not “made a great deal of difference,” “achieved a limited objective” and that while it had “built things up somewhat,” it was too soon to assess the impact.

In relation to ‘Satisfaction with Intervention’ both staff and participants felt that overall, the intervention had been a positive experience: staff spoke about it as having been “a great success,” “better than we anticipated” and “really good.” It was suggested that it had been a “social interaction” and facilitated a “joining together of the group.” One staff member commented on the social aspect of the group intervention: “I think it’s good to keep this generation of people as busy as possible because it fights loneliness and fights all sorts of other things, so I think that it has been really positive time” (Lauren, well-being team, staff member). Participants talked in terms of having been “very happy “and “pleased,” and “enjoying” the intervention: “Yes, I’m just sorry that it’s come to an end and just hope and pray that these machines can be here a bit longer. Sorry to see them go whenever” (Betty, participant, intervention). And another reflected that “in a way, it’s given us a little bit more purpose in living. It feels as though perhaps you might be, you can still be a little bit useful, even though you are old” (Mary, participant, wait-list control).

2.4.3 Health and Functional Outcomes

Analyses of pre-intervention to post-intervention compared to wait-list control indicated significant differences in some variables, however, due to the feasibility nature of this study, mean differences, 95% CI and effect sizes are also presented (see Table 2.8). Changes that are

most notable are shown in Table 2.8. These included differences in some measures of strength and functional capacity: peak torque measures for right knee extension and hip abduction, and Fried frailty walk time, walk test speed, and total score. Changes to total Fried frailty score are of particular note, as they represented an overall change in the intervention group from a pre-intervention frail status (M = 3.33, SD = 0.52) to a post-intervention pre-frail status (M= 2.00, SD = 0.89). Changes over time in some measures of functional capacity also indicated clinically important change (Kwon et al., 2009): mean difference in SPPB gait speed (0.24 $m \cdot s^{-1}$) and SPPB total score (1.50).

Measures showing improvement, as described above, are shown in Figures 2.3-2.7. The follow-up timepoint is also shown for the sake of completeness. Variables which did not seem to differ in any way between the groups over time were cytokines, stress hormones, and psychological/emotional (GDS, HADS, PSS), cognitive (SMMSE), and social support measures (ISEL).

Table 2. 8.

Effects Table: Within and Between-group Changes From Baseline to Follow-up

	Intervention					Wait-list Control					Mean difference in changes between groups		
Outcome Measure	n	Pre mean (*SD*)	Post mean (*SD*)	Mean Difference (95% CI)	p	n	Pre mean (*SD*)	Post mean (*SD*)	Mean Difference (95% CI)	p	Mean Difference (95% CI)	p	Effect size (Hedges' g)
Knee ext. left, peak torque (Nm)	6	79.44 (33.77)	92.93 (43.13)	13.49 (-0.24, 27.21)	.05*	4	49.34 (21.28)	43.51 (15.14)	-5.83 (-22.64, 10.98)	.45	19.31 (-2.39, 41.02)	.07	1.20
Knee ext. right, peak torque (Nm)	6	79.86 (33.28)	92.13 (41.68)	12.27 (4.03, 20.50)	.01**	5	52.13 (17.19)	50.04 (12.33)	-2.09 (-14.03, 9.86)	.70	14.35 (2.14, 26.57)	.03*	1.47
Knee flex. left, peak torque (Nm)	6	35.82 (17.96)	44.25 (18.38)	8.44 (0.50, 16.38)	.04*	5	28.75 (7.44)	27.24 (6.05)	-1.51 (-10.21, 7.19)	.70	9.95 (-1.81, 21.70)	.08	1.06
Knee flex. right, peak torque (Nm)	6	44.70 (20.59)	51.73 (22.74)	7.03 (1.78, 12.27)	.01**	5	29.35 (11.96)	28.77 (11.39)	-0.58 (-6.32, 5.17)	.83	7.60 (-0.33, 15.53)	.06	1.22
Hip adduction, peak torque (Nm)	6	94.74 (36.95)	105.41 (42.05)	10.68 90.28, 21.07)	.05*	5	74.50 (23.25)	72.93 (15.46)	-1.57 (-12.96, 9.82)	.76	12.25 (-3.17, 27.66)	.11	1.00
Hip abduction, peak torque (Nm)	6	61.81 (20.19)	69.22 (20.55)	7.42 (1.23, 13.61)	.02*	5	63.42 (13.56)	60.89 (8.99)	-2.53 (-9.31, 4.26)	.42	9.94 (0.76, 19.13)	.04*	1.36
SPPB Balance test (0-4)	6	3.17 (0.75)	3.17 (0.75)	0.00 (-0.70, 0.70)	1.00	5	1.80 (2.05)	1.40 (1.95)	-0.40 (-1.17, 0.37)	.27	0.40 (-0.64, 1.44)	.41	0.48
SPPB Gait speed (0-4)	6	2.00 (0.89)	3.17 (0.98)	1.17 (0.12, 2.22)	.03*	5	1.40 (0.55)	1.60 (.089)	0.20 (-0.95, 1.35)	.70	0.97 (-0.58, 2.51)	.18	0.78
SPPB Gait speed ($m \cdot s^{-1}$)	6	0.55 (0.20)	0.79 (0.19)	0.24 (0.07-0.40)	.01**	5	0.39 (0.21)	0.46 (0.27)	0.07 (-0.12-0.25)	.43	0.17 (-0.07-0.42)	.14	0.88

	Intervention					Wait-list Control					Mean difference in changes between groups		
Outcome Measure	n	Pre mean (*SD*)	Post mean (*SD*)	Mean Difference (95% CI)	p	n	Pre mean (*SD*)	Post mean (*SD*)	Mean Difference (95% CI)	p	Mean Difference (95% CI)	p	Effect size (Hedges' g)
SPPB Chair stand (0-4)	6	0.67 (0.52)	1.00 (1.10)	0.33 (-0.23, 0.90)	.21	5	0.40 (0.55)	0.40 (0.55)	0.00 (-0.62, 0.62)	1.00	0.33 (-0.52, 1.19)	.36	0.50
SPPB Total points (0-12)	6	5.83 (1.94)	7.33 (2.25)	1.50 (-0.02, 3.02)	.05*	5	3.60 (3.13)	3.40 (3.29)	-0.20 (-1.86, 1.46)	.79	1.70 (-0.57, 3.97)	.11	0.95
Katz ADL (0-6)	6	5.50 (0.84)	5.17 (0.98)	-0.33 (-0.96, 0.29)	.26	5	4.80 (1.10)	4.60 (1.34)	-0.20 (-0.89-0.49)	.53	-0.13 (-1.06, 0.79)	.75	-0.18
Fried frailty, weight loss (0-1)	6	0.17 (0.41)	0.00 (0.00)	-0.17 (-0.45, 0.11)	.21	5	0.00 (0.00)	0.00 (0.00)	0.00 (-0.31, 0.31)	1.00	-0.17 (-0.60, 0.26)	.36	-0.50
Fried frailty 2a, depression (0-3)	6	1.33 (1.21)	1.00 (0.89)	-0.33 (-1.59, 0.92)	.56	5	1.00 (0.71)	1.60 (1.14)	0.60 (-0.77, 1.97)	.35	-0.93 (-2.79, 0.92)	.28	-0.63
Fried frailty 2b, depression (0-3)	6	1.00 (1.10)	0.50 (0.55)	-0.50 (-1.34, 0.34)	.21	5	1.20 (1.30)	1.20 (1.30)	0.00 (-0.92, 0.92)	1.00	-0.50 (-1.75, 0.75)	.39	-0.50
Fried frailty, grip strength (kg)	6	21.82 (6.39)	24.55 (7.44)	2.73 (0.82, 4.65)	.01**	5	15.78 (2.96)	16.48 (3.23)	0.70 (-1.39, 2.79)	.47	2.03 (-0.75, 4.82)	.13	0.90
Fried frailty, walk test (s)	6	9.03 (4.48)	5.80 (1.31)	-3.23 (-5.90, -0.56)	.02*	5	16.06 (12.25)	17.07 (12.77)	1.01 (-1.91, 3.93)	.45	-4.24 (-8.19, -0.28)	.04*	-1.34
Fried frailty, walk speed ($m \cdot s^{-1}$)	6	0.60 (0.24)	0.82 (0.17)	0.22 (0.13-0.31)	.00***	5	0.44 (0.29)	0.40 (0.27)	-0.03 (-0.13-0.07)	.46	0.25 (0.12-0.39)	.00***	2.35
Fried MLTAQ ($kcal \cdot wk^{-1}$)	6	75.61 (89.54)	76.89 (63.88)	1.28 (-72.57, 75.13)	.97	5	32.47 (32.49)	8.55 (16.08)	-23.92 (-104.81, 56.98)	.52	25.20 (-84.34, 134.73)	.62	0.29

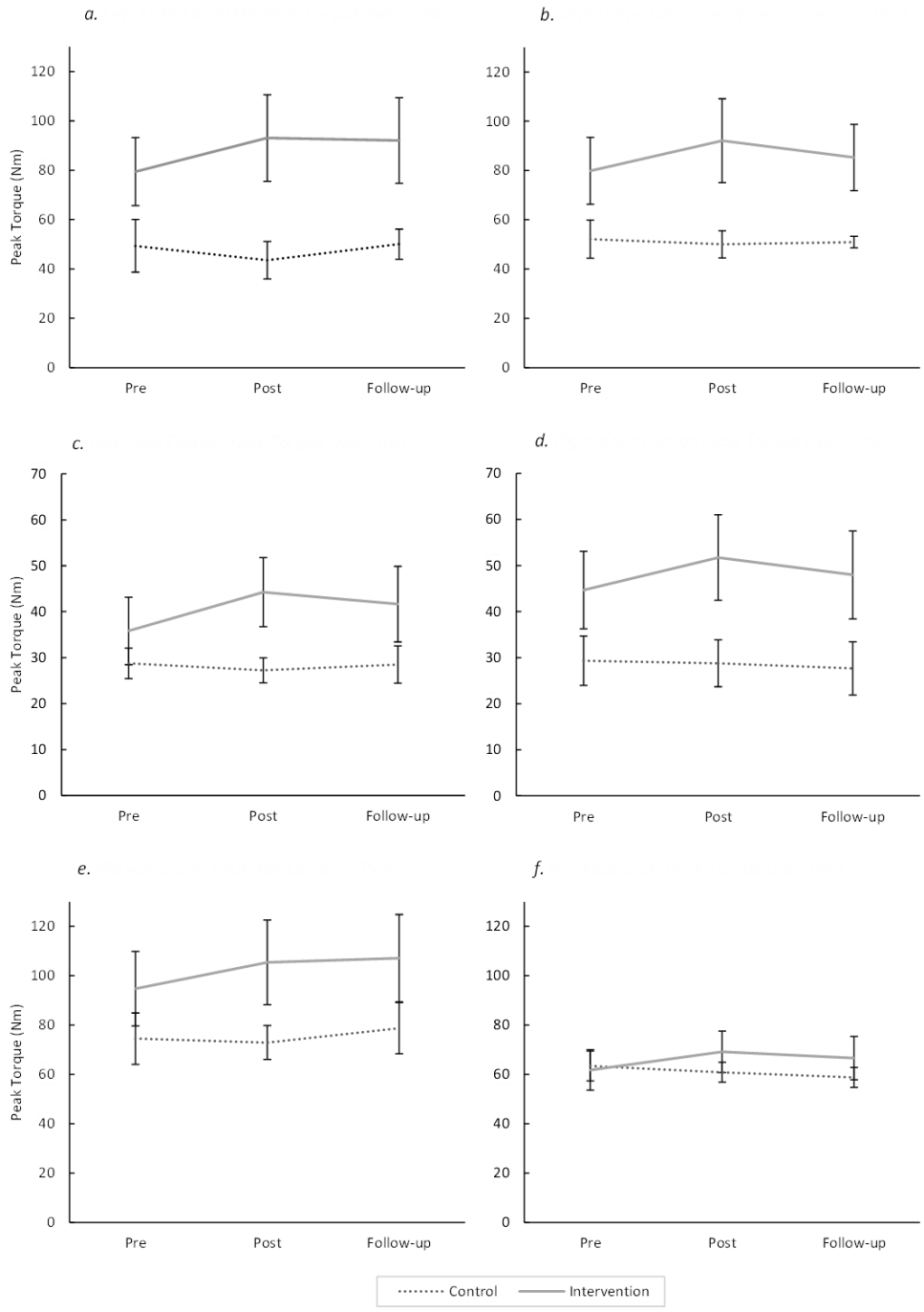
	Intervention					Wait-list Control					Mean difference in changes between groups		
Outcome Measure	n	Pre mean (*SD*)	Post mean (*SD*)	Mean Difference (95% CI)	p	n	Pre mean (*SD*)	Post mean (*SD*)	Mean Difference (95% CI)	p	Mean Difference (95% CI)	p	Effect size (Hedges' g)
Fried frailty Total (0-5)	6	3.33 (0.52)	2.00 (0.89)	-1.33 (-1.96, -0.71)	.00***	5	3.20 (0.45)	3.40 (0.55)	0.20 (-0.49, 0.89)	.53	-1.53 (-2.46, -0.61)	.00***	-2.07
GDS total (0-30)	6	5.67 (3.20)	5.33 (3.67)	-0.09 (-74.85, 74.67)	.87	5	6.20 (1.92)	4.80 (3.03)	-1.40 (-3.75, 0.95)	.21	-2.11 (4.25, 0.47)	.47	0.42
HADS anxiety (0-7)	6	2.33 (2.66)	2.83 (3.31)	0.50 (-2.13, 3.13)	.67	4	3.75 (2.06)	3.25 (3.30)	-0.50 (-3.72, 2.72)	.73	1.00 (-3.16, 5.16)	.60	0.32
HADS depression (0-7)	6	4.67 (2.80)	4.33 (3.08)	-0.33 (-1.79, 1.13)	.62	5	2.40 (2.07)	3.80 (3.42)	1.40 (-0.20, 3.00)	.08	-1.73 (-4.56, 1.10)	.17	-1.02
PSS total (0-40)	6	10.33 (6.62)	10.67 (7.58)	0.33 (-4.35, 5.02)	.88	5	14.00 (9.57)	10.00 (7.68)	-4.00 (-9.13, 1.13)	.11	4.33 (-2.61, 11.28)	.19	0.78
SMMSE total (0-30)	6	29.17 (1.17)	29.00 (1.10)	-0.17 (-2.39, 2.05)	.87	5	24.40 (5.13)	24.80 (7.73)	0.40 (-2.03, 2.83)	.72	-0.57 (-3.86, 2.73)	.71	-0.22
ISEL appraisal (0-12)	6	6.67 (3.08)	7.67 (2.07)	1.00 (-1.01, 3.01)	.29	5	7.40 (2.30)	7.20 (1.79)	-0.20 (-2.41, 2.01)	.84	1.20 (-1.79, 4.19)	.39	0.50
ISEL belonging (0-12)	6	5.33 (2.16)	6.17 (2.14)	0.83 (-0.74, 2.40)	.26	5	7.20 (2.28)	6.60 (0.89)	-0.60 (-2.32, 1.12)	.45	1.43 (-0.90, 3.76)	.20	0.77
ISEL tangible (0-12)	6	7.83 (0.98)	8.00 (0.63)	0.17 (-0.97, 1.30)	.75	5	6.00 (1.73)	7.20 (1.10)	1.20 (-0.05, 2.45)	.06	-1.03 (-2.72, 0.65)	.20	-0.77
MNA total (0-14)	6	12.67 (1.51)	11.50 (2.59)	-1.17 (-3.38, 1.05)	.26	5	12.40 (1.82)	11.60 (1.67)	-0.80 (-3.22, 1.62)	.47	-0.37 (-3.65, 2.91)	.81	-0.14

	Intervention					Wait-list Control					Mean difference in changes between groups		
Outcome Measure	n	Pre mean (*SD*)	Post mean (*SD*)	Mean Difference (95% CI)	p	n	Pre mean (*SD*)	Post mean (*SD*)	Mean Difference (95% CI)	p	Mean Difference (95% CI)	p	Effect size (Hedges' g)
IL-6 (pg/mL)	6	0.60 (1.20)	0.33 (0.36)	-0.27 (-0.89, 0.35)	.35	5	0.44 (0.37)	0.18 (0.14)	0.26 (-0.94, 0.43)	.42	-0.01 (-0.94, 0.91)	.97	-0.02
IL-8 (pg/mL)	6	37.43 (41.22)	20.34 (18.79)	-17.09 (-57.74, 23.55)	.37	5	57.05 (51.57)	18.49 (13.02)	-38.57 (-83.09, 5.96)	.08	21.47 (-38.81, 81.76)	.44	0.45
TNFα (pg/mL)	6	0.99 (0.70)	1.00 (0.53)	0.02 (-0.43, 0.47)	.93	5	1.00 (0.52)	1.08 (0.64)	0.08 (-0.41, 0.57)	.71	-0.06 (-0.73, 0.60)	.83	-0.12
IFNγ (pg/mL)	6	0.06 (0.13)	0.03 (0.04)	-0.03 (-0.14, 0.07)	.49	5	0.01 (0.01)	0.01 (0.03)	0.01 (-0.11, 0.12)	.91	-0.04 (-0.20, 0.12)	.58	-0.32
Cortisol (ng/mL)	6	121.44 (24.93)	150.45 (37.01)	29.01 (-3.53, 61.54)	.07	5	130.89 (38.64)	142.84 (46.42)	11.95 (-23.69, 47.59)	.47	17.06 (-31.14, 65.25)	.42	0.44
DHEAS (ng/mL)	6	409.73 (249.48)	394.37 (225.05)	-15.37 (-85.31, 54.58)	.63	5	600.53 (500.22)	582.49 (432.77)	-18.04 (-94.66, 58.58)	.61	2.67 (-101.07, 106.42)	.95	0.03
Cortisol:DHEAS	6	0.39 (0.19)	0.52 (0.34)	0.14 (-0.02, 0.29)	.08	5	0.71 (1.07)	0.66 (0.92)	-0.05 (-0.22, 0.12)	.50	0.19 (-0.04, 0.42)	.10	1.03

Note. * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$, differences indicated by independent t-tests. ADL = Activities of Daily Living, DHEAS = Dehydroepiandrosterone Sulphate, ext. = extension, flex = flexion, GDS = Geriatric Depression Scale, HADS = Hospital Anxiety and Depression Scale, IFNγ = Interferon gamma, IL = Interleukin, ISEL = Interpersonal Support Evaluation List, MLTAQ = Minnesota Leisure Time Activity Questionnaire Shortened Version, MNA = Mini Nutritional Assessment, PSS = Perceived Stress Scale, SMMSE = Standardised Mini Mental State Examination, SPPB = Short Physical Performance Battery, TNFα= Tumour Necrosis Factor alpha.

Figure 2. 4.

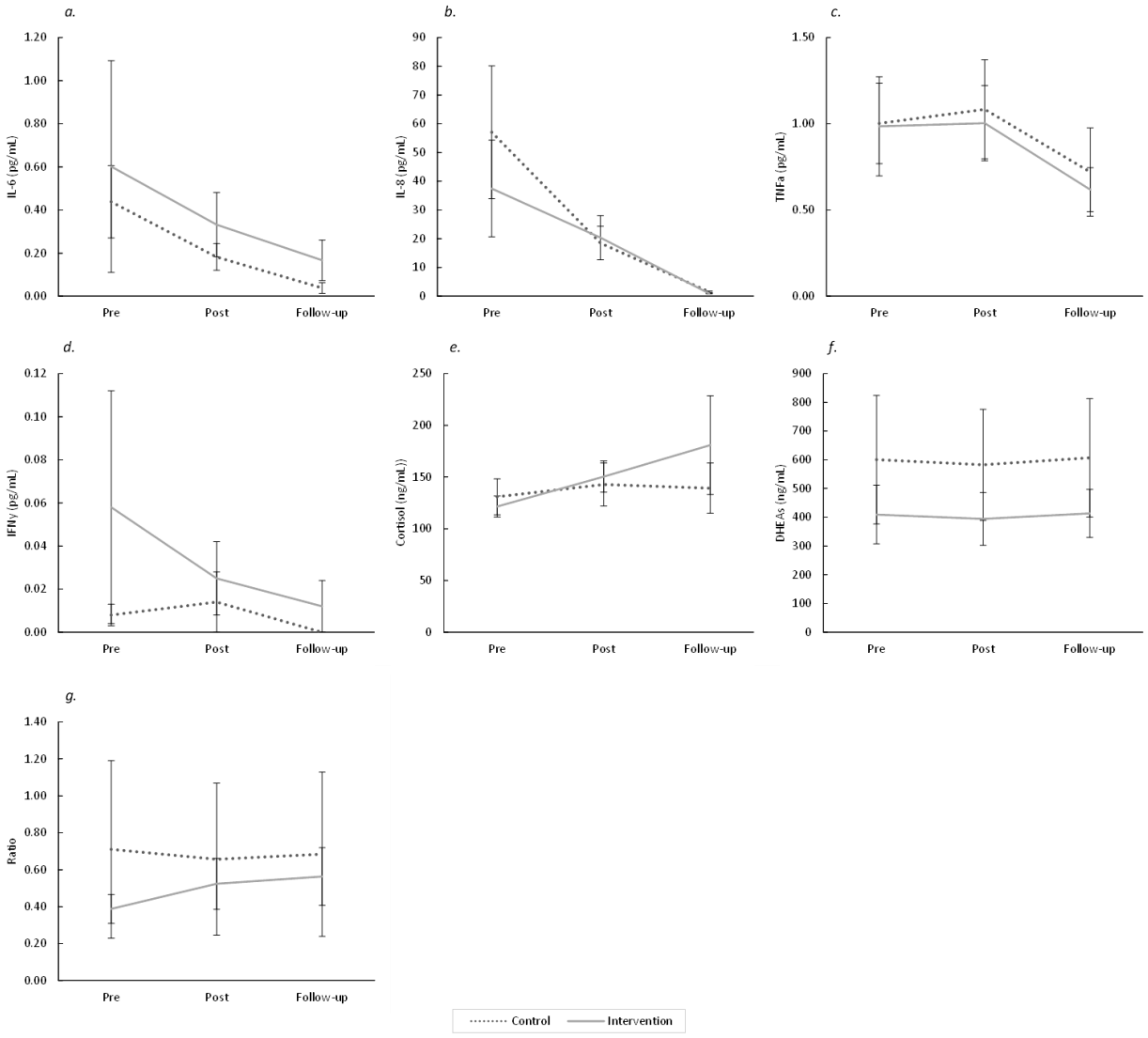
Strength Measures



Note. Peak torque measures (in Newton metres, Nm) over time in intervention and wait-list control groups a. Left knee extension, b. Right knee extension, c. Left knee flexion, d. Right knee flexion, e. Hip adduction, f. Hip abduction. Error bars represent *SE*.

Figure 2. 5.

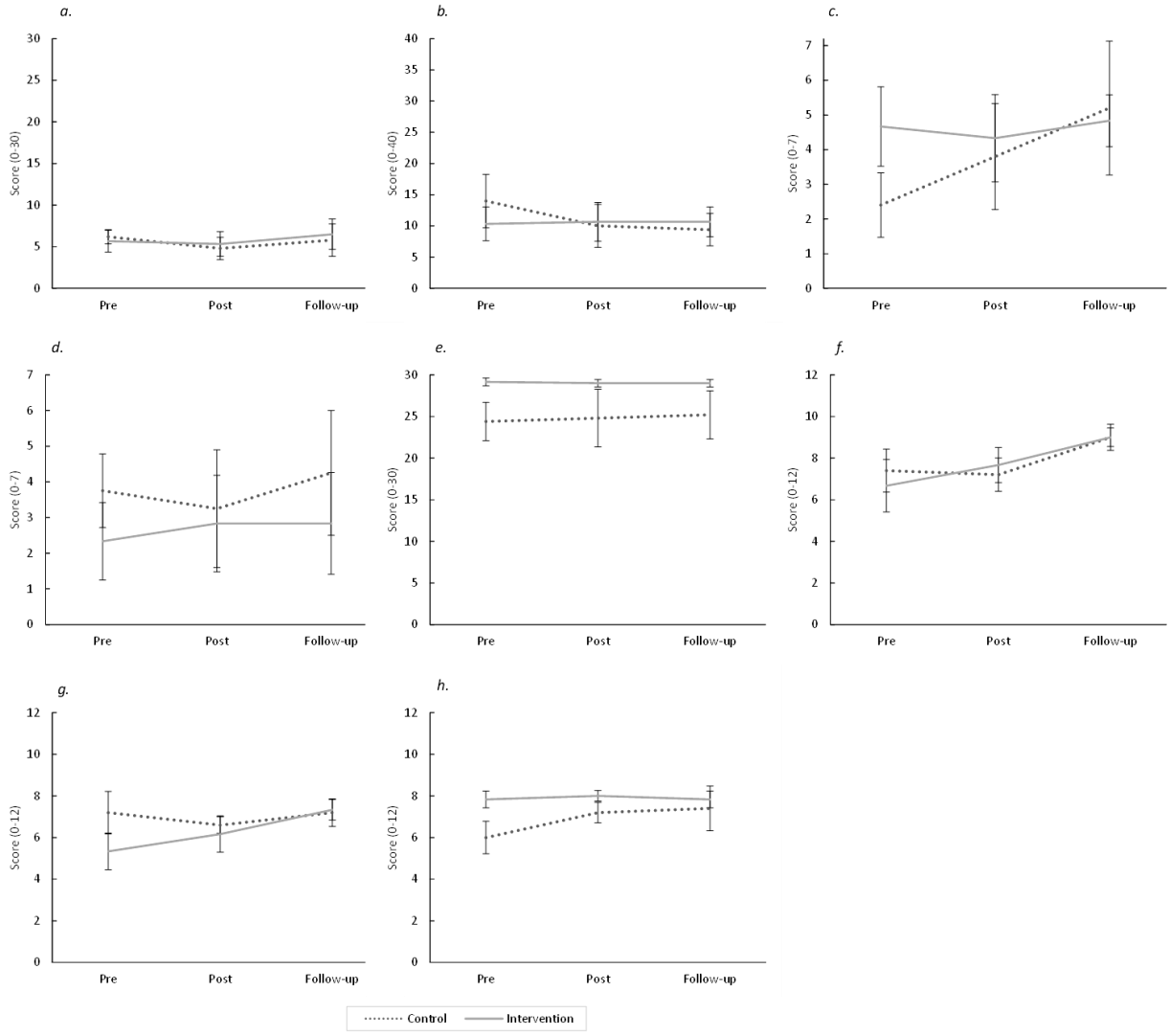
Physiological Measures



Note. Blood measures over time in intervention and wait-list control groups a. Interleukin-6 (IL-6), b. Interleukin (IL-8), c. Tumour necrosis factor alpha (TNFα), d. Interferon gamma (IFNγ), e. Cortisol, f. Dehydroepiandrosterone Sulphate (DHEAS) g. Cortisol: DHEAS. Error bars represent *SE.*

Figure 2. 6.

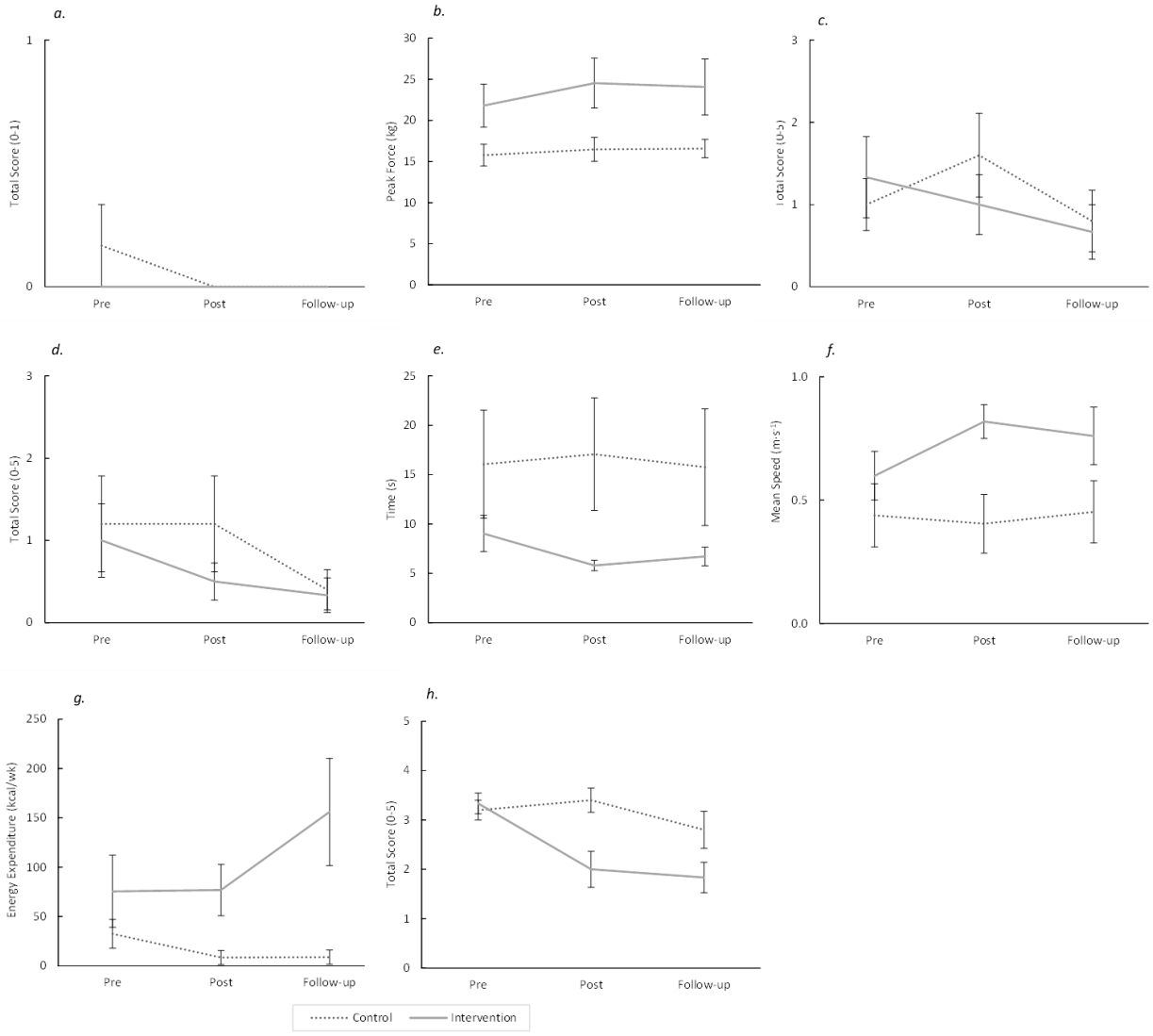
Psychological, Emotional, Cognitive and Social Support Measures



Note. Psychological, Emotional, Cognitive and Social Support measures over time in intervention and wait-list control groups a. Geriatric Depression Scale (GDS), b. Perceived Stress Scale (PSS), c. Hospital and Anxiety Depression Scale (Depression), d. Hospital and Anxiety Depression Scale (Anxiety), e. Standardised Mini Mental State, f. Interpersonal Support Evaluation List (Appraisal), g. Interpersonal Support Evaluation List (Belonging), h. Interpersonal Support Evaluation List (Tangible). Error bars represent *SE.*

Figure 2. 7.

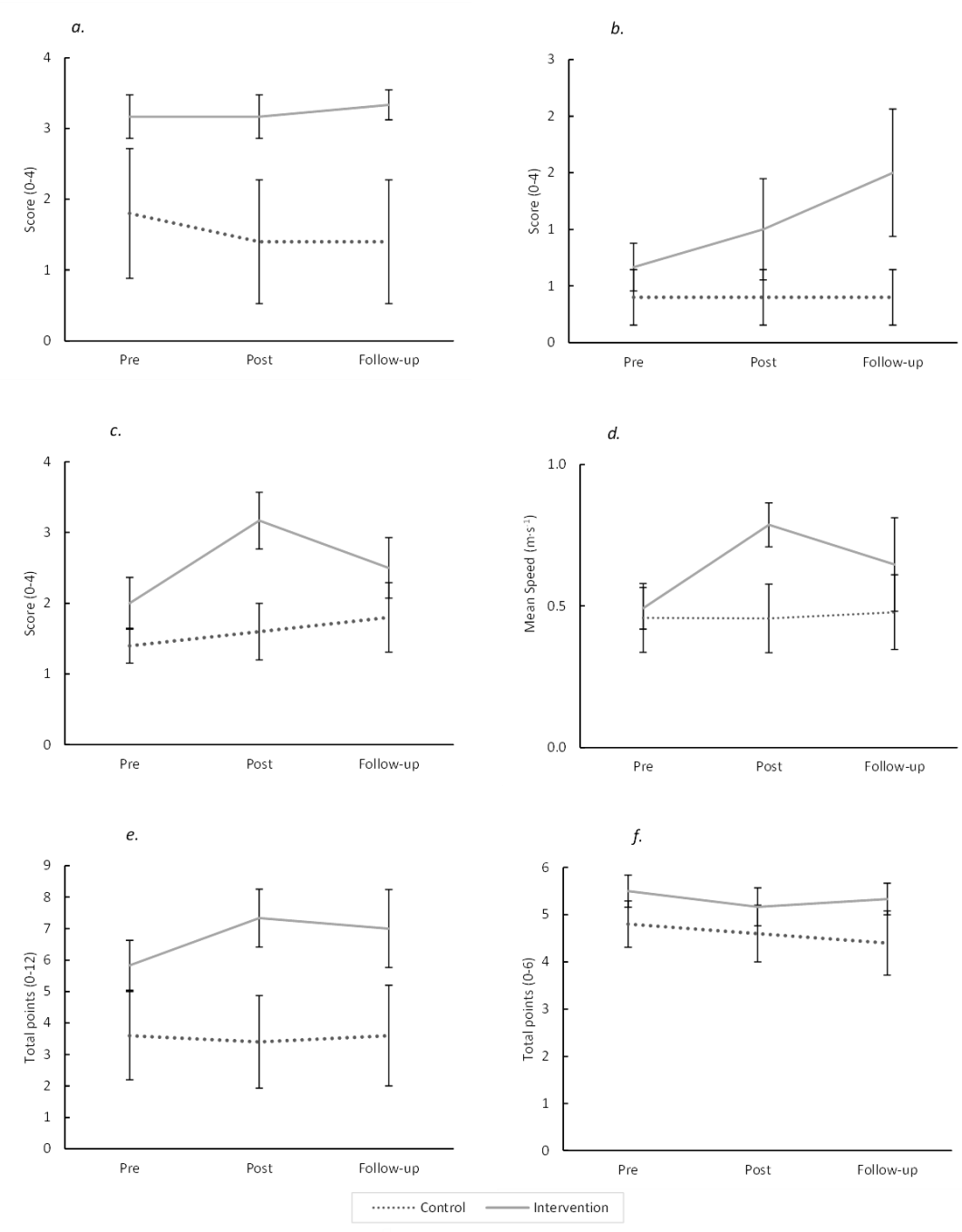
Eligibility Screening and Functional Capacity Measures



Note. Fried frailty phenotype measures over time in intervention and wait-list control groups a. Self-reported unintentional weight loss, b. Grip strength, c. Centre for Epidemiological Studies Depression scale (CES-D) question 1, d. CES-D question 2, e. Mean walk test time, f. Mean walk test speed, g. Minnesota Leisure Time Activity Questionnaire (MLTAQ) Shortened Version, h. Total Score. Error bars represent *SE.*

Figure 2. 8.

Functional Capacity Measures



Note. Functional Capacity measures over time in intervention and wait-list control groups a. Short Physical Performance Battery (SPPB) Balance test, b. SPPB Chair stand test, c. SPPB Gait speed test, d. SPPB mean gait speed, e. SPPB total score, f. Katz Index of Independence in Activities of Daily Living (Katz ADL). Error bars represent *SE.*

Harms

There were no reported adverse events during the feasibility trial.

2.5 Discussion

This study has shown that a RT intervention designed to improve multidimensional health and functional capacity of frail older adults in residential care is feasible. The results of this trial support the development of a definitive RCT, and provide relevant feedback in terms of acceptability, demand, integration, adaptation, practicality, implementation, and expansion. With respect to the secondary aim of performing limited efficacy testing on measures of health and functional capacity, the results indicate large effect size values, positive trends and meaningful improvements in frailty, strength, and functional capacity. No meaningful change was found in terms of psychological, cognitive, and emotional health, physiological and social support measures.

2.5.1 Acceptability

Acceptability of the intervention was evident, with positive feedback on the trial structure, equipment, and exercise prescription. Levels of interest, uptake, and retention suggest that recruitment and screening processes were effective and appropriate. The recruitment rates were similar or higher than other RT studies with older adults in residential care (Fien et al., 2016; Johnen & Schott, 2018), and drop-out rates lower than those reported in RCTs examining exercise programmes in older adults (Chin et al., 2008; Martin & Sinden, 2001) with no adverse effects reported. The number and range of assessments were well tolerated by all participants, with perceived or measurable changes in strength and functional ability considered as most relevant and interesting. In line with work by Dionigi and Cannon (2009), these actual and perceived changes appeared to contribute to increased feelings of achievement, confidence, and satisfaction. Despite no meaningful change in social support measures, participants reported enjoying the social interaction, engagement with other residents and staff, and gaining a sense of purpose. This finding is consistent with Devereux-Fitzgerald et al. (2016) who found perceived value, enjoyment and social interaction to be key factors relating to older adults' acceptability of PA interventions.

2.5.2 Demand

Levels of attendance and adherence were comparable with or higher than previous studies of older adults in long term care (Ferreira et al., 2018; Finnegan et al., 2015; Forster et

al., 2010), and an exercise frequency of three times per week was considered appropriate. This supports earlier findings from group RT interventions (Hruda et al., 2003; Lazowski et al., 1999; Sahin et al., 2018) and is consistent with current exercise guidelines for older adults (Davies et al., 2019; Fragala et al., 2019). Clear differences were identified between the groups for adherence and attendance. Although the magnitude of this difference was surprising, challenges and barriers relating to retention, adherence, and participation are not uncommon. Previous research highlighted the complex multidimensional nature of frailty (Ferrucci et al., 2004; Provencher et al., 2014) and identified several barriers including poor health, pain and fatigue (Burton et al., 2017; Hassan et al., 2016). In the present study, these differences could be attributed to two likely factors that occurred when the wait-list control received their intervention. First, there was lower one-to-one support during this time due to unforeseen reduced availability of the researcher. Second, there was unanticipated disruption to the schedule due to timetabling conflicts, a period of restricted access due to infection control measures and bank holidays. Further reasons for non-attendance were consistent with the literature and included sickness, other medical/hospital appointments and prior commitments with family/friends (Fien et al., 2019). Interest and willingness to be involved was evident with reported reasons for involvement spanning enjoyment, interaction, improvements in physical function, and a desire to help others by contributing to research. These results match those of previous studies where participants cited keenness to contribute to society or knowledge (Lui et al., 2009), and enjoyment of social interaction (Devereux-Fitzgerald et al., 2016).

2.5.3 Implementation

The trial was ably supported by the care staff and management team. Consistent with the literature, supportive partnerships with on-site carers and allied health professionals, and enthusiastic backing from welfare activity coordinators and instructors may have been influential in the success of the intervention (Finnegan et al., 2015; Hawley-Hague et al., 2016; Provencher et al., 2014). Using a busy communal area for the equipment, however, remained a somewhat contentious issue throughout. Nonetheless, deliberately creating a high level of visibility in the home may have had a positive influence on levels of adherence, interest, and long-term sustainability (Fien et al., 2016; Fien et al., 2019; Mulasso et al., 2015).

Implementation of all multidimensional health measures presented some challenges including scheduling, equipment availability, time commitment, and energy levels. However, participants did willingly take part with only limited numbers requiring rescheduling due to

unanticipated illness or fatigue. Several participants questioned the requirement for such comprehensive measures and reported finding them repetitive and tiring. These findings correspond with previous observations which suggest that respondent burden (Ferrucci et al., 2004) and unfavourable benefit-burden ratio (Mody et al., 2008) may negatively impact recruitment and retention rates of older adults. Given this, and that the meaningful effects here were shown for measures of physical function and frailty, fewer assessments of psychosocial factors should be included in the definitive trial, or briefer versions could be considered.

2.5.4 Practicality

The intervention placed some additional demand on staff and management time, and resources. This was most apparent during equipment installation, recruitment, scheduling, and assessment periods. However, the requirement for extra support declined during the exercise intervention phases as routines became established, and participants became increasingly confident and familiar with the programme and equipment. These results suggests that initial financial outlay on specialised resistance machines may pay off longer term with ease of use, and individualised progressive programmes. Previous research lends support to the use of technology with Valenzuela et al. (2018) suggesting that an under-used advantage of technology-based exercise programmes with older adults is the provision of automatically recorded exercise sessions, load progression, and real-time feedback. Work by Bossers et al. (2014) with older, institutionalised adults with dementia, and Johnen and Schott (2018) with nursing home residents, also identified the ability to start individualised, progressive programmes from a low baseline intensity as a contributor to higher adherence rates. Concerns about space for the equipment and appropriate location and timetabling of group sessions, highlighted some potential barriers. These findings are in line with Lazowski et al. (1999) who drew attention to the challenges of intervention delivery, location, and competing appointment times with other activities in long-term care facilities, and Benjamin et al. (2009) who reported space constraints and limited designated space for exercise.

2.5.5 Integration

The exercise intervention was perceived to fit in well to the existing culture and, once established, it quickly became recognised as part of the care home's broader commitment to wellness and health. A positive attitude towards research from management and well-being staff was critical to this level of integration. These results broadly support earlier findings citing the positive impact of motivated, enthusiastic staff on attendance of group exercise in nursing

homes (Finnegan et al., 2015), and the social influence of health care workers, health professionals and physicians on PA in older adults (Burton et al., 2017; Rhodes et al., 1999; Wilson & Spink, 2006). Longer-term sustainability in this setting appeared viable with participants continuing to use the equipment after the trial completion, additional requests to use the equipment, and a keen interest in future research. This result agrees with Bastone Ade and Jacob Filho (2004) who, after a six-month exercise intervention with nursing home residents, reported an expressed hope from participants for the programme continuation. However, this would need formal longitudinal assessment to establish longer term adherence rates.

2.5.6 Adaptation

Potential modifications to the existing intervention were considered, and although there was no firmly identified need for amendments, there was interest to increase the number and availability of exercise sessions. This was somewhat contrary to expectations given the age, frailty, and low levels of PA of the participants and may be explained by the reported high levels of enjoyment, social interaction, and achievement. It is encouraging to compare these findings with work by Rydeskog et al. (2009) and Dionigi and Cannon (2009) who reported a rich variety of positive feedback from older adults' experiences of RT including increased zest for life, confidence, enhanced feelings of self-esteem and competency. The requirement to modify one exercise machine that required stepping backwards to exit was evaluated in the light of risk of injury and concerns by staff regarding less able participants. This finding agrees with previous work highlighting potential barriers for older adults participating in RT including a lack of age-appropriate training programmes, equipment, and facilities (Burton et al., 2017), and concerns about pain and falling (Franco et al., 2015; Freiberger et al., 2016). However, some participants revelled in mastering this task, and in agreement with Lazowski et al. (1999) this demonstrates the requirement for appropriately challenging individualised programmes.

2.5.7 Expansion

Further expansion of the programme raised budgetary concerns from staff relating to the cost of the equipment, maintenance, and training. A requirement for more dedicated space to house equipment and run group sessions was also seen as a potential obstacle. This fits with previous studies that found although administrators spoke positively about the benefits of PA, they identified substantial staffing and funding constraints, limited space, and a lack of dedicated rooms as barriers to provision in long term care homes (Baert et al., 2016; Benjamin et al., 2009; Kalinowski et al., 2012). In fact, the home has retained three of the five machines.

2.5.8 Limited Efficacy Testing

With respect to the feasibility outcome of limited efficacy testing on measures of multidimensional health and functional capacity, the results indicated meaningful change and large effect sizes across some but not all measures. Consistent with the literature on progressive RT for frail, older adults, this study indicated positive change in strength and functional capacity (Chin et al., 2008; Fragala et al., 2019; Latham et al., 2004; Liu & Latham, 2009; Maestroni et al., 2020; Valenzuela, 2012) and reduction of frailty (Arrieta et al., 2019; Binder et al., 2002; Ferreira et al., 2018). Interestingly, no evidence was found for changes to other multidimensional health measures. These findings are contrary to earlier research that identified overall improved mood and cognitive function, lower state and trait anxiety, and increased IGF-1 levels in older men after 24 weeks of high intensity RT (Cassilhas et al., 2010; Cassilhas et al., 2007), and a meta-analysis indicating that PA and exercise can be effective in improving mental well-being in older adults aged 65 and over (Windle et al., 2010). A possible explanation for these findings is that the six-week exercise intervention was too short to effect significant change in these measures. It is also possible that the supportive, faith-based community within the residential care home positively impacted on the stability of measures of psychological, emotional, and social support status. The qualitative analysis identified a positive meaningful impact on self-reported functional capacity, and high levels of enjoyment and satisfaction with the intervention. Similarly, previous qualitative studies with older adults engaged in regular RT reported enhanced appetite for life, calm, self-esteem, and physical confidence (Dionigi & Cannon, 2009; Rydeskog et al., 2009).

2.5.9 Limitations

The present feasibility study had several limitations. First, the short duration of the RT intervention may have influenced levels of uptake and attendance, and might not accurately represent dropout and adherence rates for a longer duration RCT. This may also have impacted physiological adaptations and affected the lack of measurable changes in other markers of multidimensional health due to a lack of sensitivity to subtle change over a short time course. Second, the specialised equipment utilised in this study may not be accessible or affordable for larger or multicentre trials, consequently limiting broader expansion. Third, the current study was based on a small sample size thus limiting statistical power; however, as the primary aim of the study was to investigate feasibility, this was deliberate.

2.5.10 Recommendations and Future Directions

Based on the findings discussed above, we would make the following recommendations for the definitive RCT. To reduce potential bias, where possible, all assessments should be carried out by a researcher who is blinded to group allocation. The exercise sessions should run for at least 12 weeks, with fewer and/or more sensitive questionnaire measures. Ideally, an experienced, enthusiastic instructor should be present at all sessions to ensure consistency of delivery and support. The intervention should also be run in a visible setting and in a group for the positive effects that this brings. Additional help with, and reminders about, session attendance should be provided for participants with disability or mobility limitations, or cognitive impairment. Additionally, facilitating wider use of the equipment by care home residents who are not study participants, staff and families should be actively encouraged.

As well as the future RCT, future research could usefully explore whether there is any measurable impact on markers of multidimensional health over a longer follow-up. Further studies to determine longer-term attendance and adherence would also be worthwhile. It could equally be valuable to assess the impact of moving toward independent exercising, as this may be important for longer term adherence, sustainability and expansion. It would also need to examine whether such programmes are economically viable. We aim to assess the longer-term impact of a resistance training intervention on health and well-being and examine the reasons influencing longer-term adherence via a follow-up study with this study's participants at about one-year post-intervention. Research is also needed to investigate the effects of RT on frail, older adults with cognitive impairment and dementia, which, although included in this study was not the focus. Prevention of the progression to frailty would also be interesting to examine, by testing the intervention in pre-frail older adults in residential care and/or supported housing. Our next project addresses this latter question.

2.6 Conclusion

The KARE feasibility trial was found to be feasible in terms of acceptability, demand, integration, adaptation, practicality, implementation, and expansion. Some modifications are recommended to reduce potential assessor bias and ensure consistency of exercise delivery and support. These could be addressed with minor changes to the study design and additional support from residential care staff. Limited efficacy testing indicated that a RT intervention with frail, older adults may positively impact measures of frailty, strength, and functional capacity.

Qualitative feedback suggested that enjoyment, social interaction, achievement and gaining a sense of purpose were key motivators. Participants also reported a meaningful impact on self-reported functional capacity and physical confidence.

Collectively these findings support the feasibility of a definitive, RCT using a RT intervention with frail older adults in residential care. The study findings reinforce the value of RT interventions with improvements in strength and functional capacity contributing to a reduction of frailty.

Chapter 3: A Mixed Methods Feasibility Study of Machine-Based Resistance Training with Pre-frail Older Adults in Residential Care: The Keeping Active in Residential Elderly (KARE) Trial II

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3.1 Abstract

Physical activity is an effective, pro-active intervention to reduce or reverse frailty and functional decline. However, uncertainty exists about the impact and feasibility of resistance training (RT) on multidimensional health in pre-frail older adults in residential care. This mixed methods feasibility study assessed practicability with limited efficacy testing on health and functional outcomes. Eleven pre-frail older adults participated in a 6-week progressive RT protocol three times per week. The intervention and measures were found appropriate and acceptable by those who completed the trial, with participants self-reporting improved well-being, mood, and function. Analysis identified several barriers to recruitment including prior commitments, seasonal impact and session timing and offered potential solutions with further recommendations for programme refinement prior to a definitive randomised controlled trial. These findings add to our understanding of pre-frail older adults preferences regarding participation in physical activity research and the perceived benefits of RT. This trial was registered with ClinicalTrials.gov: NCT03141879.

3.2 Introduction

Frailty is an age-associated multidimensional clinical syndrome characterised by diminished resistance to stressors and decreased reserve, energy, and well-being (Fried et al., 2001; Lyndon, 2015; Rodriguez-Manas et al., 2013). It is typified by weakness and reduced physical resilience and functional capacity (Fried et al., 2021; Morley et al., 2013) and associated with adverse outcomes including disability, falls, hospitalization, and death (Clegg et al., 2013; Vermeiren et al., 2016; Xue, 2011). Even with no consensus definition of frailty (Rockwood & Howlett, 2018; Theou et al., 2015) there is growing acknowledgment that a rising proportion of the world's ageing population are affected by this declining later-life state (Cesari et al., 2016; Collard et al., 2012; Ofori-Asenso et al., 2019). However, the true scale of the problem is difficult to determine due to differences across measuring tools, countries, and settings (Collard et al., 2012; Gale et al., 2015). Accordingly, studies using physical frailty measures in community dwelling older adults report European and global prevalence rates of 7.7% (Manfredi et al., 2019) and 12% (O'Caoimh et al., 2021), respectively, while pooled estimates of prevalence of frailty in nursing homes were reported as 52.3% (Kojima, 2015). With prevailing research suggesting that increases in lifespan are outpacing healthspan (healthy disease-free years) (Partridge et al., 2018; Whittaker et al., 2019) the potential burden of increased levels of frailty on the provision of health and social care, and the associated economic costs are substantial (Cesari et al., 2016; Pinedo-Villanueva et al., 2019).

However, frailty is not a necessary outcome of ageing, and preventative, proactive and effective management at all points of the frailty continuum has the potential to delay or reverse functional decline (Dent, Martin, et al., 2019; Morley et al., 2013; Woolford et al., 2020). Identification of frailty status has thus become of increasing importance (Alvarez-Bustos et al., 2022; Galluzzo et al., 2018). Fried et al. (2001) phenotypical model of frailty is an established approach which uses diagnostic criteria to differentiate between earlier or intermediate states (pre-frailty) and later stages (frailty) of multisystem dysregulation and decline. The five criteria are weakness (grip strength), slowness, low physical activity, exhaustion (or fatigue), and unintentional weight loss (0, robust; 1-2, pre-frail; $\geq$3, frail) (Fried et al., 2021). As a result, pre-frailty is now recognised as a multifactorial, dynamic condition increasing vulnerability to, and directly preceding, frailty with increased risk of poor clinical outcomes such as disability and increased risk of mortality (Sacha et al., 2017; Sezgin et al., 2020).

The prevalence of pre-frailty in community dwelling older adults is higher than that reported for frailty: Rasiah et al. (2020) cite figures between 35% to 60% in large cohort studies using physical frailty measures. An overall population level estimate of 46% was reported by O'Caoimh et al. (2021), with other global and European studies reporting a weighted average prevalence of 44.2% and an overall prevalence of 42.9%, respectively (Collard et al., 2012; Manfredi et al., 2019). As such, the proportion of older people living with pre-frailty is considerable and important particularly given that a significant proportion of those are at high risk of progression to a future frail state (Fernandez-Garrido et al., 2014; Harrison et al., 2015; Xue, 2011). It is with this in mind that there is increasing interest in multidimensional predictors of physical frailty (Ding et al., 2017), the effectiveness of interventions for pre-frail older adults (Apostolo et al., 2018; Rasiah et al., 2020) and their influence on possible trajectories of frailty (Ding et al., 2017; Woolford et al., 2020).

Current evidence suggests that there are several potentially viable interventions to address frailty progression including PA and exercise, nutritional strategies, social support, cognitive training, and multicomponent interventions (Apostolo et al., 2018; Jadczak et al., 2018; Theou et al., 2011; Woolford et al., 2020). There is also growing support for proactive, preventative management (Harrison et al., 2015; Xue, 2011). Although there is still some uncertainty around the optimal approach, it is becoming clear that PA may have an important role to play. Recent findings based on the Ageing Trajectories of Health: Longitudinal Opportunities and Synergies project which harmonised data across 17 international ageing studies, suggest that abstinence from any type of PA was associated with poor healthy ageing trajectories through low baseline scores and fast decline rates (Moreno-Agostino et al., 2020). Healthy ageing is defined in line with the World Health Organization (WHO) as “the process of developing and maintaining the functional ability that enables well-being in older age”(World Health Organization, 2020a). Correspondingly, PA interventions have been consistently shown to support healthy ageing and preserve physical function, with the beneficial effects being well documented and compelling (Bangsbo et al., 2019; Izquierdo et al., 2021; Moreno-Agostino et al., 2020). This is clearly observed by the positive impact of PA on muscle and bone strength, balance, and its role in maintaining and promoting functional capacity, quality of life and reducing the risk of falls, fractures, and frailty (Marzetti et al., 2017; Skelton & Mavroeidi, 2018a; Witard et al., 2016).

PA interventions for older adults with pre-frailty have typically focused on multi-component trials, with the inclusion of strength and balance, mobility, and functional movement exercise (Frost et al., 2017; Jadczak et al., 2018). Recent research with community-dwelling older adults in England, including those identified as pre-frail, reported

significant improvements in lower limb function following a low-cost multi-modal exercise and behavioural maintenance intervention designed to improve lower limb muscle strength and balance (Stathi, Greaves, et al., 2022). Other modalities have also included Tai Chi (Ge et al., 2021), seated chair exercise (Furtado et al., 2021), myofascial release (Barrachina-Igual et al., 2021), or functional walking (Faber et al., 2006) or aimed to combine strengthening exercise with components such as diet and education in specific disease groups such as diabetes (Rodriguez-Manas et al., 2014). However, there is an emerging body of research recognising resistance exercise training as a primary countermeasure to physical frailty (Fragala et al., 2019; McLeod et al., 2019). Resistance training (RT) is a specialised form of PA that uses a range of resistive loads to enhance health, fitness, and performance (Lloyd & Faigenbaum, 2015). It has been repeatedly shown to improve muscle strength and function, support well-being and quality of life, and counter age-related changes and dysregulation across physiological, neurological, and metabolic systems (Coelho-Junior et al., 2022; Fragala et al., 2019; Maestroni et al., 2020; McLeod et al., 2019; Skelton & Mavroeidi, 2018b). In addition, a growing body of research is recognising the potential for RT to reverse the loss of functional capacity and change the trajectory of frailty (Bray et al., 2016; Coelho-Junior et al., 2021; Lopez et al., 2018; Talar et al., 2021). An early, proactive approach is of relevance to pre-frail older adults as research suggests that they may respond better than those who have already moved to a frail state (Faber et al., 2006; Kidd et al., 2019; Vermeiren et al., 2016).

Research to date using RT as the primary focus with community dwelling pre-frail older adults has included a range of methods such as bodyweight and functional movements (Tou et al., 2021), resistance bands (Tan et al., 2018), weight vests and ankle weights (Coelho-Junior & Uchida, 2021; Lai et al., 2021), free weights (Bray et al., 2020) and resistance machines (Drey et al., 2012; Lee et al., 2021). In contrast, there is little published data on those living in assisted living/residential care facilities (de Souto Barreto et al., 2016; Valenzuela, 2012) despite an acknowledgement that findings cannot be generalised across settings (Arrieta et al., 2019; Lee et al., 2021).

PA research interventions present unique challenges including recruitment, retention, and adherence (El-Kotob & Giangregorio, 2018), and factors influencing older adults' participation are complex. A recent review paper by Forsat et al. (2020), for example, found that the literature on older adults willingness to engage with research trials was somewhat contradictory: some studies identified a declining inclination to participate with age, while other studies found higher levels of curiosity and interest in research. Frequently reported barriers influencing recruitment and retention include study eligibility criteria with rigid

exclusion conditions, and declining participation based on advice from relatives or physician (Forsat et al., 2020). A recent RCT with community-dwelling older adults including those with pre-frailty also reported physical health barriers which included mobility issues, pain, discomfort and tiredness (Stathi, Withall, et al., 2022). There are additional challenges to RT interventions in residential care facilities. A pilot study by Fien et al. (2016) examining the feasibility and benefits of group RT in residential care facilities using bodyweight and dumbbells, noted that some residents declined to participate due to fear of never having done RT and not wanting to try. There is limited work addressing recruitment challenges specific to RT in residential care homes, and an acknowledged need to examine these (Fien et al., 2019). Pilot and feasibility trials may help investigators better understand issues unique to older adults' participation in exercise, PA and rehabilitation interventions including barriers to recruitment and retention (El-Kotob & Giangregorio, 2018), and inform future recruitment methods and study design.

In addition to the physical benefits noted earlier, group-based RT interventions within assisted living/residential care homes potentially offer opportunities to improve social connectedness, well-being, peer support, and adherence (Dionigi & Cannon, 2009; Finnegan et al., 2015). With recent research highlighting the negative impact of loneliness, isolation, and poor social support on the trajectory of frailty (Davies et al., 2021; Ding et al., 2017), regular group interaction among those living in the same setting may offer a proactive mitigation. Research to date has not clearly established the impact of group RT on multidimensional health, well-being, and physical function in pre-frail older adults in assisted living/residential care. With pre-frailty increasingly acknowledged as a potentially reversible, multifactorial, and transitional risk state, research to evaluate the feasibility and impact of this is imperative.

3.2.1 Aims and Objectives

Consequently, the primary aim of this feasibility study was to assess the feasibility of a definitive, RCT using a RT intervention with pre-frail older adults in an assisted living/residential care setting. The secondary aim was to perform limited efficacy testing on measures of multidimensional health, including physiological, psychological, cognitive, and emotional health measures, and functional capacity from pre- to post-intervention compared with a wait-list control group. These measures were proposed as the primary dependent variables in a future definitive RCT.

The specific objectives were to: a) evaluate the experiences of the participants and care home staff (acceptability); b) determine levels of interest and adherence to the training intervention (demand); c) evaluate the requirement for organisational change, including

perceived cultural fit (integration and adaptation); d) determine the practicality of the intervention with this population group (practicality); e) evaluate the suitability and relevance of the selected multidimensional health measures (implementation and expansion); and f) examine changes in multidimensional health measures using mean differences, effect size, and meaningful change, pre- to post-intervention compared with the wait-list control (limited-efficacy testing). Bowen et al.'s (2009) feasibility framework was used to guide the research design structure, aims and objectives. Due to the feasibility design, there were no directional hypotheses. This research has been reported in line with Consolidated Standards of Reporting Trials (CONSORT) 2010 guidelines for reporting randomized pilot and feasibility trials (Eldridge et al., 2016), Consensus on Exercise Reporting Template (Slade et al., 2016) and Standard Protocol Items: Recommendations for Interventional Trials Schematic Participant Timeline (Chan, Tetzlaff, Altman, et al., 2013). The CONSORT 2010 checklist is included as Appendix B (Table B.1.)

3.3 Method

3.3.1 Participants

The trial site was a residential care home in Birmingham, United Kingdom, who agreed to participate having been involved in previous studies that were aimed at improving health and ageing. The residential care home was a unique facility for up to 68 people and included residential, nursing and dementia care in one setting, allowing older adults with varying care needs to live together in a supportive community. Participants were recruited by well-being or care staff, or by direct volunteering to a member of the research team following an on-site introductory talk by the researcher (July 2019). The introductory talk was advertised to all residents and staff in a weekly well-being and activities timetable to try to ensure engagement with as many potential participants as possible. Eligibility criteria required participants to be: (a) resident in the care home; (b) age $\geq$ 65 years; (c) identified as pre-frail by scoring one or two on the Fried frailty phenotype criteria (adapted from Fried et al. (2001); (d) without severe sensory impairments that would profoundly impact upon their ability to participate; (e) able to speak and read English; (f) currently not taking part in any other clinical trial which could potentially affect the results of this study; and (g) with a predicted life expectancy greater than the length of the trial.

3.3.2 Recruitment

Potential participants were offered a summary document about the study (a two-page leaflet based on the participant information sheet). This leaflet summarised the purpose and procedures, the benefits and risks of participation, research team contact details, and

confidentiality and data protection. Use of a summary document has been previously described in Swales et al. (2022), and was designed to improve accessibility for all potential participants including those with any cognitive or sight impairment. All potential participants who expressed further interest in the study were given the full participant information sheet and had 10 days to consider if they wished to take part and to discuss any further queries with a member of the research team. Interested potential participants received an informed consent form. The trial design was inclusive of those who may have lacked capacity to provide informed consent, and documentation was in place for personal or nominated consultees, if required.

All participants had capacity, i.e., they did not have a dementia diagnosis and were deemed capable of consent by their care staff and provided written informed consent before the trial commencement and verbal consent before interviews. They were free to withdraw from the study at any time.

3.3.3 Sample Size

As this was a mixed methods feasibility trial, a formal sample size calculation was not performed. However, sample size was guided by current recommendations for qualitative and quantitative feasibility studies which suggest that even small samples of 5-20 individuals may be informative for decisions relating to acceptability and practicality (Hertzog, 2008; O'Cathain et al., 2015), and that it depends on circumstances (Shanyinde et al., 2011). Following the initial level of interest in the trial, and collaboration with the care staff, the researcher aimed for a sample size of 20 participants.

3.3.4 Trial Design

Ethical approval for this study was provided by London Harrow Research Ethics Committee. REC: 17/LO/1316. Protocol: RG_17-108 IRAS: 219616. The full study protocol has been published elsewhere (Doody et al., 2019); the trial was registered with ClinicalTrials.gov: NCT03141879 on 5th May 2017. Important changes to health and functional outcome assessments, equipment and delivery, and exercise prescription made after the protocol was published are detailed in Swales et al. (2022). Important changes to trial design are detailed below.

The mixed methods feasibility study was conducted between July and December 2019. The participant timeline is shown in Table 3.1 and represents the overall study duration. All study participants completed eligibility screening (week -2) and baseline assessments (weeks -1 and 0) prior to group allocation. The intervention group only participated in scheduled instructor-led group-based RT sessions during weeks 1-6. The wait-list group did not have access to the equipment during this time. Post-intervention

testing was completed by both groups in weeks 7-8. The wait-list control group only participated in their scheduled group-based training sessions during weeks 9-14. Follow-up testing was arranged for weeks 13-14 and weeks 15-16 for the intervention and wait-list control groups, respectively. This approach ensured that follow-up testing was carried out six weeks after completion of the group exercise sessions. During their designated training weeks, all study participants followed the same programme as detailed in Table 3.2. Participants were advised to avoid any strenuous PA for at least 24 hours prior to assessment of strength or functional capacity, or blood sampling. Due to the comprehensive test measures, and to minimise participant fatigue, assessments were scheduled over several days/visits (Table 3.1).

Table 3. 1.

Participant Timeline (Schedule of Enrolment, Interventions, and Assessments Based on SPIRIT [2013])

	Study Period													
	Enrolment	Baseline		Intervention	Postintervention			Intervention (wait-list control)	Follow-up (intervention group)			Follow-up (wait-list control)		
		B1	B2		P1	P2	P3		F1	F2	F3	F1	F2	F3
Timepoint (weeks)	-2	-1	0	1-6	7	8	8	9-14	13	14	14	15	16	16
ENROLMENT														
Eligibility Screen	x													
Informed Consent	x													
Fried frailty phenotype	x				x				x			x		
SMMSE	x				x				x			x		
Allocation			x											
STUDY GROUPS														
Intervention				x										
Wait-list control								x						
ASSESSMENTS														
SPPB		x				x				x			x	
GDS		x			x				x			x		
ISEL-12		x			x				x			x		
Socio-demographics		x												
MNA		x				x				x			x	
Leg Strength/RFD			x		x					x			x	
HADS			x			x				x			x	
PSS			x			x				x			x	
Katz ADL			x			x				x			x	
Blood measures			x				x				x			x
Semi-structured interviews											x			x
Focus Groups (staff)											x			x

Note. SMMSE = Standardised Mini Mental State Examination, SPPB = Short Physical Performance Battery, GDS = Geriatric Depression Scale, ISEL = Interpersonal Support Evaluation List, MNA = Mini Nutritional Assessment, RFD = Rate of Force Development, HADS = Hospital Anxiety and Depression Scale, PSS = Perceived Stress Scale, ADL = Activities of Daily Living, B1 = Baseline 1, B2 = Baseline 2, P1 = Postintervention 1, P2 = Postintervention 2, P3 = Postintervention 3, F1 = Follow-up 1, F2 = Follow-up 2, F3 = Follow-up 3.

3.3.5 Randomisation

Randomisation and allocation were conducted by the principal investigator, independent of the identification, consent, screening, and baseline assessments. The researcher enrolled participants, conducted eligibility screening and baseline testing, and informed participants of their group allocation. Permuted block randomisation (1:1) was used to randomise participants to either the intervention or wait-list control group. Randomisation was conducted using a computer-generated random number generator (www.randomizer.org). Group allocation was not revealed until after consent, eligibility screening and baseline assessments had been completed to ensure allocation concealment and minimise selection bias. Further blinding was not possible, due to the researcher's dual role (intervention delivery and assessments). The trial participants and care home staff were also aware of group allocation. All post-intervention and follow-up tests were completed unblinded by the researcher. Minimisation of conscious bias was upheld by exact adherence to standardised assessment measures, timing of tests and consistency of encouragement across all tests.

3.3.5.1 Important Changes to Trial Design After the Protocol was Published

Eligibility criteria in the published protocol (Doody et al., 2019) stated a requirement for participants to be frail according to the Fried frailty phenotype criteria (Fried et al., 2001), having at least three of the five key clinical signs. For this study, eligibility was amended (and given Research Ethics Committee approval of the amendment) to comprise participants classified as pre-frail, having one or two of the criteria only (Fried et al., 2001). In addition, the published protocol outlined assignment of individual participants to either the intervention or the control group. However, in response to participant feedback and discussions with care home staff about adaptability and long-term sustainability, this process was modified. Individual participants were assigned as per protocol and any eligible married couples, who requested to do so, were randomly allocated as a pair, and completed the study together. A wait-list control design was used to ensure that all participants could have access to the potential benefits of the intervention, and to counter the possible negative psychological impact of expressing interest in a healthy ageing initiative and then being randomised to no treatment. As described in Swales et al. (2022), this was a revision from the published protocol and supported by the care home management in terms of inclusivity and sustainability.

3.3.6 Measures

The primary aim of this study was to evaluate the feasibility of conducting a definitive RCT. The feasibility outcome measures address all principal focus areas for feasibility studies (Bowen et al., 2009).

3.3.6.1 Primary Feasibility Outcomes

Qualitative Methods

Feasibility outcomes related to acceptability, demand, implementation, practicality, integration, adaptation and expansion were assessed using semi-structured interviews and focus groups. The researcher conducted all the participant interviews in a quiet, recess of the communal lounge outside of scheduled activities, and all staff focus groups and interviews in private staff offices. The researcher had previous interviewing experience and had established professional relationships with the participants and staff during the study. Audio was digitally recorded using an IBM ThinkPad X1 Laptop (Lenovo, China), Voice Recorder App (Microsoft 2018) and iGOKU USB Microphone (iGOKU, China). The researcher also kept a reflective diary and written field notes. Full details of the data collection are provided in the published protocol (Doody et al., 2019).

Quantitative Methods

Feasibility outcomes related to acceptability and demand included study uptake, retention, attendance, and adherence. The researcher recorded uptake and retention. Measures of attendance and adherence were monitored and recorded by the researcher and tracked by the software log-in data linked to the HUR (HUR Ltd., Finland) exercise equipment. Attendance was reported as a percentage of exercise sessions attended. The adherence to exercise prescription was reported as the percentage of total repetitions completed at the prescribed load. The HUR SmartTouch (HUR Ltd., Finland) software automatically recorded all exercise data (including attendance, exercises performed, sets, repetitions, and load). Any technical issues that compromised accurate electronic record-keeping, including issues with wi-fi connectivity, log-in or card recognition, were documented to ensure data integrity.

3.3.6.2 Secondary Outcome Measures

Multidimensional health and functional measures are summarised in Table 3.1 and a detailed description is in the published protocol (Doody et al., 2019). These were classified into physiological, psychological, cognitive, and emotional health measures, social support, and functional capacity. The physiological measures were cortisol, and dehydroepiandrosterone-sulphate (DHEAS) from blood serum. Psychological and emotional measures consisted of the Geriatric Depression Scale (Yesavage et al., 1982), the Hospital

Anxiety Depression Scale (Zigmond & Snaith, 1983) and the Perceived Stress Scale (Cohen et al., 1983). The Standardised Mini-Mental State Examination (SMMSE) (Molloy et al., 1991) and the Interpersonal Support Evaluation List-12 (Cohen et al., 1985) were utilised for measuring cognitive assessment, and social support, respectively. Lastly, functional capacity was assessed using the Activities of Daily Living scale (Katz et al., 1970), the Short Physical Performance Battery (Guralnik et al., 1994) and maximal isometric leg strength. Maximal isometric strength was assessed using the HUR Performance Recorder 9200 (HUR Ltd., Finland) as detailed in Swales et al. (2022). The Fried frailty phenotype (Fried et al., 2001) and SMMSE (Molloy et al., 1991) also comprised part of eligibility screening (Table 3.1). Each participant's data were recorded on an individual case report form.

3.3.7 RT Intervention

3.3.7.1 Equipment

The RT intervention used specialised, pneumatic, strength training equipment from the premium line of HUR SmartTouch (4th Generation; HUR Ltd., Finland). The machines were specifically designed for active-ageing programmes and utilised touch screens, web-based software, and radio-frequency identification (RFID) user login systems with smart cards. The touch screens displayed participant name on log-in and sign-out, the prescribed programme, sets, repetitions, and load.

Five independent, standalone machines were used: leg press, leg extension/curl, chest press, hip abduction/adduction, and optimal rhomboid. The leg extension/curl and hip abduction/adduction machines had dual functionality, and all machines (except for hip abduction/adduction) had unilateral and bilateral capability. The programme prescription included all seven exercises. The machines were installed in the main communal room (lounge) at the care home with sufficient space between them to support usability and accessibility. All machines were used in accordance with the manufacturer's guidelines. Individual seat heights, lever arm lengths and range of motion limiters were established, stored on personal RFID cards, and checked prior to each session by the researcher.

Participants were encouraged to perform the full range of movement (unless limited by pain, or specific joint or medical problems) with correct form and technique including body and limb positioning, breathing patterns, and speed. The researcher assisted the participants with any technology issues (including RFID card recognition or wi-fi connectivity); modifications to load or lever arms; and offered feedback and encouragement. Participants with hearing, sight or movement impairments were supported with individual attention, as needed. All RFID cards were stored in an index card box next to the machine compressor and only accessed by the participants or researcher.

Figure 3. 1

Photo of HUR Equipment in Care Home Lounge (own photo)

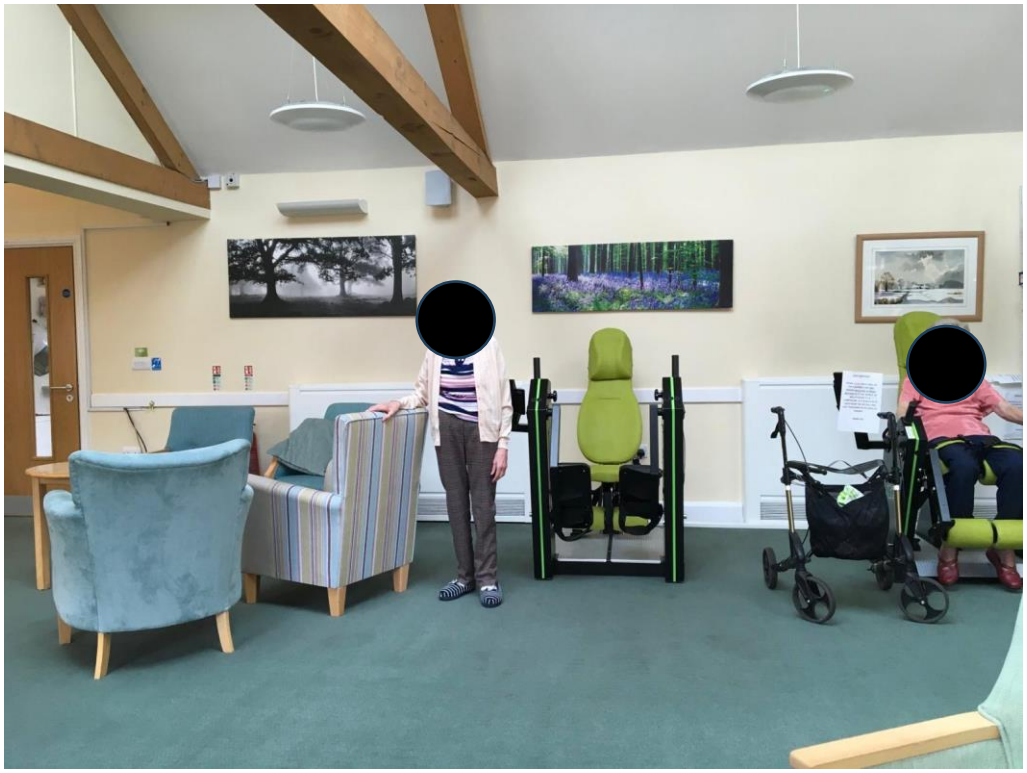


Figure 3. 2

Photo of Study Participant Using HUR Equipment (own photo)

3.3.7.2 Delivery

All exercise sessions were scheduled as a group-based activity, supervised by the researcher, and the participants wore their usual day clothes. The researcher was a qualified strength and conditioning coach with previous experience of working with older adults and HUR equipment (including isometric strength testing with Performance Recorder and HUR Labs Performance Recorder software). Additional technical support was available from HUR Ltd. (Finland) throughout the trial duration. The researcher and care home staff were supportive throughout the intervention, and participants were encouraged to attend all scheduled assessment and exercise sessions. This could include a verbal reminder of the day/time of the session from care staff or researcher. While attendance was actively championed, no formal motivation strategies were used, and the participants were reassured that involvement was voluntary.

3.3.7.3 Exercise Prescription

The exercise programme prescription was based on published guidelines for strength training for older adults including American College of Sports Medicine (ACSM) Guidelines for Exercise Testing and Prescription (American College of Sports Medicine, 2018), United Kingdom Chief Medical Officers (UK CMO) PA Guidelines (Davies et al., 2019), and National Strength and Conditioning Association (NSCA) Resistance Training for Older Adults (Fragala et al., 2019). Special considerations included the session structure, duration, number, and frequency, loading, sets, repetitions, total volume load, rest intervals, and progression.

All participants were scheduled to attend 18 sessions in total, with a minimum of a 48-hr recovery between sessions. The sessions were timetabled three times per week for 6 weeks, on Monday, Wednesday, and Friday mornings (09:30-10:30). The duration of the first sessions (Week 1) was 45-50 min and allowed additional time for participants to familiarise themselves with warm-up and cooldown exercises, machines and log-in cards, individual machine setup, and determine appropriate individual loads. After this initial phase, total session duration, including warm-up and cooldown, was 30-35 min.

The warm-up routine (5-10 min) was performed immediately prior to the resistance exercises and comprised a range of low-intensity, movement preparation exercises primarily aimed at increasing blood flow, joint fluid viscosity and range of movement. It included shoulder circles, reaches, trunk rotations, marching on the spot and chair sit-to-stands. The exercise sequence was not strictly standardized and could be completed either sitting or standing depending on each participant’s ability. The researcher encouraged a focus on movement quality, posture, and technique. Post-exercise, the participants performed approximately five minutes of light stretching and mobility work to ensure a gradual reduction

in intensity and effort. The warm-up and cooldown sections were often periods of feedback, social interaction and engagement between the researcher, the participants and other care home residents. The researcher supervised all exercise sessions to ensure high levels of consistency for delivery, coaching, and encouragement.

The intervention was delivered as planned, and the programme prescription is detailed in Table 3.2. For the duration of the study intervention, study participants did not use the machines at other times. Although the exercise selection was standardized, practical issues of time to transfer between machines, use by another participant, or individual preference required some flexibility in the order of completion. Any confirmed preferences or sequencing were recorded.

All the participants were beginners with no previous experience of RT. To ensure an appropriate primary focus on skill acquisition and movement competency, the initial loads (week 1) were conservative (Conlon et al., 2018). Subsequent training loads were guided by the participants' subjective feedback using the OMNI resistance exercise scale (Gearhart et al., 2009) and "repetitions in reserve" (Helms et al., 2016). Load progression, while not a condition of the feasibility study, was acknowledged as a key principle of RT and a programmable feature of the equipment: micro-adjustments (100g and 1kg) allowed an automatic inter-session increase of 5% for upper limb and 10% for lower limb when more than 14 technically sound repetitions were completed (Sheppard & Triplett, 2016). The loads were also manually adjustable by the participant or researcher intrasession, if required, and immediate confirmation of volume load (sets x repetitions x load) achieved was given on the SmartTouch screen. The participants were encouraged to achieve their goals and progressively increase load, but the focus was on consistency, movement proficiency and enjoyment. For the duration of the intervention, all participants were asked to follow the RT programme as specified and not make any other major PA changes. There were no non-exercise components in the study i.e., lifestyle coaching or health education.

Table 3. 2.

Programme Prescription Including Sets, Reps, Inter-set Recovery Interval and Intensity (Load)

Exercise	Sets	Reps	Inter-set recovery (s)	Speed of movement	Load
Optimal Rhomboid	2	12	120	Concentric: as rapidly as possible while maintaining sound technique. Eccentric: controlled (1-2 sec)	Progression from 'light-moderate' intensity (RPE 5-6) to 'moderate-hard' (RPE 7-8). (Equivalent OMNI-RES 4-6 progressing to 6-8, with 2-4 RIR)
Hip Adduction	2	12	120		
Hip Abduction	2	12	120		
Chest Press	2	12	120		
Leg Extension	2	12	120		
Leg Curl	2	12	120		
Leg Press	2	12	120		

Note. RPE = rating of perceived exertion; reps = repetitions; OMNI-RES = OMNI-resistance exercise scale; RIR = repetitions in reserve.

3.3.8 Data Analysis

3.3.8.1 Primary Feasibility Outcomes

Qualitative Methods

All qualitative interview data were manually transcribed verbatim by the researcher into Microsoft Word and uploaded into NVivo (version 12, QSR International Pty Ltd.) for analysis. Supporting data, including the researcher's reflective journal and additional field notes were also uploaded. Thematic analysis (Braun & Clarke, 2006) was used to identify, interpret, and communicate themes in the qualitative data. The researcher read and re-read the text alongside the supporting notes to ensure deep reflection and engagement with the data. Initial themes (codes) were developed deductively based on the feasibility outcomes, key areas of interest, and interview questions. An initial Mind Map framework, based on these, was created in NVivo (version 12, QSR International Pty Ltd.). Sub-themes were subsequently refined and developed inductively through purposeful, deliberative, and

thorough data coding. The researcher documented this stage of active reflection, development of ideas and coding decisions to improve trustworthiness of the data (Nowell et al., 2017). Reappraisal and refinement of themes, including any recoding and renaming, were completed by all the authors before the final analysis and write-up.

Quantitative Methods

To provide additional insight into feasibility, demand and acceptability, the attendance and adherence data for both groups were analysed over the duration of their corresponding 6-week intervention (weeks 1-6 and weeks 9-14, as described in Table 3.1).

3.3.8.2 Secondary Outcome Measures

All quantitative data management and analysis was performed using IBM SPSS Statistics for Windows (version 25.0; IBM Corp., Armonk, NY). Limited efficacy testing was completed on all measures. Descriptive statistics were used to report participant characteristics, recruitment, adherence, participation rates and pre- and post-health and functional outcome measures.

3.4 Results

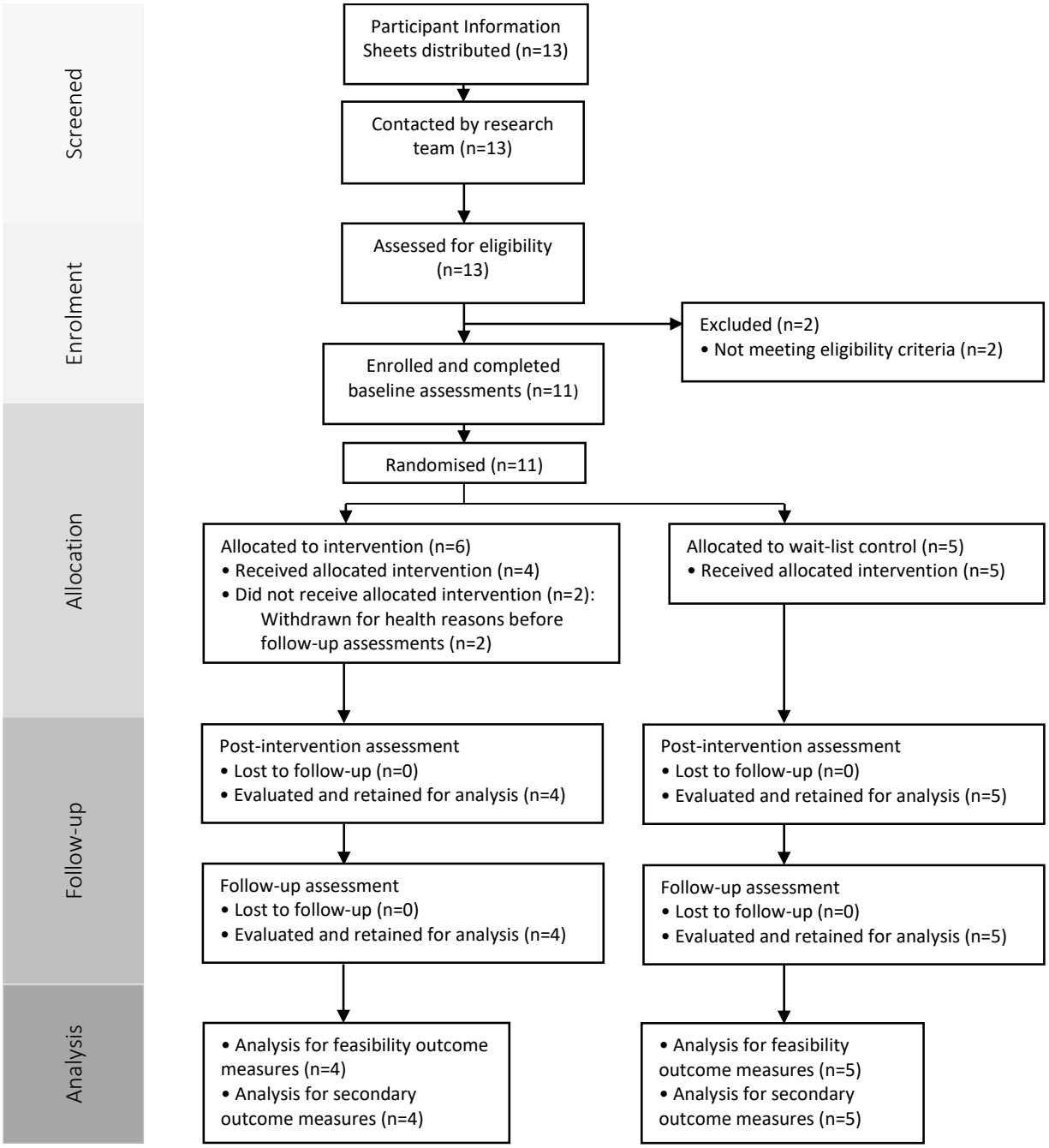
3.4.1 Participants

All those who requested further information and Participant Information Sheets were contacted (*n* = 13), and all consented to eligibility screening giving an uptake of 100% (see Figure 3.1 CONSORT Diagram). Two were excluded through not meeting the Fried frailty criteria for pre-frailty. All the eligible participants (*n* = 11) completed the full baseline assessments. Six participants (54.5%) were randomly allocated to the intervention group and five (45.5%) to the wait-list control group. Two participants in the intervention group withdrew due to unrelated health complications. All remaining participants (81.8%) (intervention and wait-list control) were assessed for every feasibility and health and functional outcome.

Just over half the sample (55%) were female with a mean (SD) age of 80.73 (4.24). All participants were white British in origin. Baseline descriptive characteristics are summarised by intervention and control groups in Table 3.3. The Fried frailty mean (SD) score was 1.36 (0.50) with SPPB scores ranging from five to 10 indicating a risk of developing frailty and functional limitations. The Katz ADL mean (SD) score was 6.00 (0.00) representing physical independence. Calculated mean (SD) gait speed from the Short Physical Performance Battery (SPPB) walking test suggested increased likelihood of poor health and functional capacity, but the SMMSE mean (SD) score indicated normal cognitive function.

Figure 3. 3.

CONSORT 2010 Participant Flow Diagram



Note. Figure 3.1 is based on CONSORT extension for Pilot and Feasibility Trials Flow Diagram (Eldridge et al., 2016).

Table 3. 3.

Baseline Sociodemographic, Anthropometric, and Health-related Characteristics of Sample

Variable	Mean (SD) / n (%)	
	Intervention *(n*=6*)*	Control *(n*=5*)*
Age (years)	83.50 (3.21)	77.40 (2.61)
Range (years)	80-88	75-81
Sex (female)	3 (50.0)	3 (60.0)
BMI (kg/m^2)	27.43 (3.02)	32.93 (4.09)
Medical conditions	1.83 (1.47)	1.80 (1.48)
Education		
Secondary	5 (83.3)	4 (80.0)
Degree/Diploma	1 (16.7)	1 (20.0)
Education years	10.00 (0.0)	11.00 (1.00)
Occupational category (manual)	2 (33.3)	0 (0.0)
Marital status		
Married	4 (66.7)	4 (80.0)
Separated/divorced	0 (0.0)	1 (20.0)
Widowed	2 (33.3)	0 (0.0)
Length of stay (months)	112.33 (64.09)	61.20 (23.29)
Fried frailty score	1.33 (0.52)	1.40 (0.55)
SPPB score	7.33 (1.63)	7.80 (1.30)
SPPB Gait Speed (m·s^{-1})	0.67 (0.19)	0.75 (0.07)
Katz ADL	6.00 (0.00)	6.00 (0.00)
SMMSE	28.83 (1.17)	29.40 (0.89)

Note. ADL = Activities of Daily Living, BMI = Body Mass Index, SMMSE = Standardised Mini Mental State Examination, SPPB = Short Physical Performance Battery.

3.4.2 Primary Feasibility Outcomes

3.4.2.1 Qualitative Findings

The primary outcomes were concerned with feasibility and qualitative findings from the staff and participant interviews established sub-themes for each of the feasibility issues examined. These are outlined in Figure 3.2 for illustrative purposes. All nine participants who completed the study (intervention and wait-list control) and three members of care home staff

engaged in interviews (one from the management team and two from the well-being team). Interview duration ranged from 6-18 minutes.

Acceptability

For the feasibility outcome of acceptability, two themes were identified: 'Appropriateness of Intervention' and 'Participant Experience.' As regards 'Appropriateness of Intervention' discussions were focused around how "useful," "relevant," and "constructive" it had been, and a "positive move" to improve well-being and mobility. Participants reported having confidence in the intervention due to its association with the University and it being "well organised":

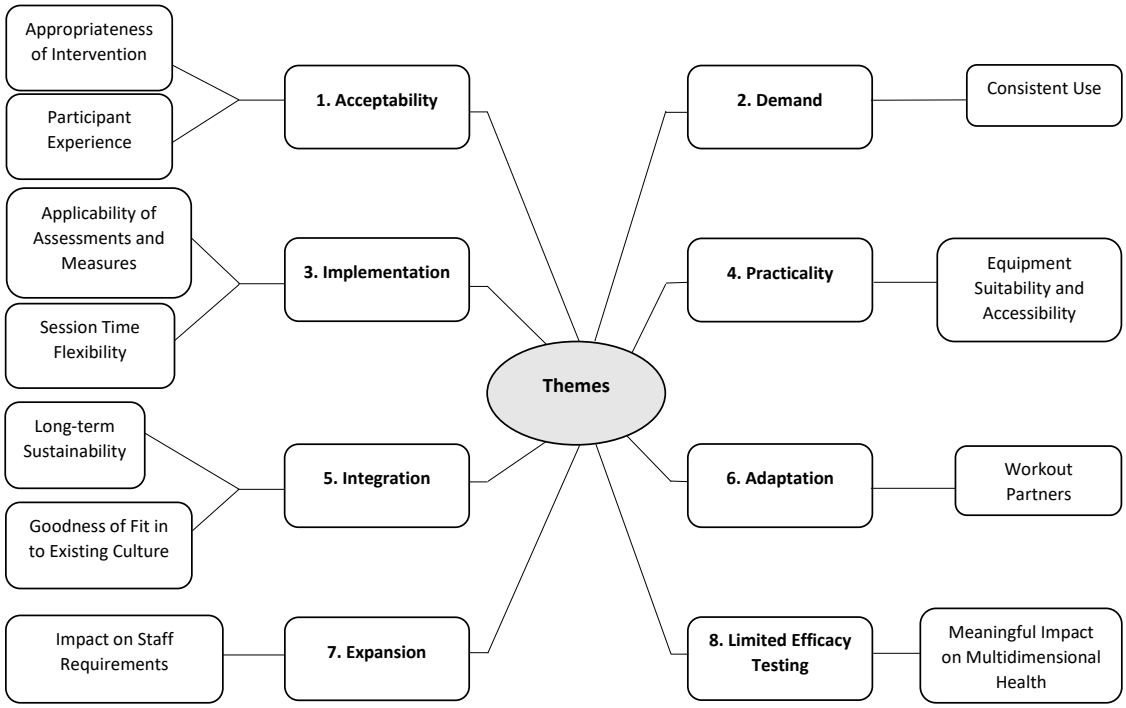
> *And I think generally, everyone is approving of what's been done here, and to have these machines here is a tremendous thing for a home like this. Especially for the older people who are not so strong that they can get better as well. (James, participant, intervention)*

Staff echoed this view commenting that it had been "nice and exciting" to see the intervention in action: "… I just think it's been the best thing, we ever took on board. And I wouldn't hesitate to do anything like this again" (Linda, care home management, staff member).

In terms of 'Participant Experience,' all participants described it as having been a positive experience, were pleased to have taken part and would do so again. Participants commented that it had been "enjoyable," "beneficial," "very good" and that it had "really been worth it." Even those who had been initially sceptical were upbeat when reflecting on their involvement, "… I just thought I didn't need these exercises, but you don't realise how much you did need them, and how it's helped me" (Richard, participant, intervention).

Figure 3. 4

Thematic Coding Structure Map



Note. Mind-map (NVivo 12) illustrating the feasibility outcomes and subsequent themes identified from the thematic analysis of the interviews and focus group discussions

Demand

The feasibility outcome of demand generated a theme of 'Consistent Use,' with study participants referring to it as an "opportunity to exercise" and an "investment in well-being." Participants reported that attending three times per week as prescribed during the intervention period had been "very doable," and linked improvements in quality of life to regular and consistence adherence. After completion of the prescribed six-week intervention and testing, several participants exercised more often while actively encouraging other residents, family, and friends to join them. As one male participant confirmed, "Yeah, yeah, I do. I come on a Thursday, I come on a Tuesday sometimes. Most days. I think it's excellent" (James, participant, intervention). Additionally, some residents who had been involved in a previous study at the care home were continuing to exercise regularly and make use of the resistance equipment at similar times. This not only created a level of interest, energy, and

social activity in the lounge area, but also some friendly challenge around attendance and training loads. As noted by a staff member, “I think the second study has gone very, very well and it’s caused a social engagement and a competition between a lot of the flat members, to be honest” (Linda, care home management, staff member).

Implementation

Two themes were developed within the feasibility focus area of ‘Implementation’: ‘Session Time Flexibility’ and ‘Applicability of Assessments and Measures.’ Regarding ‘Session Time Flexibility,’ some participants reported finding the scheduled session time as restrictive in relation to their established personal schedules and would have preferred more flexibility. Although all participants committed to complete the prescribed number of sessions, there was a clear preference for greater autonomy, and often a different pattern of attendance emerged across the intervention duration. Participants explained several different reasons for this including a busy, social life outside of the care home (pre-COVID); caring or other external commitments; a preference to exercise outside of busy times; and a dislike of early morning starts. As one participant explained, “Yes, we’re well into retirement mode and not getting up too early, or to a timetable and then, you know, we had to get up to a timetable….” (Nancy, participant, wait-list control).

In terms of ‘Applicability of Assessments and Measures,’ participants spoke positively about the physical and functional assessments, including grip strength and walking speed, stating that they were “very good and simple to do.” Despite the novel experience of maximal strength testing, this was well received, and participants commented that they could understand how the physical tests related to the study. When asked about possible improvements to the study, one participant even proposed more strength testing:

> *What I would like, which I know would take an awful long time, but I would like to test on all of them. I think if I could have seen that from what I tested in beginning, and then after to do them all for so long, to be able to be tested on each one to see if I’d improved, I’d have liked that. (Helen, participant, wait-list control)*

The questionnaires were less well received by participants and described as seeming “a bit banal,” time-consuming and requiring careful reading due to their structure. However, most participants said that they had been content to complete them as part of the study, and were interested to understand how they related to the assessment of multidimensional health:

> *I think especially the depression, I hadn't thought about that. I know I've been depressed just lately because I'm not doing what I was doing, but that's all. But I don't think on the whole that we are depressed people but it's interesting to know that it can help depression. (Helen, participant, wait-list control)*

Practicality

The feasibility outcome of 'Practicality' established a theme of 'Equipment Suitability and Accessibility.' Participants were clear and enthusiastic in their praise for the exercise equipment, and despite some initial concerns about not understanding machines and technology, had embraced the challenges. As one participant explained, "… at first, I was not going to do it because I thought I couldn't do it, it would be too much, but I find it's excellent" (Mary, participant, intervention). Several participants remarked that they had liked the technology, and found the ability to track progress, especially extra repetitions as "encouraging," and that it had given them "motivation" to continue:

> *And I think with it being computerised, that's the thing as well. So, you can tell us how we're doing better and that is important. If I thought I was doing this and there was no improvement… but this would seem that there is. (William, participant, wait-list control)*

Integration

Two themes established from the feasibility outcome of 'Integration' were 'Long-term Sustainability' and 'Goodness of Fit into Existing Culture.' As regards 'Long-term Sustainability,' care home staff were clear in their support of the resistance exercise and equipment and discussed future investment to ensure that all residents could benefit. As one staff member explained, "It's [investment] got to be there, I'm afraid, it's got to be there. It's the way forwards and I think it's possibly the best thing to do and put [the equipment and investment] into a care home anywhere" (Linda, care home management, staff member). Participants also stated an interest in continuing to keep the equipment on-site and supported longer-term use:

> *I've enjoyed what I've done and as far as the future's concerned I would like to feel that the machines were here and I would be able to use them at my own time, my own pace and continue to enjoy them. (Joan, participant, intervention)*

In terms of ‘Goodness of Fit into Existing Culture’ staff were clear that the resistance exercise sessions had become an accepted part of the care home’s investment in well-being and quality of life. Initial concerns about disruption to existing activities, demands on staff time, and it not being appropriate for some of the older female residents were swiftly rebuked:

> *No, I think that the participants actually did it all themselves, and it didn’t interfere with any other activities that were going on. It’s worked out in between, and we thought it was going to maybe, stop activities but it didn’t, and people were still using it while activities were going on anyway. So, from that point of view, it’s been great, and it’s just become part of the norm. (Linda, care home management, staff member)*

Adaptation

The feasibility outcome of ‘Adaptation’ generated a theme of ‘Workout Partners.’ From the initial recruitment stage, participants who were married had expressed a strong wish to be able to attend screenings, assessments, and exercise sessions together. This was both from a logistical standpoint (i.e., timetabling their days) and from a desire to share the experience, and offer support and encouragement. As one participant explained, “Yes, we do like to work together, and we do go together quite a bit, so we just enjoy it. I’d never say I’m going down on my own, it’s always together” (Mary, participant, intervention). While participants noted the benefits of having a specific workout partner for those occasions when they needed to be “spurred on,” the overall group social interaction was also praised as “nice,” “good” and an opportunity to interact with other people. As one participant explained, “And they help, and we’re all helping each other” (James, participant, intervention).

Expansion

The feasibility outcome of ‘Expansion’ generated a theme of ‘Impact on Staff Requirements and Support.’ Participants and staff discussed the need for an “enthusiastic person” to run the intervention and provide coaching expertise and guidance. Participants noted how they had appreciated the encouragement, the supervision and support, and the pre and post session interaction:

> *I think the talk with B helps before we even go on the machines, you know, the warming up and getting ready to go on the machines, and then after the*

> *machines, she asks you what you think about it, and I think that's good. (James, participant, intervention)*

Several participants commented that it had made a big difference to have a consistent contact who "has explained things" and "been with us":

> *…and you being here, and not giving us an instructor or whatever you are [laughter], and if we'd have had different ones, it wouldn't have worked. You've got to have the continuity, with the same person. That gives us confidence. (Helen, participant, wait-list control)*

Limited Efficacy Testing

Regarding the feasibility outcome of 'Limited Efficacy Testing,' a theme of 'Meaningful Impact on Multidimensional Health' was generated. Participants reported improvements in physical function including reduction in pain levels in specific joints, feeling stronger, and improvements in balance and walking speed. Participants talked about having more movement "confidence", including going up and down stairs, and standing up: "But it is, you know, but I feel that strength in my legs that I'm not going to fall whereas before you had the fear of falling, now that isn't so apparent" (Richard, participant, intervention).

Participants were also enthusiastic about the mental health benefits reporting that they had enjoyed the socialising, felt that they now wanted to "get out and do more, go for a walk," and were feeling "more alive." One participant explained, "I think I'm eating better, sleeping better, my outlook is much better because of it. I think it's beneficial in so many ways" (James, participant, intervention). And another simply stated, "… I can improve my life by adopting a pretty consistent approach to these machines. Positive and consistent" (William, participant, wait-list control). Care home staff also reported seeing a difference in mental health and mood:

> *Yeah, they're so much happier in themselves and they feel that they've got a purpose. They feel more energetic. They can see themselves that they're feeling stronger and more confidence. They exude happiness when they've done their session, they really do. I think it's been good from that point of view. (Linda, care home management, staff member)*

3.4.2.2 Quantitative Findings

The feasibility outcomes of acceptability and demand also included an evaluation of recruitment, retention, and adherence rates, and analysis of uptake rates. Overall study uptake was 100% with retention rates over 65%. Attendance and adherence were consistent with previous findings (Martin & Sinden, 2001) and exceeded 70% in all cases.

The Consort (2010) Participant Flow Diagram (Figure 3.1) details the number of participants screened, assessed for eligibility and subsequently enrolled. While the number of participants recruited was only 65% of the sample size target, 100% of those invited to attend screening did so, and 85% of those screened were found to be eligible.

3.4.3 Secondary Outcome Measures

Pre- to post-intervention health and functional outcomes are presented in Table 3.4. Effect sizes and 95% confidence intervals can be found in the *Supplementary Materials* version of this table, which is included in Appendix C.

3.4.4 Harms

There were two separate reported adverse events in the intervention group during the feasibility trial, at week one and three. The adverse events were reported immediately indicating causality and severity, in liaison with a medical expert, and submitted to the Research Ethics Committee and study sponsor within 24 hours. Both adverse events were assessed to be unrelated to the intervention. Both participants subsequently withdrew from the study.

Table 3. 4.

Effects Table: Within-Group Changes from Baseline to Follow-up

Outcome measure	Intervention				Control			
	n	Baseline mean (SD)	Post mean (SD)	Mean Difference [95% CI]	n	Baseline mean (SD)	Post mean (SD)	Mean Difference [95% CI]
Knee extension left, peak torque (N·m)	4	72.21 (19.26)	98.85 (5.27)	26.64 [-3.24, 56.52]	5	82.63 (41.80)	90.62 (38.30)	7.99 [-22.64, 10.98]
Knee extension right, peak torque (N·m)	4	80.56 (12.58)	103.82 (15.05)	23.26 [-6.66, 53.17]	5	83.85 (28.04)	81.25 (28.52)	-2.60 (-17.11, 11.92]
Knee flexion left, peak torque (N·m)	4	39.27 (9.26)	38.82 (14.09)	-0.44 [-16.48, 15.59]	5	39.85 (15.74)	46.98 (11.10)	7.13 [-0.23, 14.49]
Knee flexion right, peak torque N·m)	4	39.96 (13.96)	39.91 (12.40)	-0.05 [-9.81, 9.70]	5	47.93 (24.54)	50.02 (18.38)	2.09 [-3.86, 8.04]
Hip adduction, peak torque (N·m)	4	112.65 (21.30)	116.00 (21.76)	3.35 [2.62, 4.08]	5	114.97 (35.15)	124.46 (41.27)	9.49 [0.90, 18.08]
Hip abduction, peak torque (N·m)	4	75.11 (31.28)	79.04 (32.22)	3.93 [-9.51, 17.37]	5	113.62 (41.91)	107.21 (31.24)	-6.41 [-17.21, 4.40]
SPPB Balance test (0-4)	4	3.75 (0.50)	4.00 (0.00)	0.25 [-16.48, 15.59]	5	3.60 (0.55)	3.40 (0.55)	-0.20 [-0.63, 0.23]
SPPB Gait speed test (0-4)	4	2.50 (1.29)	3.50 (0.58)	1.00 [-0.30, 2.30]	5	3.20 (0.45)	3.40 (0.89)	0.20 [-0.64, 1.04]
SPPB Gait speed ($m \cdot s^{-1}$)	4	0.66 (0.24)	0.85 (0.16)	0.19 [0.02, 0.36]	5	0.75 (0.07)	0.79 (0.09)	0.03 [-0.07, 0.14]
SPPB Chair stand test (0-4)	4	1.25 (0.50)	1.75 (0.96)	0.50 [-0.42, 1.42]	5	1.00 (0.71)	1.00 (0.00)	0.00 [-0.62, 0.62]
SPPB Total points (0-12)	4	7.50 (1.91)	9.50 (1.29)	2.00 [0.70, 3.30]	5	7.80 (1.30)	7.80 (1.30)	0.00 [-1.14, 1.14]
Katz ADL (0-6)	4	6.00 (0.00)	6.00 (0.00)	0.00 [0.00,0.00]	5	6.00 (0.00)	6.00 (0.00)	0.00 [0.00, 0.00]
Fried frailty, weight loss (0-1)	4	0.00 (0.00)	0.00 (0.00)	0.00 [0.00, 0.00]	5	0.00 (0.00)	0.00 (0.00)	0.00 [0.00, 0.00]
Fried frailty 2a, depression (0-3)	4	0.50 (0.58)	0.00 (0.00)	-0.50 [-1.42, 0.42]	5	1.00 (1.22)	0.60 (0.89)	-0.40 [-1.26, 0.46]
Fried frailty 2b, depression (0-3)	4	0.50 (0.58)	0.00 (0.00)	-0.50 [-1.42, 0.42]	5	0.40 (0.55)	0.20 (0.45)	-0.20 [-0.69, 0.29]
Fried frailty, grip strength (kg)	4	28.43 (8.62)	27.35 (7.23)	-1.08 [-3.51, 1.36]	5	28.56 (8.84)	27.46 (9.86)	-1.10 [-2.69, 0.49]
Fried frailty, walk test (s)	4	7.42 (2.86)	5.14 (1.46)	-2.29 [-4.73, 0.16]	5	5.84 (0.51)	5.35 (0.92)	-0.49 [-1.83, 0.85]

Outcome measure	Intervention				Control			
	n	Baseline mean (SD)	Post mean (SD)	Mean Difference [95% CI]	n	Baseline mean (SD)	Post mean (SD)	Mean Difference [95% CI]
Fried frailty, walk speed ($m \cdot s^{-1}$)	4	0.69 (0.27)	0.95 (0.27)	0.26 [0.18, 0.34]	5	0.79 (0.07)	0.87 (0.14)	0.08 [-0.04, 0.21]
Fried MLTAQ ($kcal \cdot wk^{-1}$)	4	511.98 (572.77)	410.20 (456.92)	-101.78 [-289.13, 85.57]	5	255.62 (251.97)	153.85 (118.95)	-101.77 [-260.89, 57.35]
Fried frailty Total (0-5)	4	1.25 (0.50)	0.75 (0.50)	-0.50 [-1.42, 0.42]	5	1.40 (0.55)	1.60 (0.55)	0.20 [-0.49, 0.89]
GDS (0-30)	4	2.50 (1.29)	1.50 (0.58)	-1.00 [-2.30, 0.30]	5	4.60 (2.19)	5.80 (1.92)	1.20 [0.13, 2.27]
HADS anxiety (0-21)	4	0.75 (0.50)	2.50 (1.29)	1.75 [-0.64, 4.14]	5	5.40 (4.28)	5.40 (6.19)	0.00 [-2.76, 2.76]
HADS depression (0-21)	4	0.75 (1.50)	2.25 (1.71)	1.50 [-0.55, 3.55]	5	3.00 (1.22)	3.80 (2.59)	0.90 [-0.66, 2.26]
PSS total (0-40)	4	3.75 (2.22)	4.75 (3.20)	1.00 [-1.60, 3.60]	5	5.80 (3.56)	12.80 (9.88)	7.00 [1.96, 12.04]
SMMSE total (0-30)	4	29.00 (1.41)	28.50 (1.00)	-0.50 [-3.26, 2.26]	5	29.40 (0.89)	29.60 (0.89)	0.20 [-0.97, 1.37]
ISEL appraisal (0-12)	4	11.50 (0.58)	11.75 (0.50)	0.25 [-1.27 ,1.77]	5	11.80 (0.45)	11.80 (0.45)	0.00 [-0.57, 0.57]
ISEL belonging (0-12)	4	11.00 (1.41)	11.75 (0.50)	0.75 [-0.77, 2.27]	5	10.00 (3.39)	10.20 (3.49)	0.20 [-0.50, 0.90]
ISEL tangible (0-12)	4	11.50 (1.00)	12.00 (0.00)	0.50 [-1.09, 2.09]	5	11.40 (1.34)	11.20 (1.79)	-0.20 [-0.89, 0.49]
MNA total (0-14)	4	13.25 (1.50)	13.75 (0.50)	0.50 [-1.09, 2.09]	5	13.20 (1.30)	13.40 (0.55)	0.20 [-0.76, 1.16]
Cortisol (ng/mL)	4	128.03 (39.02)	124.61 (36.72)	-3.42 [-54.02, 47.18]	5	116.60 (40.42)	130.19 (67.22)	13.58 [-23.65, 50.82]
DHEAS (ng/mL)	4	665.08 (347.50)	647.10 (297.52)	-17.98 [-106.42, 70.47]	5	580.63 (409.90)	624.32 (399.67)	43.69 [-26.34, 113.72]
Cortisol:DHEAS	4	0.24 (0.17)	0.24 (0.18)	0.00 [-0.04, 0.04]	5	0.55 (0.76)	0.44 (0.55)	-0.11 [-0.27, 0.04]

Note. ADL = Activities of Daily Living, DHEAS = Dehydroepiandrosterone Sulphate, GDS = Geriatric Depression Scale, HADS = Hospital Anxiety and Depression Scale, ISEL = Interpersonal Support Evaluation List, MLTAQ = Minnesota Leisure Time Activity Questionnaire Shortened Version, MNA = Mini Nutritional Assessment, PSS = Perceived Stress Scale, SMMSE = Standardised Mini Mental State Examination, SPPB = Short Physical Performance Battery, TNFa = Tumour Necrosis Factor alpha.

3.5 Discussion

This study broadly supports the feasibility of a RT intervention designed to improve the multidimensional health and functional capacity of pre-frail older adults in residential care. The findings suggest that future development of a definitive RCT should be informed by the qualitative data which provided important feedback in terms of acceptability, demand, implementation, practicality, integration, adaptation, and expansion. In addition, the challenges of recruitment and possible refinement of methods needs further consideration. Regarding the secondary aim of performing limited efficacy testing on measures of multidimensional health, the generalisability of these findings is limited, and they need to be interpreted with considerable caution due to the small sample size.

3.5.1 Acceptability

Staff and participants offered positive and encouraging feedback on the relevance, usefulness and appropriateness of the intervention design and equipment. Levels of interest and uptake were higher than previous RT studies with older adults in residential care (Hassan et al., 2016; Johnen & Schott, 2018) potentially due to the established on-site presence of the researcher and the equipment. However, despite an initial enthusiasm and support for the training study, and the use of tried and tested recruitment strategies (Swales et al., 2022) the actual number of potential participants recruited was lower than anticipated. This may have been due to a number of different barriers and challenges. First, the study was scheduled to run from July until December and several of those living in the residential care facility, who had expressed an early interest in participation, had already scheduled summer holidays in August and September, and/or were keen to attend other outdoor activities run by the Well-being team during the summer months. It is possible that there was a seasonal effect, and that participation in an indoor PA study was more appealing in the winter months. Second, some of the potential participants who lived in supported living accommodation as part of the residential care community, had multiple other outside interests, family, established routines and commitments including caring for a less able spouse. The flexibility in exercise times and equipment use that evolved throughout the study may have helped resolve this barrier if it had been openly suggested up-front as an option, although this would then have reduced social interactions between members of the intervention group. Third, a broader inclusion policy involving family and friends may have been helpful for recruitment. The study protocol was changed, based on

participant and staff feedback, to allow any married couples who wished to complete the study together, to be randomised as a pair. This could have been expanded to include any eligible participant who may have liked to have exercised with a training buddy, family member or friend who did not need to meet the criteria or undertake the assessments. These documented changes to the protocol and observed barriers also raise the prospect of using a more formal co-production process. This would give those with lived experience a key role in ensuring the intervention was relevant and fit-for-purpose (Smith et al., 2022)

A further consideration for future recruitment would be to more pro-actively involve previous study participants, if they were willing to share their experiences, as intervention supporters/advocates. There were residents living in the care home who had participated in previous research trials and were vocal about their positive experiences engaging with RT research: several of whom continued to use the equipment. Their voices, opinions and shared experiences at an informal pre-recruitment social event could have given a unique perspective to other older adults who may have been considering getting involved. Finally, a unique feature of this study was the location of the exercise equipment in the communal lounge area. While this alleviated some of the commonly cited barriers to participation in trials including transport and location (Forsat et al., 2020), the full and inclusive access to the equipment for all residents may have disinclined potential study participants who already had the benefits of regular strength training without the required commitment for assessments. To explain, from an ethical perspective we had actively encouraged and supported all residents who expressed interest to use the equipment whilst the previous study was underway (Swales et al., 2022). However, this level of access may have influenced engagement in this present trial. Overall study retention rate and reasons for withdrawal were consistent with those reported for RT interventions with older adults in care homes (Valenzuela, 2012) and with frail older adults' participation in research trials in others' (Provencher et al., 2014) and our own work (Swales et al., 2022).

Participants also reported high levels of enjoyment and satisfaction, and despite some initial misconceptions that it could be boring, they were vocal about the benefits of participation in resistance exercise. These findings agree with previous research which found that while some older adults may doubt the potential benefits of RT, perceived improvements in capability, movement confidence and functional capacity are highly valued (Dionigi & Cannon, 2009; Henwood et al., 2011).

3.5.2 Demand

Levels of attendance and adherence were similar to or greater than previously reported figures for older adults in residential care (Fien et al., 2019; Hassan et al., 2016), and the three-times weekly exercise prescription was considered achievable and suitable, as found previously in frail individuals (Swales et al., 2022). This is in line with current UK and NSCA resistance exercise guidelines and position statements for older adults (Davies et al., 2019; Fragala et al., 2019) which recommend strengthening exercises on at least two days per week, and two to three times per week, respectively, and recent recommendations for resistance and power training to prevent frailty in community-dwelling older adults (Coelho-Junior et al., 2021). Recent research from Stathi, Greaves, et al. (2022) brings further support to these recommendations, and found that a twice-weekly multi-modal, group-based PA session (reduced to once-weekly after 12 weeks) for community-dwelling older adults was an effective way to maintain good physical function. Reasons for non-attendance, when given, included illness, other medical/hospital appointments and prior social engagements with family and friends. This is in line with recent research addressing the feasibility and sustainability of resistance exercise in a residential aged care setting (Fien et al., 2019).

It is interesting to note that there was additional demand for the exercise equipment from the study participants, staff, and other care home residents, and similarly to the RCT by Stathi, Withall, et al. (2022) many attendees did not want the sessions to end. A possible explanation for this might be the enduring impact of the prior, successful on-site RT study (Swales et al., 2022). Likely factors include increased awareness of the equipment in the communal lounge area and the benefits of engaging in RT, positive feedback from previous participants and growing levels of support from staff. It may also be related to the emergence of ‘peer-leaders’ who boosted social interaction, encouraged other residents to try the equipment, and prompted friendly competitive banter around training loads and attendance. Previous research has highlighted the influence of ‘exercise champions’ for older adults (Barras et al., 2021), and the importance of the social aspect of group exercise in residential care settings (de Souto Barreto et al., 2016; Franco et al., 2015). Given the impact of these findings, and the feedback from participants, use of peer-leaders in the recruitment and delivery stages of the future intervention should be considered.

3.5.3 Implementation

Participants displayed a high level of commitment to the study, and several of them made changes to their established routines to ensure full attendance and adherence at the designated exercise times. This agrees with Fiordelli et al. (2021) findings that older adults display a sense of duty and responsibility to contribute to research, particularly around well-being and health. Additionally, some participants quickly developed the confidence and ability to use the resistance equipment independently, and subsequently expressed a desire for greater overall autonomy, e.g., the ability to complete sessions on different days or at different times, and/or complete additional sessions with family and friends. This finding was unexpected given their inexperience with resistance exercise, however there are several possible explanations. First, it is possible that this was due to participants pairing up with spouses, friends and 'workout partners;' greater engagement by family members and staff; and a cultural shift at the care home to support RT for all residents. Second, it is also likely that the need for exercise sessions to fit into their established routines became increasingly important. Third, it is possible that the simple, smart-touch pre-programmed digital nature of the machines gave participants more confidence about independent use than traditional equipment; this is discussed further below under practicality. Given this feedback, and the decision to pair up spouses within the trial protocol, greater flexibility to incorporate training time preference and training partners should be considered in the definitive trial.

Implementation of all multidimensional measures was manageable, with participants willing to prioritize these and schedule them in advance. Most of the participants displayed a particular interest in the maximal strength and functional assessments, including the protocols, rationale for inclusion, expected changes and normative data. However, several participants queried the relevance and viability of multiple, time-consuming questionnaires. This was in line with previous research findings (Ferrucci et al., 2004; Swales et al., 2022) and suggests that this may negatively impact participation in a future definitive RCT. Potentially a future trial wishing to incorporate measurement of psychosocial health and well-being should consider fewer and shorter validated measures.

3.5.4 Practicality

The specialised resistance exercise equipment was widely praised by participants and staff, many of whom had been initially unsure of computerised equipment and touchscreen technology. Several participants expressed delight at their ability to engage with technology,

learn new skills and track their own progress. These results reflect those of Valenzuela et al. (2018) who suggested that the provision of automatically recorded exercise sessions, load progression and real-time feedback are underutilised benefits of technology-based exercise programmes with older adults. In association with the ease of use reported by participants, this may lend support to the initial financial outlay for ageing-specialized pneumatic exercise equipment in residential care facilities.

3.5.5 Integration

Care home staff and participants were united in their support of a longer-term commitment to RT, continued investment in equipment and wider accessibility for all care-home residents. Care staff voiced a clear opinion that the inclusion of resistance exercise equipment into future residential care developments should be a key consideration. Moreover, this should sit within a wider responsibility towards multidimensional well-being, quality of life and proactive healthcare. These findings are very encouraging and support the work of Baldelli et al. (2021) in relation to well-being of older adults in care facilities. They also lend support to investment in proactive approaches to reduce health care costs, including RT to mitigate frailty trajectories (Angulo et al., 2020; Pinedo-Villanueva et al., 2019) and access to rehabilitation support and digital enhancement of care (British Geriatrics Society, 2021).

3.5.6 Adaptation

Possible modifications to the existing intervention were discussed, and although there was no clearly identified need for amendments, there was firm support for the protocol amendment which granted random group allocation as couples, with spouses, if requested. This finding reflects those of others who identified spousal support as a key motivator for consistent attendance and longer-term participation (Gellert et al., 2011). High levels of social interaction and camaraderie were also established more broadly, both within the participant groups and between other care home residents who either accessed the equipment independently of the study or were attending other activities in the community lounge. These promising results reinforce the documented benefits of group RT programmes for older adults in residential care (de Souto Barreto et al., 2016), and the impact of peer support to nurture social interaction, guarding against loneliness and isolation (Barras et al., 2021; Franco et al., 2015).

3.5.7 Expansion

Future expansion of the programme raised queries about staffing requirements. There was collective acknowledgement that the success of any future intervention would be heavily

dependent on enthusiasm and encouragement from a suitably qualified individual. Participants and staff noted that consistency of delivery was vital to build trust, confidence, and rapport. Although previous studies have identified staffing as a barrier to provision of PA in long-term care homes (Baert et al., 2016; Benjamin et al., 2009) this was not regarded to be a substantial obstacle, in this instance. However, in line with previous findings, the person delivering an intervention can make all the difference between success and failure (Harvey & Griffin, 2020). This suggests that a future trial of this specific training programme would need to evaluate the effectiveness of a care staff-delivered intervention where care staff are trained to utilise the equipment and deliver the exercise programme. Unless care homes invested substantial funding to support the input of trained exercise programme deliverers, it is likely that local staff delivery of the intervention would be essential for wider roll-out and uptake. Training would need to be comprehensive as PA interventions for older adults have been shown to be more effective when delivered by a medical or exercise professional (Shvedko et al., 2018) and can improve adherence (Hawley-Hague et al., 2016) although the impact of the support of professionals on intervention success has received little attention according to a recent review of meta-analyses (Di Lorito et al., 2021).

3.5.8 Limited Efficacy Testing

Limited efficacy testing on measures of multidimensional health and functional capacity was completed with both groups for thoroughness. However, it should be noted that the small sample size restricts the value of interpreting treatment effects beyond the actual groups measured and, as indicated by Sim (2019) formal decision making about proceeding to a full RCT should not be based on this. While it was disappointing that the small sample size limited the trustworthiness of the quantitative data trends, specifically in relation to measures of strength, functional capacity and frailty status, there was still value in completing the full assessment protocol and subsequent analysis. Important qualitative feedback from participants relating to test burden and timings, and future consideration of the importance of clinically important change (Kwon et al., 2009) may help refine changes to the potential future RCT and ensure it is informed by both participant perspectives and clinical judgement (Sim, 2019),

Interestingly the qualitative analysis did identify a positive meaningful impact on self-reported movement confidence, strength levels and functional capacity. These positive improvements also extended to self-rated energy levels, happiness, mood, and well-being. These findings corroborate those of Dionigi and Cannon (2009) and Rydeskog et al. (2009)

which reported enhanced enthusiasm for life, joy, and physical confidence. Qualitative interviews with older adults engaged in a group multi-modal PA intervention also reported improved mental and social-well-being, higher physical confidence, and improved motivation (Stathi, Greaves, et al., 2022). It is interesting to note that the extent of RT benefits on physical function have also been shown to relate to the amount of improvement in self-reported health-related quality of life (Geirsdottir et al., 2012). This might suggest the value of including measures of self-efficacy in a future trial but should be considered carefully alongside the issue of questionnaire burden discussed above.

3.5.9 Limitations

This feasibility study had some limitations. First, the small sample size prohibited any statistical analysis; however, with the primary aim identified as feasibility, a small sample was deliberate and decisions to move to a full RCT were to be based on feasibility objectives and not the exploratory secondary outcome measures. Recruitment challenges further limited the sample size, and practical issues relating to these need to be considered and addressed. Second, the short duration of the RT intervention may have affected levels of participant uptake and attendance and may not be representative of levels of dropout and adherence over a longer duration RCT, however, again as this was a feasibility study, a shorter duration was deemed appropriate to test feasibility as the primary outcome. Third, broader expansion may be limited due to the affordability and accessibility of the specialised resistance equipment used in this trial and regular access to a qualified instructor. However, as noted above, the care home involved thought it worthwhile continuing investment in this equipment due to its accessibility, technology, and design. It would be beneficial to test whether care staff trained by qualified resistance exercise instructors could successfully deliver the intervention, given the relative ease of set-up and use of this specialised equipment. An important limitation is the lack of behaviour change techniques which can be successfully used to increase self-efficacy, enhance participant motivation, and support maintenance of PA in older adults. This would be a beneficial addition to the RCT and ensure that longer term change mechanisms were integrated into the intervention. The lack of a behaviour change theoretical basis to the trial is a key limitation and should be a primary consideration for inclusion in any expansion of this preliminary study.

3.5.10 Recommendations and Future Directions

Progression to a future definitive RCT would benefit from several recommended changes. First, revision of the study design to include a theoretical framework and behaviour

change elements to increase intervention effectiveness and support adoption and longer-term maintenance of RT in residential care homes. Second, revision of recruitment strategies to address the identified barriers and potential solutions. This could be supported by further discussion and emphasis on co-production with care home staff and residents and include offering greater flexibility in scheduling exercise sessions and encouraging engagement of family and friends. Third, all assessments should be carried out by a researcher who is blinded to group allocation, to reduce potential bias. Fourth, the exercise prescription should be extended to at least 12 weeks, with fewer and/or more sensitive questionnaire measures, and greater emphasis on self-reported changes in overall well-being and movement competency. Longer duration studies have been shown to lead to better physical function outcomes and would offer an important insight into the longer-term maintenance of a RT intervention in the care home setting. With further regard to exercise prescription it is also important to note that recent research with community-dwelling older adults indicated a dose-response relationship supportive of group, multi-modal PA once a week, in the initial stage and once per fortnight in the maintenance phase for achieving meaningful clinical change in functional measures (Stathi, Greaves, et al., 2022). It may be that a lower level of commitment is required to achieve health and functional benefits in this population group, and this has important implications for broader health messaging and engagement. Fifth, pairing of workout partners and proactive recruitment of peer-leaders should be encouraged. In addition, to ensure continuity of delivery and support, an enthusiastic, experienced instructor should be present at all sessions, and actively encourage equipment use by other care home residents.

Further research in residential care facilities is timely and important, particularly with older adults at risk of physical function and mobility limitations. In future investigations it could be possible to include more social interaction and intergenerational support from peers, family, and friends. It may also be feasible to link more closely with allied professionals including doctors and physiotherapists already supporting older adults care to provide a clearer pathway of proactive muscle strengthening exercise supported by behaviour change techniques. Longer term involvement could also be supported and embedded into the daily activities of the care facility, with the opportunity to involve activity-coordinators and work in tandem with existing programmes for community-based older adults. To ensure cost effectiveness of future interventions they may need to be delivered by suitably trained in-house care staff and activity coordinators with an interest in PA. In addition to the future RCT, future research could usefully address the impact of peer-leaders and workout partners on attendance and adherence, and

broader care-home resident use of the RT equipment over a longer-term follow-up. This would also help give some indication of economic viability of equivalent programmes and equipment. We aim to evaluate the longer-term impact of a resistance training intervention on multi-dimensional health and examine the reasons influencing longer-term attendance and adherence via a follow-up study with this study's participants at about one-year post-intervention.

3.6 Conclusion

Taken together, these findings offer preliminary support for the feasibility of a definitive, RCT using a RT intervention with pre-frail older adults in residential care. The study findings add to our understanding of RT interventions, with important insights into older adults' preferences concerning participation in exercise trials, barriers to recruitment and possible solutions, and perceived changes in strength, well-being, and physical competence.

Chapter 4: The Reliability and Suitability of Strength Assessments in Frail and Pre-frail Older Adults: Recommendations for Strength Testing in Older Populations

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4.1 Abstract

Background: Lifelong strength is fundamental to physical function, health, and quality of life. Reliable appropriate strength assessment measures for older adults play an important role in effective evaluation of baseline ability and exercise prescription to counter disease and disuse. This study aimed to investigate the within-session reliability of maximal isometric knee extension and flexion, hip abduction and adduction, and handgrip strength measures in frail and pre-frail older adults. Method: The study was conducted at a residential care home in Birmingham, UK. All care home residents aged ≥65 years; pre-frail or frail according to the Fried frailty phenotype criteria; able to speak and read English; not currently involved in any other clinical trial; without severe sensory impairments; and with a predicted life expectancy greater than the trial length were eligible. Maximal isometric lower limb testing was performed using specialised resistance training equipment and a portable measurement device, and grip strength was assessed using a portable dynamometer. All eligible participants attended a single testing session and performed three trials per measure. Peak force measures were obtained for analysis. Within-session reliability for each measure was calculated from repeated-measures analysis of variance, intraclass correlation coefficients (ICC), and coefficients of variation (CV) with 95% confidence

intervals. Results: Eleven frail and eleven pre-frail older adults participated in the study. Within-session absolute and relative measures were found to be reliable with the highest overall repeatability indicated between trial 2 and trial 3 for knee extension, hip abduction, and handgrip (CV≤ 4.65%, ICC ≥ 0.96) with variation evident across all measures, except knee extension, from trial 1 to 2. Conclusions: Overall, maximal isometric strength in frail and pre-frail older adults with no previous testing experience can be measured with good to high reliability within their first testing session. An initial two familiarisation trials followed by two measurement trials is recommended to achieve the highest level of overall repeatability. Trial registration: The trial was registered with ClinicalTrials.gov: NCT03141879 on 05/05/2017.

4.2 Introduction

Muscle strength plays a critical role in health status throughout the life span. In concert with skeletal muscle mass, muscle strength offers both multisystemic and specific musculoskeletal benefits and underpins physical function and capacity (Fragala et al., 2019; Maestroni et al., 2020). Age-related loss of muscle strength is strongly associated with an overall decrease in physical function (Hairi et al., 2010), loss of independence (Dos Santos et al., 2017) and adverse outcomes associated with frailty, falls and sarcopenia (Cruz-Jentoft et al., 2019; Fried et al., 2021; Menant et al., 2017). Frailty is a multicomponent clinically significant syndrome typified by reduced resistance to stressors and associated with an increased risk of falls, disability, and mortality (Fried et al., 2001).

Measuring muscle strength accurately and appropriately with reliable and easy to use devices is essential for case finding and diagnosis but also prevention and treatment strategies (Cruz-Jentoft et al., 2019). This is particularly important with mounting evidence supporting the role for resistance exercise in reversing or changing the trajectory of strength decline and frailty (Coelho-Junior et al., 2021; Lopez et al., 2018). Isometric measures of maximal strength are common in the published clinical and rehabilitation research (Buckinx et al., 2019; Sarabon et al., 2021) and have been shown to be predictive of mortality (Guadalupe-Grau et al., 2015), functional status and health outcomes (Chan et al., 2014) and clinically appropriate for older adults (Arnold et al., 2010). Isometric tests require minimal familiarity and movement skill (Moir, 2012); are relatively easy to administer; pose minimal injury risk; and are less fatiguing than dynamic 1RM testing (James et al., 2023). When compared to dynamic strength tests, this arguably makes them better suited for weaker and/or inexperienced participants (Arnold et al., 2010). Further, isometric tests can provide additional RFD data (Moir, 2012). RFD has shown

direct association with the ability to contract muscles rapidly and maximally, related to falls risk (Fragala et al., 2019).

Handgrip strength is a commonly used isometric strength assessment in clinical, and research settings (Firth et al., 2020; McNicholl et al., 2020). Reasons include portability, simplicity, affordability, and ease of measurement (Beaudart et al., 2019; Buckinx & Aubertin-Leheudre, 2021). A systematic review and meta-analysis (Rijk et al., 2016) concludes that handgrip strength has predictive validity for decline across mobility, functional status, cognition, and mortality, and it has been proposed as a biomarker of ageing. However, there is no universally agreed protocol for strength assessments with frail and pre-frail older adults (Schaap et al., 2016).

Lower limb strength is frequently assessed in research, clinical and rehabilitation settings due to established relationships with ADL (Hairi et al., 2010), walking speed (Cadore et al., 2013), and falls (Ding & Yang, 2016). Further, lower limb measures may be more representative of functional ability and motor skills than grip strength (Buckinx & Aubertin-Leheudre, 2021; Pereira et al., 2019), emphasising that handgrip should not be relied on as a proxy for overall muscle strength as there is low to moderate agreement between measures of handgrip strength and knee extension force (Yeung et al., 2018). A combination of measures may provide a clearer indication of strength deficit (Fragala et al., 2016; Mijnarends et al., 2013). Previous research has focused on isometric knee extension test (Sarabon et al., 2021) due to its multiple clinical applications for older adults including screening, disability and falls assessment risk (Valenzuela et al., 2020). Other reported measures include knee flexion, hip abduction and hip adduction (Jerez-Mayorga et al., 2020).

Established measurement devices of muscle strength include fixed laboratory or clinical based dynamometers, or portable hand-held dynamometers. Laboratory-based dynamometers are considered gold standard and have high levels of test re-test reliability (Buckinx & Aubertin-Leheudre, 2021). However, time, cost and accessibility issues may limit practical application in a field setting. While lower reliability has been reported with hand-held dynamometers (Chamorro et al., 2017) this may be due to a lack of protocol standardisation and tester skill (Buckinx & Aubertin-Leheudre, 2021). Improvements in reliability and practicality have been noted with the use of additional stabilisation (Kozinc et al., 2021). Work with nursing home residents showed high relative and moderate absolute reliability of maximal isometric muscle strength measures for knee extensors and flexors, hip abductors and extensors, and elbow flexors and extensors Buckinx et al. (2017). Other studies have completed field-based assessments with a portable

strain gauge (Buendia-Romero et al., 2021) or used this in conjunction with resistance exercise training equipment (Bjorkgren et al., 2021; Swales et al., 2022). Data from healthy, active adults reported excellent test re-test reliability for peak knee flexion and extension using resistance exercise equipment and the Performance Recorder (HUR Ltd., Finland) (Neil et al., 2013). However, to the authors' knowledge, no study to date has examined the test re-test reliability of this methodology with knee extension, knee flexion, hip adduction and abduction measures with frail or pre-frail older adults in residential care.

This thorough lower-limb analysis would bring insight to the suitability and reliability of these measures in assessment of health and help guide appropriate orientation and familiarisation for this participant group. Reliable testing protocols and equipment are required to ensure accurate evaluation and confidently detect meaningful changes in force production. Establishing within-session reliability and estimating measurement errors for muscle strength tests in frail and pre-frail older adults is indispensable for accurate evaluation but has not yet been clearly defined. Consequently, this exploratory study aimed to (i) quantify the within-session reliability (repeatability) of lower limb isometric strength measures and handgrip strength in frail and pre-frail older adults within one session to establish ability prior to intervention and (ii) relate this to the feasibility and appropriateness of field-based strength testing measures with frail and pre-frail older adults.

4.3 Method

4.3.1 Participants

Participants were recruited by either a direct approach from a staff member, introduction to a member of the research team, or by voluntary attendance at a short introductory talk given by the Principal Investigator and researcher in the care home. Participants were screened against the following eligibility criteria: (a) resident in the care home; (b) age $\geq$ 65 years; (c) having at least three of the five Fried frailty phenotype criteria (adapted from Fried et al. (2001) for the frailty study, and one or two of the five Fried frailty phenotype criteria (adapted from Fried et al. (2001) for the pre-frailty study ; (d) no severe sensory impairments that would profoundly impact upon their ability to participate; (e) ability to speak and read the English language; (f) not currently taking part in any other clinical trial which could potentially affect the results of this study; and (g) with a predicted life expectancy greater than the length of the trial.

Data collection took place between February 2019 and December 2019 at a residential care home in Birmingham, UK. Ethical approval was provided by London Harrow Research Ethics Committee. REC: 17/LO/1316. Protocol: RG_17-108 IRAS: 219616. The trial was registered with ClinicalTrials.gov: NCT03141879 on 05/05/2017.

4.3.2 Design

This was a within-session reliability study. It was an analysis of a sub-set of data collected at baseline during randomised feasibility trials with frail (Swales et al., 2022) and pre-frail older adults (Swales et al., 2024).

The full feasibility protocol has been published elsewhere (Doody et al., 2019) and amendments to the eligibility criteria and strength assessments have been documented (Swales et al., 2022, 2024). As both trials used the same methods, and were conducted by the same researcher, the data were combined to obtain a larger sample of older adults. Analysis of the reliability of the strength assessments has not been previously reported.

4.3.3 Measures and Equipment

4.3.3.1 Anthropometrics

Baseline measures of standing height (m) and body mass (kg) were recorded as documented in the full study protocol (Doody et al., 2019). Height was recorded to the nearest 0.1 cm (Marsden HM-250P Leicester Portable Height Measure; Rotherham, UK) and body mass using scales to the nearest 0.1 kg (Marsden Chair Scales; Rotherham, UK).

4.3.3.2 Strength Testing

Handgrip strength was assessed with a Takei grip strength dynamometer (T.K.K. 5401, Grip-D, Takei Scientific Instruments Co. Ltd, Tokyo, Japan) in an upright, seated position with the participants forearm resting on the chair arm. The wrist position was just over the end of the arm of the chair in a neutral position with thumb upwards, and feet flat on the floor. The researcher supported the weight of the dynamometer and gave verbal encouragement. Maximal voluntary isometric strength was reported in kg, and relative values per kilo body mass were also calculated, kg/kg.

Isometric maximal lower-limb strength testing was performed using premium line HUR SmartTouch RT equipment (4th Generation; HUR Ltd., Kokkola, Finland) leg extension/curl (model 5530) and hip adduction/abduction (model 5520) machines, connected to Performance Recorder 9200 (HUR Ltd., Kokkola, Finland). The Performance Recorder consists of a hand-held display unit and portable industrial grade strain gauge which attaches to a permanent

bracket on the machine. Performance Recorder Software Suite 3.0 11.0 (HUR Ltd., Kokkola, Finland) was installed on the researcher's laptop IBM ThinkPad X1 Laptop (Lenovo, China) and used to record all measurement data. All programme and equipment settings, test procedures and analysis were conducted according to methods detailed in the HUR Ltd. Performance Recorder Software Suite User Manual, 2010 (HUR Ltd., Kokkola, Finland) and HUR Isometric Measurement Instruction Guide, 2012 (HUR Ltd., Kokkola, Finland). All measurement angles were determined by machine sensor attachment sites and lever arm position reported as 120° for extension and 140° for flexion (with 180° = full extension) and 15° between legs for hip adduction/abduction (HUR Ltd., Kokkola, Finland).

Knee extension and flexion tests were completed in a seated, upright position with each participant's back against the machine back-rest, and stabilisation straps secured across their body at the hip and the thigh of the tested leg prior to testing. Using the electrically adjustable back support and lever arm lengths, the near-seat roller was positioned under the knee joint to ensure the axis of rotation of the swing arm was aligned with the lateral epicondyle of the femur. The ankle pad was positioned on the front (for knee extension) or rear (for knee flexion) of the shank at a comfortable position proximal to the lateral malleolus. All seat and roller positions, and lever arm length were recorded in the programme software before testing. Participants performed bilateral hip adduction and abduction tests in a seated, upright position with their back supported by the machine back-rest and each leg in an individual, padded support bracket. The brackets were non-adjustable, and depending on participant lower limb length, provided support behind the knee and shank.

4.3.4 Procedure

Individuals completed all the measures on-site and at two separate testing sessions, separated by at least one week. In session one, participants completed the handgrip strength test as part of eligibility screening. In session two, participants performed unilateral knee extension and flexion tests, and bilateral hip adduction and abduction measures. The full study timeline is detailed previously (Swales et al., 2022).

No specific warm-up was completed before session one. Following one practice trial, the handgrip strength test was performed three times using the dominant hand, with 60 s between trials. All participants completed a standardized warm-up before session two. This comprised two sets of 12 repetitions at light-moderate intensity (Rating of Perceived Exertion, (RPE) 3-5)

with 60 s recovery between sets and was performed bilaterally on all test machines (leg extension/curl, and hip abduction/adduction).

Following sensor attachment, participants performed one practice trial on the HUR machines. After a 60 s recovery, participants completed three trials of five seconds with a minimum rest of 60 s between trials. Each trial was initiated by a “3,2,1 Go” countdown with corresponding audible beeps from the software, and verbal encouragement. All three trials were completed on each measure before re-positioning for the next test. All machine-based measures were taken in the same order (left knee extension, left knee flexion, right knee extension, right knee flexion, adduction, abduction) and reported using Performance Recorder software (HUR Ltd., Kokkola, Finland). Absolute maximal voluntary isometric strength was reported as peak torque (Nm), and relative values were reported as peak torque divided by the participants body mass in kg, (Nm/kg).

Figure 4. 1

Photo of Participant Setup for Strength Testing: Knee Extension (own photo)

4.3.5 Statistical Analysis

Initially all HUR force data were exported into Microsoft Excel™ and combined with measures of handgrip strength recorded in individual case report forms. All data was later transferred into IBM® SPSS® Statistics Version 28.0 for further analysis. Data cleaning was performed and included screening descriptive data for cases of statistical outliers, errors, erroneous inliers, and other extreme values. After identification, any suspected cases were checked against original case report forms and excluded from analysis if there was documented protocol violation or technical error. Separate analysis was performed with and without excluded data points. Descriptive statistics (means ± standard deviations) were calculated for all force variables for the whole group, men, and women. The assumption of normality was assessed via the Shapiro-Wilk test. A repeated-measures analysis of variance (ANOVA) was conducted to establish reliability within sessions (trials 1, 2 and 3) on each strength measure. Statistical significance was set at an alpha level of $p < 0.05$. Sphericity was assessed via Mauchley's Test, and where violated, Greenhouse-Geisser was applied. A Bonferroni post-hoc test was used to identify pairwise differences. Within-session test-retest reliability was determined using coefficient of variation (CV) and intraclass correlation coefficient (ICC) to establish both absolute and relative reliability. Based on prior recommendation (Koo & Li, 2016) ICC (3,1) a two-way mixed effects model with absolute agreement was calculated. ICC values were classified where scores <0.5 poor, 0.5-0.75 moderate, 0.75-0.9 good, and >0.9 excellent. The level of reliability was based on the 95% confidence interval, not the ICC estimate itself (Koo & Li, 2016). As regards to CV%, acceptable thresholds were determined as <10%. Overall repeatability was classified as very high (CV≤ 5%, ICC ≥ 0.95), high (CV ≤ 10%, ICC ≥ 0.90) and moderate (CV ≤ 15%, ICC ≥ 0.80), in accordance with previous reliability studies (Courel-Ibáñez et al., 2020) including intra-session repeatability studies of maximal isometric lower limb testing in older adults in care homes (Buendia-Romero et al., 2021). The reliability sections of this study are described based on the guidelines for reporting reliability and agreement studies (Kottner et al., 2011). As this was a feasibility study, an *a priori* sample size calculation was not performed.

4.4 Results

4.4.1 Participant and Within-session Descriptive Statistics

Twenty-two older adults (n = 11 frail, n = 11 pre-frail) with a mean age of 83.4 (SD = 6.37) years ranging from 73 to 95 (13 female) were included. Frailty status was determined

using the Fried frailty phenotype criteria (Fried et al., 2001). Participants reported no injuries at the time of testing, no previous experience of RT or the isometric strength testing procedures. Baseline participant characteristics are shown in Table 4.1.

Repeated measures ANOVAs identified variation in most measures across trials 1-3, with a general pattern of increase in mean score across all measures identified, except for left and right knee extension. Full descriptive statistics and results of ANOVAs are shown in Table 4.2.

4.4.2 Absolute Reliability: Coefficient of Variation

Across absolute and relative comparisons, no differences emerged between tests or limb tested, so the results are narratively summarised for both below. Pairwise intra-session comparisons found that CV ranged from 6.26% to 12.01% between trial 1 (T_1) and trial 3 (T_3). All measures, except left and right knee flexion, were <10% indicating high reliability. Pairwise comparisons between T_1 and trial 2 (T_2) revealed CV of <10% across all measures ranging from 4.73% to 9.97%. Notably hip adduction and handgrip measures were <5% suggesting very high reliability. CV ranged from 3.40% to 8.31% between T_2 and T_3 indicating high to very high reliability across all measures: very high values of <5% were found for knee extension, abduction, and handgrip. CVs and ICCs across all pairs of trials are shown in Table 4.3.

Table 4. 1.

Participant Characteristics

Variable	Mean (SD)/n (%)
Age (years)	83.4 (6.37)
Age Range (years)	73-95
Sex - Female	13 (59.0)
Height (m)	1.62 (0.09)
Body Mass (kg)	74.1 (16.58)
Body Mass Index (BMI) (kg/m^2)	28.2 (4.43)
Medical conditions	2.1 (1.4)
Fried frailty score (0-5)	2.3 (1.1)
Pre-frail (0-2)	11 (50.0)
Frail (3-5)	11 (50.0)
Fried frailty criteria met	
Unintentional weight loss	1 (4.5)
Self-reported exhaustion	9 (40.9)
Weakness (grip strength)	15 (68.2)
Slow walking speed	10 (45.5)
Low physical activity level	18 (81.8)

Note. Fried frailty score is calculated using Fried frailty phenotype criteria. The Fried frailty phenotype proposes that frailty be defined as a clinical syndrome in which 3 or more of the five following criteria are present, and pre-frailty in which 1 or 2 criteria are present: unintentional weight loss (> 10lbs in the past year), self- reported exhaustion, weakness (grip strength), slow walking speed, and low levels of physical activity (Fried et al., 2001).

Table 4. 2.

Means, Standard Deviations, and Analysis of Variance for all Strength Measures

Measure		Trial 1		Trial 2		Trial 3		ANOVA
	n	M	SD	M	SD	M	SD	
Absolute Peak Torque (N·m)								
L Knee Extension	20	66.2_{a}	32.24	70.1_{a}	31.67	68.6_{a}	29.02	F (1.4, 26.7) = 2.33, p = .13, n^2 = .11
R Knee Extension	20	72.7_{a}	26.03	74.4_{a}	26.97	75.7_{a}	29.13	F (3, 38) = 1.95, p = .16, n^2 = .09
L Knee Flexion	22	31.9_{b}	13.05	33.3_{b}	13.30	35.1_{a}	12.39	F (1.5, 30.8) = 5.26, p = .02, n^2 = .20
R Knee Flexion	21	36.3_{b}	15.41	39.2_{ab}	16.20	40.6_{a}	18.47	F (2, 40) = 5.19, p = .01, n^2 = .21
Adduction	22	90.4_{b}	29.97	92.2_{b}	30.23	100.3_{a}	34.59	F (2, 42) = 9.37, p = <.001, n^2 = .31
Abduction	19	67.5_{a}	24.85	70.8_{ab}	26.00	71.8_{b}	25.60	F (2, 36) = 6.45, p = .004, n^2 = .26
Absolute Peak Force (kg)								
Handgrip	22	21.9_{a}	8.01	23.1_{b}	8.07	23.2_{b}	8.42	F (1.6, 32.8) = 7.88, p = .003, n^2 = .27
Relative Peak Torque (N·m/kg)								
L Knee Extension	20	0.89_{a}	0.34	0.95_{a}	0.34	0.93_{a}	0.32	F (1.5, 27.8) = 3.04, p = .08, n^2 = .14
R Knee Extension	20	0.97_{a}	0.30	0.99_{a}	0.32	1.01_{a}	0.34	F (2, 38) = 3.04, p = .08, n^2 = .10
L Knee Flexion	22	0.43_{b}	0.16	0.45_{b}	0.17	0.48_{a}	0.16	F (1.5, 32.3) = 7.03, p = .01, n^2 = .25
R Knee Flexion	21	0.48_{b}	0.16	0.51_{ab}	0.16	0.53_{a}	0.18	F (2, 40) = 4.62, p = .02, n^2 = .19
Adduction	22	1.22_{b}	0.31	1.25_{b}	0.34	1.35_{a}	0.34	F (2, 42) = 12.42, p = <.001, n^2 = .37
Abduction	19	0.94_{b}	0.23	0.98_{ab}	0.25	0.99_{a}	0.24	F (2, 36) = 5.23, p = .01, n^2 = .23
Relative Peak Force (kg/kg)								
Handgrip	22	0.30_{b}	0.08	0.31_{a}	0.08	0.31_{a}	0.08	F (1.5, 31.8) = 6.74, p = .01, n^2 = .24

Note. Means with different subscripts (not sharing any letter) indicate pairs of means which differ significantly at α = .05 level as indicated by Bonferroni procedure. a= means not significantly different from other means marked a or including a; b= means not significantly different from other means marked b or including b.

Table 4. 3.

Within-session Reliability Comparison for all Strength Measures Across Three Trials

Measure	Trial 1-3	Trial 1-2	Trial 2-3	Trial 1-3	Trial 1-2	Trial 2-3
	CV [95% CI]	CV [95% CI]	CV [95% CI]	ICC [95% CI]	ICC [95% CI]	ICC [95% CI]
Absolute Peak Torque (N·m)						
L Knee Extension	8.50 [5.41, 11.59]	7.48 [4.59, 0.37]	4.49 2.35, 6.62]	0.94 [0.87, 0.98]	0.97 [0.90, 0.99]	0.98 [0.95, 0.99]
R Knee Extension	6.26 [3.70, 8.82]	5.59 [3.20, 7.98]	4.65 [3.18, 6.11]	0.95 [0.88, 0.98]	0.97 [0.93, 0.99]	0.98 [0.95, 0.99]
L Knee Flexion	12.0 [8.22, 15.80]	7.81 [5.13, 0.49]	8.31 [4.99, 11.63]	0.88 [0.67, 0.95]	0.93 [0.84, 0.97]	0.96 [0.89, 0.99]
R Knee Flexion	10.91 [7.79, 14.03]	9.97 [6.65, 3.30]	7.17 [3.54, 10.80]	0.90 [0.69, 0.97]	0.92 [0.79, 0.97]	0.93 [0.84, 0.97]
Adduction	7.34 [4.13, 10.55]	4.96 [2.75, 7.18]	5.85 [3.01, 8.69]	0.88 [0.57, 0.96]	0.96 [0.91, 0.98]	0.91 [0.69, 0.97]
Abduction	7.57 [4.45, 10.68]	5.85 [2.51, 9.19]	3.40 [1.98, 4.83]	0.96 [0.81, 0.99]	0.98 [0.93, 0.99]	0.99 [0.97, 1.00]
Absolute Peak Force (kg)						
Handgrip	6.71 [4.17, 9.25]	4.73 [2.86, 6.59]	3.94 [2.57, 5.31]	0.96 [0.86, 0.99]	0.98 [0.87, 0.99]	0.98 [0.96, 0.99]
Relative Peak Torque (N·m/kg)						
L Knee Extension	8.50 [5.41, 11.59]	7.48 [4.59, 0.37]	4.49 [2.35, 6.62]	0.92 [0.81, 0.97]	0.95 [0.84, 0.98]	0.98 [0.95, 0.99]
R Knee Extension	6.26 [3.70, 8.82]	5.59 [3.20, 7.98]	4.65 [3.18, 6.11]	0.94 [0.84, 0.97]	0.95 [0.89, 0.98]	0.97 [0.93, 0.99]
L Knee Flexion	12.01 [8.22, 15.80]	7.81 [5.13, 0.49]	8.31 [4.99, 11.63]	0.87 [0.61, 0.95]	0.94 [0.85, 0.97]	0.95 [0.85, 0.98]
R Knee Flexion	10.91 [7.79, 14.03]	9.97 [6.65, 3.30]	7.17 [3.54, 10.80]	0.85 [0.58, 0.94]	0.87 [0.69, 0.95]	0.89 [0.75, 0.95]
Adduction	7.34 [4.13, 10.55]	4.96 [2.75, 7.18]	5.85 [3.01, 8.69]	0.84 [0.38, 0.95]	0.95 [0.88, 0.98]	0.89 [0.58, 0.96]
Abduction	7.57 [4.45, 10.68]	5.85 [2.51, 9.19]	3.40 [1.98, 4.83]	0.91 [0.67, 0.97]	0.93 [0.81, 0.97]	0.97 [0.92, 0.99]
Relative Peak Force (kg/kg)						
Handgrip	6.71 [4.17, 9.25]	4.73 [2.86, 6.59]	3.94 [2.57, 5.31]	0.92 [0.76, 0.97]	0.96 [0.77, 0.99]	0.96 [0.92, 0.99]

Note. L = left; R = right.

4.4.3 Relative Reliability: Intraclass Correlation Coefficient

Pairwise comparisons for T_1 and T_3 using absolute values reported ICC values ranging from 0.88 to 0.96 with large confidence intervals (CI) across some measures. Notably, adduction and knee flexion (R and L) measures were classified as 'moderate to excellent' reliability, with all other measures classed as 'good to excellent,' using CI as the basis for evaluation. Pairwise comparisons between T_1 and T_2 revealed ICC values for all measures ranging from 0.92-0.98 [95% CI = 0.79, 0.99] with right knee extension, adduction and abduction values representing 'excellent' reliability. ICC values ranged from 0.91 to 0.99 [95% CI = 0.69, 1.00] between T_2 and T_3, with knee extension measures (right and left), abduction and handgrip rated as 'excellent'.

Pairwise comparisons for T_1 and T_3 (relative) revealed ICC values ranging from 0.84 to 0.94 with large confidence intervals across adduction and knee flexion measures. Adduction test reliability ranked 'poor' to 'excellent' whereas all other measures classified either 'moderate' to 'excellent' (knee flexion and hip abduction) or 'good' to 'excellent' (knee extension and handgrip) (Koo & Li, 2016). Pairwise comparisons between T_1 and T_2 revealed ICC values for all measures ranging from 0.87-0.96 [95% CI = 0.69, 0.99], and rating 'good' to 'excellent' apart from right knee flexion, which was classified 'moderate to excellent'. ICC values ranged from 0.89 to 0.98 [95% CI = 0.58, 0.99] between T_2 and T_3 for all measures, with knee extension (right and left), abduction and handgrip rated as 'excellent'.

4.4.4 Overall Repeatability

All pairwise measures, except adduction, achieved progressively higher overall repeatability across trial comparisons indicating improved test re-test reliability: T_2 to T_3 > T_1 to T_2 > T_1 to T_3. In absolute and relative terms, T_2 to T_3, hip abduction, knee extension, and handgrip measures report 'very high' overall repeatability (CV≤ 5%, ICC ≥ 0.95), with right knee flexion classified as 'high' (CV = 7.17%, ICC =0.93 (absolute) and 0.89 (relative). Adduction and knee flexion measures both displayed 'high' and 'moderate' overall repeatability, in absolute and relative terms, respectively.

4.4.5 Feasibility and Appropriateness

Being able to complete the measures above reliably and accurately without risk of injury showed that these field-based strength testing measures were feasible and appropriate for use with frail and pre-frail older adults.

4.5 Discussion

The aims of this study were to (i) quantify the within-session reliability of lower limb isometric strength measures and handgrip strength in frail and pre-frail older adults and (ii) relate this to the feasibility and appropriateness of field-based strength testing measures with frail and pre-frail older adults. The main study finding indicates that isometric hand grip and lower limb strength can be assessed in a field-based setting with the specialised equipment used in this study with high reliability in frail and pre-frail older adults. The results confirm previous findings that isometric strength can be reliably evaluated using a portable measurement device and specialised gym equipment. The findings also show that lower limb strength in frail and pre-frail older adults with no previous testing experience can be measured with good to high reliability within the first testing session. Overall, the results suggest high levels of within-session reliability across all measures with highest overall repeatability indicated between T_2 and T_3 and for knee extension, hip abduction, and handgrip strength. This suggests that two practice familiarisation trials and two data collection trials would be reliable in this setting with the specialised equipment used in this study, but more practices and repeats may yield slightly higher reliability.

Previous studies and current testing guidelines agree with the present findings in frail and pre-frail participants by underscoring the importance of an appropriate warm-up and familiarisation process prior to isometric strength testing (Blazevich & Gill, 2006) and indicate that an initial practice trial and at least a further two trials are necessary to obtain an accurate maximal strength value (Jeon et al., 2019). Research suggests that the reliability of a strength test may develop with repetition and be influenced by unfamiliar or non-practised conditions (Guralnik et al., 1994) which is supported by the present finding of better reliability between T_2 and T_3 rather than the first trial and subsequent trials. It has been suggested that older adults, particularly those unaccustomed to strength training or testing, may additionally require more practice and familiarisation (Ordway et al., 2006; Symons et al., 2005).

In agreement with this, the present research study identified variation across trials, with a general pattern of increase in mean scores across all measures across the three trials after the initial practice trial. This is likely to be related to a ‘learning effect’ between trials (Atkinson & Nevill, 1998) and could potentially be attributed to the omission of a separate familiarisation session (Pekunlu & Ozsu, 2014). However, given the practical implications of additional sessions for this population group including time constraints, costs, and increased participant burden, additional extra familiarisation sessions may not be feasible. The present data suggest two

practice trials then two actual trials would be appropriate for high repeatability in future investigations in a single-session test protocol.

There are equipment differences between the present study and previous research, precluding absolute direct comparison. However, CV for maximal isometric grip strength was rated good to high across all trial comparisons and indicated the highest levels (very high $\leq$ 5%) of reliability across all measures between T_2 and T_3, (CV = 3.94%). These findings compare favourably with previous studies which reported CV for maximal voluntary isometric grip strength in older men as 10.93% (Jenkins et al., 2014) and 5.18-7.63% (Schaubert & Bohannon, 2005) in community dwelling older adults.

According to the present findings, all lower limb measures, between T_2 and T_3, can be assessed with high to very high reliability (CV = 3.40 – 8.31%) with higher levels of reliability indicated in knee extension and abduction measures (CV < 5%). These results are in line with reported findings of CV $\leq$ 6.0% for intra-session repeatability in isometric knee extension tests with institutionalised older adults (Buendia-Romero et al., 2021) and CV = 3.0% (range 0-6.0%) in older women (Francis, Toomey, et al., 2017). The current study found CV for hip abduction of 3.40% indicating high reliability. To date, the research on hip abduction measures utilises a variety of different protocols, positions, and equipment, so there is limited direct comparison. However, the findings do corroborate earlier work (Bruyneel et al., 2018) which found that hip abductor strength could be measured reliably in older adults in varying positions. Hip abductor strength has been shown to have good diagnostic accuracy to distinguish between fallers and non-fallers, and future studies should focus on the evaluation of reliable, field-based testing solutions for older adults (Gafner et al., 2017).

It is interesting to note that reliability for knee flexion measures in this study was less consistent than other reported measures with large confidence intervals, showed notable differences between right and left leg reliability, and differed from previous research findings (Francis, Toomey, et al., 2017). Possible explanations for this could be the small sample size, unfamiliar movement pattern and unilateral action (Blazevich & Gill, 2006) or protocol differences with other studies which identified the participants dominant and non-dominant limb (Courel-Ibáñez et al., 2020; Neil et al., 2013). Limb dominance was not recorded as part of the current study and may be a useful consideration for further research. However, the present study suggests that knee flexion may be less valuable in comparison to knee extension, particularly when time is limited and/or participant burden is high, particularly in vulnerable participants such as older frail and pre-frail adults.

Relative reliability was good across most measures for absolute and relative values with the highest levels of reliability consistently reported for handgrip, knee extension and abduction, ICC ≥0.96. High levels of reliability for knee extension peak torque matched those observed in earlier studies using a laboratory-based dynamometer which reported within session reliability (ICC 0.99-1.00) with older women (Francis, Toomey, et al., 2017). The current study findings were similarly found by others (Arnold et al., 2010; Bruyneel et al., 2018) who reported high levels of reliability, feasibility, and clinical relevance for maximal voluntary isometric strength testing for hip abduction in standing and supine positions in older adults. Others (Gafner et al., 2017) also reported good levels of reliability for hip adduction although it is important to interpret direct comparisons with caution due to differences in equipment, protocol, and positioning. Even so, the present findings suggest that hip abduction measures may be more valuable than adduction measures if time limits using both.

Handgrip is consistently used as a strength measure, not least due to its relative low cost and portability, and the present data in frail and pre-frail older adults contribute further confirmation that reliability is high in this population. However, while handgrip strength measures may be considered a proxy for global strength, there is growing recognition that a combined assessment including measures of isometric lower limb strength, as noted in this study, may offer a more comprehensive evaluation.

With regards to the testing equipment, previous reliability trials that used HUR specialised gym equipment (HUR Ltd., Finland) and a portable measurement device (Neil et al., 2013) reported excellent test re-test reliability for knee extension and knee flexion measures with healthy adults on their dominant leg: peak knee flexion torque (ICC = 0.96 [95% CI: 0.85, 0.99]) and peak knee extension torque (ICC = 0.96 [95% CI: 0.87, 0.99]). It is encouraging to compare the current study findings and note corresponding high levels of reliability across right and left leg measures of peak knee flexion (ICC = 0.93 – 0.96 [95% CI: 0.84, 0.99]) and for both limbs with peak knee extension (ICC = 0.98 [95% CI: 0.95 – 0.99]). However, the large confidence intervals for peak knee flexion, reported in relative terms, suggest that these should be viewed with some caution. Further, the present findings are specific to older adults with pre-frailty or frailty so this adds data in a novel population to the current literature but also suggests that with this population, knee extension may be a preferable measure to flexion.

4.5.1 Limitations

The sample size is small in relation to the aims of the study. Additionally, the scope of the study did not extend to comparisons across conditions with different numbers of practice tests or actual trials. However, it did offer valuable insight into the practical implications for future strength testing, concluding that two practice trials and two actual trials offer the highest level of repeatability. It is a strength of the present study that it demonstrates that maximal strength testing is feasible in older adults and gives clear recommendations for the number of practice tests and trials optimal for reliability and repeatability.

The present study utilised four specific lower limb tests and three trials per test, but for some participants and contexts, this may be too much. However, the study has shown that measures of knee extension, hip abduction and handgrip strength may be preferable if time is limited, and participant burden is a concern. Finally, it is important to note that the specialised equipment used for lower limb testing in this study may not be accessible or financially viable for all residential care facilities and has limited portability for researchers in relation to field testing. This limits practicality and generalisability in many residential care settings. In which case further data supporting the reliability of handgrip strength from this study can at least inform practitioners that they are using an appropriate strength assessment tool which is also more affordable and portable.

4.5.2 Recommendations and Future Directions

The development of practical and reliable field test measures for maximal isometric strength is challenging, and particularly for frail older adults in residential care facilities. In terms of the present study, measures of knee extension, hip abduction, and handgrip strength are identified as the best options. Although there is variation across trials, the data also support the use of two practice trials and two real trials for high reliability.

The specialised RT equipment used in this study provides a reliable measure of maximal isometric strength in frail older adults that could be used in a clinical, research or rehabilitation setting. Issues with practicality, generalisability and economic viability may limit wider use in residential care facilities and would need further consideration. However, data regarding the reliability of handgrip strength from this study, lends further support to its use as an appropriate assessment tool which is also more affordable and portable. Finally, given the limited capacity of this study to test a range of conditions with different numbers of practice trials and actual trials, future research in an experimental setting may be valuable to determine the optimal number of

each. However, the present study does strongly support the ‘two-plus-two’ design which may be more feasible and practical than longer protocols which may only provide incremental improvements in reliability e.g., from high to very high across all measures.

4.6 Conclusion

This study shows the appropriateness of isometric hand grip and lower limb strength measures, using the specialised equipment in this study, in a field-based setting with high within-session reliability in frail and pre-frail older adults with no testing experience in their first testing session. For optimal repeatability in a manageable protocol design, we would recommend, where possible, testing knee extension, hip abduction, and handgrip strength with two practice trials followed by two measurement trials. A larger-scale study in this population would confirm the reliability further.

Chapter 5: Overall Discussion and Conclusion

5.1 Introduction

The beneficial effects of RT for older adults are well established and convincing, and it is regularly shown to support multidimensional health and preserve physical function. Further, RT has been repeatedly found to counter age-related changes and dysregulation across measures of immune function, stress, inflammation, mental health and cognition, and reduce chronic disease risk. However, despite research endorsing the safety and efficacy of PA as a first-line therapeutic agent for many age-related conditions including frailty, there is limited evidence that examines the quantifiable impact of RT on multifactorial health and well-being outcomes in frail older adults in residential care settings (Izquierdo & Fiatarone Singh, 2023; Merchant et al., 2021). Most research of this type occurs with community-dwelling older adults. Consequently, the overall aim of this PhD was to assess the feasibility and impact of a group RT intervention, on measures of multidimensional health, well-being and physical function, with frail and pre-frail older adults in residential care.

The primary aim of this thesis was to assess the feasibility of a future definitive RCT using a RT intervention with (a) frail and (b) pre-frail older adults in residential care. A secondary aim was to perform limited efficacy testing on measures of multidimensional health from pre- to postintervention compared with the wait-list control. These measures were intended to be the primary dependent variables in a future RCT and included physiological, psychological, cognitive, and emotional health measures, and functional capacity, thus the acceptability of these measures was also assessed. The feasibility objectives aligned with the aims were those of acceptability, demand, integration and adaptation, practicality, implementation and expansion. A further aim of this thesis was to establish within-session reliability for maximal isometric muscle strength tests in frail and pre-frail older adults using lower limb and handgrip strength measures.

This thesis Discussion Chapter starts by outlining the primary findings from each study and their unique contributions to knowledge.

Primary Findings and Unique Contributions to Knowledge

Study one in Chapter Two addressed a research gap identified in Chapter One: a lack of data on the impact of RT on multidimensional health and well-being of frail older adults in residential care. This study provided the first comprehensive assessment of the feasibility and impact of a RT intervention designed to improve multidimensional health and functional capacity in this population group. Of particular note is the rigorous mixed-methods approach which generated unique and practical insights into the feasibility of a future RCT. The results of the trial supported the development of a definitive RCT and provided relevant feedback in terms of the stated feasibility objectives (acceptability, demand, integration, adaptation, practicality, implementation, and expansion). With respect to the secondary aim of performing limited efficacy testing on measures of health and functional capacity, the results indicated large effect sizes, positive trends, meaningful change in frailty and strength, and clinically important change in some measures of functional capacity. No meaningful change was found in terms of psychological, cognitive, and emotional health, physiological and social support measures.

In Chapter Three, study two addressed a further research gap identified in Chapter One: the lack of data on the impact of RT on multidimensional health and well-being of pre-frail older adults in residential care or supported living accommodation. This study has been one of the first attempts to thoroughly examine the feasibility and impact of a RT intervention designed to improve the multidimensional health and functional capacity of this population group. It brings new and valuable insight into motivators and barriers for pre-frail older adults participating in RT interventions. The findings offered some preliminary support for the feasibility of the intervention for this group and acknowledged the need for several recommended changes. The results suggested that future development of a definitive RCT should be informed by the qualitative data which provided important feedback in terms of the feasibility objectives (acceptability, demand, implementation, practicality, integration, adaptation, and expansion). In addition, the challenges of recruitment and possible refinement of methods needed further consideration. Regarding the secondary aim of performing limited efficacy testing on measures of multidimensional health, the small sample size meant that the generalisability of these findings was limited, and as such they needed to be interpreted with some caution. However, despite the small sample size, there was still value in completing analysis of the data, and, although not published, the main findings are summarised here, and the data included in Appendix C (Table C.1. and figures C.1-C.5).

Contrary to expectations, measures of multidimensional health and functional capacity indicated no meaningful change across all measures, pre- to post intervention

between groups using ITT analyses, bar a negative change in one marker of emotional health in the control group only. Interestingly, per-protocol analysis (also not published but presented in Appendix C) did indicate improvements in strength and functional capacity measures in the intervention group, and clinically meaningful change in walking speed and functional capacity pre- to post-intervention between groups. While this sensitivity analysis should be viewed with appropriate caution, and is secondary to ITT, it may offer an insight into the estimate of the true efficacy of the intervention (Ranganathan et al., 2016), and thus potential implications for the future RCT (Eldridge et al., 2016). The qualitative analysis did identify a positive meaningful impact on movement confidence, strength, and functional capacity. These positive developments were also noted in self-rated energy levels, happiness, mood, and well-being.

Chapter Four (study three) addressed research gaps highlighted in Chapter One: limited data on the reliability of maximal strength measures with frail and pre-frail older adults, and a lack of recommendations for maximal strength testing with this group. This study appears to be the first to test within-session reliability of maximal isometric knee extension and flexion, hip abduction and adduction, and handgrip strength measures in frail and pre-frail older adults in residential care. As such it provides a new understanding of appropriate and reliable testing with this group. Findings indicated that maximal isometric hand grip and lower limb strength could be assessed in a field-based setting with high reliability in frail and pre-frail older adults with no previous testing experience. The results confirmed previous findings that isometric strength could be reliably evaluated using a portable measurement device and specialised gym equipment. Overall, the results indicated high levels of within-session reliability across all measures with the highest overall repeatability reported between the second and third trial, and for knee extension, hip abduction, and handgrip strength. This indicated that two practice familiarisation trials and two data collection trials would be reliable in this setting, but that more practices and repeats may further increase reliability.

The following overall discussion presents a critical appraisal of the principal findings presented in this thesis, including strengths and limitations and orientates them in the current literature. First, the focus is on the feasibility objectives, with recommendations for future definitive trials. Following this is a discussion of resource costing, practical implications, and future research directions.

5.2 Recommendations for a Definitive Randomised Controlled Trial

Overall findings provided evidence that a RT intervention assessing measures of multidimensional health, well-being, and physical function with frail and pre-frail older adults in residential care is feasible in terms of acceptability, demand, integration and adaptation, practicality, implementation and expansion. However, follow-up definitive RCTs should endeavour to address and include the specific recommendations from each respective feasibility study. Further, there are broad learnings from both trials, which I outline in detail below.These should be considered for future similar definitive RT interventions with this population group and identify several potential areas in which to refine study design before a definitive RCT is proposed.

Revisions and Amendments to Study Design

Revision of Recruitment Strategies

First, in line with outcomes from Chapter Three, there is a need to revise recruitment strategies to address the identified barriers and potential solutions, which I revisit in this section. While both KARE trials (Chapters Two and Three) recruited adequate numbers (n=11) to address questions of feasibility, and a combined group (n=22) was appropriate for within-session reliability analysis (Chapter Four), a substantially larger sample size would be required for a definitive RCT and may require recruitment across multiple sites. Sample size calculations would need to be completed after revisions and amendments. These would differ depending on the primary outcomes identified for a future RCT. Based on the findings from Chapters Two and Three, it might be recommended that physical function should be a primary goal and outcome measure: analysis found clinically important change in some measures of functional capacity (SPPB gait speed and total score) with frail older adults (study one) and self-reported improvements in movement confidence and ability with pre-frail older adults (study two). Although effect sizes from feasibility studies are often used to form the basis of a sample size calculation, this can be problematic, particularly where small samples may produce imprecise estimates (Teare et al., 2014) and would be a concern for these studies. Further consideration of the use of minimal clinically important change may be appropriate, and better indicate the effect that is ‘worth finding’ aligned with clinical judgement and participant perspectives (Sim, 2019).

Greater Emphasis on Co-production

Barriers to recruitment noted in Chapter Three included a seasonal effect, other obligations or responsibilities, and the use/inclusion policy which covered any limitations on

times and duration of equipment access and/or involvement of family and friends. While some protocol changes, based on staff and participant feedback, had been implemented prior to the commencement of the pre-frail trial (Chapter Four) including randomisation of married couples as a pair, there is clearly room for further co-design to address potential issues such as implementing longer and more flexible access times, having more trained staff on-site, and encouraging involvement of friends and family. Although there is growing interest in utilising co-creation and co-design with older adults in residential care settings to develop healthy ageing solutions, there is as yet limited research detailing its use (Gine-Garriga et al., 2019; Hallam-Bowles et al., 2022). Embedding active involvement and collaboration into future RT trials with this population group offers a clear opportunity to expand the current literature and to better understand context-specific demands, such as potential burden on care staff, and complex health conditions of potential participants. Key priorities for reducing burden on care staff would be to upskill more support staff, including allied health professionals based in the home, and actively recruit and involve volunteers, friends, and family.

Blinding

Findings from Chapters Two and Three highlighted a need to ensure that all screening and assessments were completed by a researcher who was blinded to the group allocation. Blinding is acknowledged as a robust method to reduce the risk of bias and ensure validity of results (Bespalov et al., 2020). As noted in both trials (study one and study two), the researcher fulfilled dual roles of tester (screening and assessments) and instructor. Although screening and baseline testing could be conducted blind, following being the instructor for the intervention it was then not possible to blind the researcher for post-intervention or follow-up testing. This risk of bias was found also in Fien et al. (2016) feasibility trial of a group-based RT training study with residential aged care adults where the same allied care practitioner fulfilled both roles. In a future trial it would be ideal to expand the research team to include a dedicated researcher for all testing, and a separate qualified and experienced instructor to deliver all RT sessions, although this was beyond the scope of the current thesis studies.

Instructor Competencies, Skills and Personal Qualities

This thesis lends further support to the contribution of an instructor and acknowledges the importance of their role in successful delivery, adherence and retention. For example, the high value that staff and participants placed on continuity of support and delivery, enthusiasm and experience of the instructor was noted in both trials. As discussed in Chapters Two and Three, participants described that having a consistent contact who “explained things” and

offered encouragement and support, had made a “big difference.” This is found also in a recent scoping review which reported that exercise instructors working in older adult fitness play a key role in fostering group social cohesion; display leadership, communication and education skills; and require competency in both fitness and gerontology (Harvey & Griffin, 2020). It is not known whether a different instructor or less hands-on approach would have changed the outcomes for the present feasibility trials, but this is entirely possible. Further evidence to support this is that although care staff at the home were trained to enrol new participants and continue supervising and supporting residents in continuing the intervention, once the instructor was no longer present session attendance dropped substantially. Analysis of attendance indicated a drop from over 80% in the intervention group (who had full support from the instructor at all sessions) to nearly 34% in the wait-list control (more limited instructor availability). Additionally, the findings indicated low adherence levels (<25%) and no positive change across all measures of strength and functional capacity in the wait-list control group following their engagement with RT which suggest some further influence of the instructor being present.

Future trials with this population group should acknowledge the pivotal role of the instructor and ensure that competency and qualifications are also matched by the personal qualities and skills preferred by older adults. However, this may require a range of possible options based on available funding and could include up-skilling existing care team staff or allied professionals, or employing an exercise consultant to support multiple residential care homes within a whole care group. This thesis confirms earlier findings which reported these qualities as being caring and patient, fun, conscientious, flexible, realistic and encouraging (Harvey & Griffin, 2020; Hawley-Hague et al., 2014). It also indicates potential future research directions including examining the effect of different instructors’ personal qualities on adherence, or evaluation of the impact of recruiting instructors based on certain characteristics and interpersonal skills.

Intervention Duration

Based on findings presented in both trials (Chapters Two and Three), there is evidence to support increasing the RT intervention duration from six weeks to at least 12 weeks. This is primarily driven by proposed timelines for physiological adaptations, including morphological and neural factors, which underpin changes to measures of physical function (Folland & Williams, 2007). Research indicates that neurological adaptations occur in the earliest phase (within two weeks) and may involve learning patterns of intermuscular coordination, and be dependent on prior level of activity and skill while morphological changes are significant after 8-12 weeks (Folland & Williams, 2007). In a key difference

between trials, meaningful change was reported in frail older adults in measures of strength and physical function in only six weeks, but this was not shown with pre-frail participants.

It was somewhat surprising that no positive change was indicated in strength measures, contrary to rapidly expanding research with pre-frail older adults (Haider et al., 2019; Talar et al., 2021) and the previous study with frail older people in this setting (Swales et al., 2022). Additionally, finding no meaningful change in functional capacity or frailty status was disappointing, particularly in the light of recent findings with pre-frail older adults in which RT was clearly identified as a viable strategy to reverse or halt functional decline and frailty (Bray et al., 2020; Coelho-Junior et al., 2021). Although there was no further decline in frailty status or strength over the trial duration, which may indicate a maintenance effect, this would require further evaluation. No evidence was found for changes to other measures of multidimensional health. This was also unexpected given that previous studies evaluating the impact of RT with community dwelling pre-frail older adults identified some positive changes in cognition (van de Rest et al., 2014), mental well-being (Travers et al., 2022), and blood inflammatory markers (Lustosa et al., 2013), although most studies of RT do not focus on these outcomes. Possibly the absence of positive effects was due to the higher baseline functioning of the pre-frail group compared to the frail group meaning that change over a short period is less likely to be observed. This also emphasises the importance and effectiveness of RT interventions for those with lower levels of function who may benefit the most. This aligns with the well-known positive effects of exercise where improvements in health are greatest for those who were previously inactive moving to being somewhat active (Davies et al., 2019).

While an increase in intervention duration to improve effectiveness is a viable argument and broadly supported by current RT literature (e.g., Fragala et al. (2019), RT intervention studies with frail and pre-frail older adults have yet to identify a clear dose-response relationship or define a predictable physiological timeframe. Consequently, these findings present a methodological issue regarding the selection of the optimal duration for future RT interventions and suggest that this may differ based on frailty status. This becomes increasingly complex with a multidimensional health assessment due to the differing timeframe of changes and adaptation across multiple physiological systems. Nonetheless, the current findings extend our knowledge of the effect of short-term RT interventions with older adults and found positive improvements in muscle strength and functional ability (frail) and perceived well-being and movement confidence (frail and pre-frail) in only six weeks. Similarly, a six-week lower limb RT intervention was found to significantly improve muscle quality and functional ability in sedentary older women (Pinto et al., 2014). That said, a more

extended study (24-week) such as that utilised by Fien et al. (2019), would offer valuable insight into the sustainability of RT within a care home setting and the longer-term impact on other measures across the range of health and well-being including inflammatory biomarkers, cognition, mental health and social support.

Reduction in Measures and Greater Focus on Self-reported Changes

A further outcome, reported in both feasibility trials, was the need to reduce the number of measures, specifically questionnaires. Due to the comprehensive multidimensional health measures assessed and the multiple assessment timepoints (pre- and postintervention and follow-up) there was a reasonably high participant burden. While measures were spaced across several days, as detailed in Chapters Two and Three, to minimise participant fatigue, it was the use of multiple questionnaires, including HADS, GDS, PSS and ISEL that was most frequently cited as time consuming and “a bit banal.” This emphasises a need to focus on the most important and succinct measures, perhaps through co-design of measures to include with older adults and care staff. Conversely, despite the frailty status of participants, multiple measures of maximal strength and physical function were repeatedly well received. It is reasonable to surmise that participants may have been motivated by real and perceived increases in strength measures, and the use of computerised strength assessment tools with immediate on-screen feedback. This nuance is consistent with some of the challenges raised by Provencher et al. (2014) and highlights the need to improve population specific knowledge of barriers and motivators for recruitment and retention in research trials. A future definitive RCT could either consider reducing the number of questionnaires, using shorter versions, or placing greater reliance on self-reported changes in well-being and movement ability. Issues relating to overall participant burden, including the length and number of assessments, are not a newfound problem in studies with frail older participants. This is found also in a recent review which identified a need to specifically refine research processes and minimise participant burden to better meet the needs of historically under-served groups, including older adults with frailty (Dismore et al., 2023). Further reflection on a co-production approach may be valuable, for example the use of an advisory group comprising researchers, care staff and older adults. This method was successfully used by Ofosu et al. (2023b) to define and reduce the number of key measures in a music and movement intervention for older adults in care homes.

Further Considerations for Future RT Trials in Residential Care Settings

RT interventions in residential care settings present unique and complex challenges. While these will undoubtedly vary between organisations and care homes, and appreciating

that the data presented is from one care home, the findings in this thesis offer some genuine optimism to support broader acceptability in other care homes. Some general suggestions and commentary on this are offered below.

Equipment Location

Findings reported in Chapter Two provided insight into feasibility objectives of implementation and practicality for frail older adults, specifically in relation to the location of the RT equipment and where the exercise sessions were held. In this trial, despite initial concerns about the potential negative impact of installing and using equipment in a busy lounge area, the use of communal space ensured consistent, high visibility for all care home residents (including those not participating in the study), staff, family and visitors. The study findings suggest that this may have had a positive influence on levels of adherence, interest, and long-term sustainability. However, somewhat surprisingly, the accessibility of the location may have negatively impacted on recruitment for pre-frail participants. As reported in Chapter Three all residents had access to the RT equipment while the preceding frail trial was underway, and this may have disinclined those who were already feeling the benefits of RT without the requirement for assessments. Comparison of these findings with earlier work shows that while some group-based RT studies in residential care facilities identified sharing spaces as a potential limitation for engagement (Mulasso et al., 2015), others support the positive findings reported in Chapter Two (Fien et al., 2019). Additionally work by Provencher et al. (2014) identified that conducting recruitment and studies in natural gathering places may be an effective strategy to improve recruitment and retention of frail older adults in research studies. Again, this shows that context is a unique variable of each residential care setting and needs to be individually considered. Co-creation and co-production approaches are recommended to tailor to the specific setting.

Additional Session Reminders and Support

As noted in Chapters Two and Three, care-home staff were supportive and encouraging throughout the intervention, and along with the researcher, would offer verbal reminders of the day/time of the RT sessions and/or physical assistance, if required. However, findings with frail participants (Chapter Two) suggested that additional help and prompts for session attendance should be provided for participants with disability or mobility limitations, or cognitive impairment. It was interesting that this was not raised as a barrier for pre-frail participants (Chapter Three) and suggests that different levels of support are required depending on frailty status. There is limited evidence to differentiate how barriers and challenges in RT interventions in residential care settings may present differently across the frailty continuum. However, it is reasonable to suggest that those with more severe frailty

and/or cognitive impairment may be keen to participate but that mobility and cognitive issues may prevent them from doing so. This is reported also by Provencher et al. (2014). Specific recommendations could include factoring in additional time and support to assist participants moving to the location of the RT intervention. Further studies are needed to establish a clearer understanding of the complexity of frail older adults needs, particularly given current projections for levels of cognitive impairment or dementia diagnosis within those living in residential care (Wittenberg et al., 2020)

Wider Use of RT Equipment

A further consideration raised in both trials was that of encouraging and facilitating wider use of the RT equipment by care home residents who were not study participants, as well as staff, friends, and family. This was associated with feasibility areas of integration and expansion and related to longer term sustainability. Due to the novel approach used in this thesis, there is limited research evidence to suggest that this either facilitates research engagement or increases adherence or retention. However, it seems tenable that strengthening relationships, building rapport and investing in the care home workforce, family and friends may help to make them feel more valued and willing to facilitate resident recruitment and attendance. This is in line with a recent review by Nocivelli et al. (2023) in which the development of good and trusting relationships with care staff, recognition of their unique role as gatekeepers, and investment in training and development, were identified as both direct and indirect facilitators to research in residential care homes. In addition, as noted in Chapter Three, building an inclusive living and working environment that supports RT for lifelong health, sends a clear message about investment in multidimensional health and proactive healthcare for all. Innovative examples of this can be seen via a range of unpublished case studies in Finland, Japan and USA where gym facilities and health care providers offer community access to older adults and caregivers (HUR Ltd., 2024).

Identifying and Training Peer Leaders

Findings reported in Chapter Three identified additional levels of demand from participants, staff, and older care home residents. It was suggested that some of this may have been driven by the organic emergence of ‘peer-leaders’ and workout partners. Interestingly this was not noted in Chapter Two and may be related to level of physical function and frailty status. As such, pre-frail participants were likely to be more competitive around physical measures, training loads and attendance, and actively encouraged other residents to try the RT equipment. These findings are broadly consistent with Barras et al. (2021) systematic review which reported that ‘exercise champions’ of a similar age and social demographic can be successful in improving residents’ well-being and health

behaviours including increased participation in RT. Building on the findings from Chapter Three, it is recognised that future investment in identifying and training peer-leaders could hold value. Further study is also recommended to better understand the effectiveness of this role with more frail participants.

Theoretical Framework and Behaviour Change Techniques

Finally, as noted in Chapter Three, future RT interventions should consider the inclusion of a theoretical framework and behaviour change elements. These may increase intervention effectiveness and support adoption, and longer-term maintenance of RT in residential care homes. A behaviour change theoretical basis was not included in this PhD, for several reasons including the already high participant burden with multiple measures, and the pragmatic approach to assessing feasibility of the RT intervention before examining any additional supporting elements. While a lack of a behaviour change component was noted as a key limitation and a primary consideration for inclusion in any expansion of these preliminary studies, behaviour change interventions are recognised as being complex, and there is limited research specific to RT training interventions in older adults. A recent scoping review of interventions to improve RT participation, reported the use of social cognitive theory, transtheoretical model and self-determination theory (Ma et al., 2022). These may align with factors previously identified as effective in influencing RT participation such as self-efficacy (confidence to do RT), subjective norms (belief that others support the behaviour) and intentions. A recent RCT with community dwelling frail older adults evaluating the effect of an individualised exercise programme with/without behaviour change strategies found that the combined intervention showed better immediate and more sustainable benefits (Liu et al., 2023). It also showed a greater improvement in psychological well-being, and as such may indicate a potential way to improve motivation and adherence. The Health Action Process Approach was used as a framework and emphasised the role of perceived self-efficacy. However, it is important to note that behaviour change techniques that are effective at increasing PA in younger adults may have more limited success in older adults, particularly those with a self-regulatory component such as goal setting and self-monitoring (French et al., 2014). Interestingly, the progressive RT protocol used in this study and immediate feedback from the RT equipment software was noted as motivating by study participants and may have been an effective, albeit unplanned, behaviour change technique. Positive feedback and recognition of progress are key behavioural strategies associated with increasing and maintaining levels of PA in adults. However, the use of behaviour change techniques with frail older adults in residential care settings has not been investigated, and

further research is needed to clearly identify the selection and dosing of the selected model and techniques.

Table 5.1 summarises the recommended revisions and amendments for the definitive RCT of the KARE trial. It also includes further considerations for future trials with this population group.

Table 5. 1.

Summary of Recommendations for the Definitive RCTs

Revisions and amendments to study design
Revision of recruitment strategies to address identified barriers.
Greater emphasis on co-production with care home staff and residents.
All assessments to be carried out by a researcher who is blinded to group allocation.
An experienced and enthusiastic instructor to attend all sessions.
RT sessions to run for at least 12 weeks.
Less and/or more sensitive questionnaire measures.
Greater focus on self-reported changes in movement confidence and overall well-being.
Further considerations
Location of RT equipment in a visible and easily accessible area.
Provide additional reminders about session attendance for participants with cognitive impairment.
Offer additional support for participants with disability or mobility limitations.
Facilitate wider use of RT equipment by residents, staff and family.
Peer leaders.
Inclusion of a theoretical framework and behaviour change techniques.

5.3 Strengths

There were several strengths of this thesis. The KARE feasibility trial protocol utilised in this thesis was originally designed to address a lack of studies assessing the impact of a RT intervention on multidimensional health and functional capacity of frail older adults living in residential care (Doody et al., 2019). Subsequently the implementation of this revised and expanded feasibility protocol as two independent studies with frail and pre-frail older adults (Chapter Two and Three, respectively) was a novel intervention in a long-term care setting.

Further, the assessment of within-session reliability of maximal strength measures made an original contribution to strength testing research with this population group (Chapter Four).

An innovative feature of the studies was the use of specialised pneumatic RT equipment with web-based software. This equipment could be programmed to automatically adjust load, sets and reps, seat height and lever length, and was operated via a smartcard log-in with a personalised on-screen greeting. This equipment was designed at the University of Technology, Helsinki for use in active ageing, wellness, and rehabilitation programmes, and featured a zero-starting load, 100g to 1kg load increments and range limiters. Other unique features of the studies were the RT training equipment located on-site within the care home lounge; a progressive RT prescription; inclusive criteria for frailty and those who may have lacked capacity; comprehensive measures of physiological, psychological, cognitive, immunological, social and emotional health and functional capacity; and maximal isometric lower limb and handgrip strength testing with frail older adults in a field-based setting with no previous experience of testing or training. The RT interventions documented in this PhD targeted a population and a setting that have much to gain from the documented clinical benefits of PA yet are often the most overlooked due to concerns about safety, appropriateness, and acceptability.

5.4 Limitations

The studies presented within this PhD are not without limitations. Several of these, noted in Chapters Two and Three, have already been addressed within the recommendations, revisions, and amendments section. These include those relating to a lack of possibility of full blinding, short intervention duration, small sample size and lack of including behaviour change techniques. However, a consistently noted limitation, not yet addressed, across all three studies was that of the specialised equipment utilised. This was both in terms of RT delivery (Chapters Two and Three) and testing (Chapter Four).

The primary concern regarding the equipment was in relation to accessibility and affordability for larger and multicentre trials, which may limit broader expansion. The major costs associated with a proposed future definitive RCT are for the specialised RT equipment, including portable isometric strength testing capability and software. Current prices (from 1st April 2024) are listed below. Maintenance and servicing are included in a 2-year warranty. The full costing can be seen in Table 5.2.

Table 5. 2.

Major Equipment Costs for Definitive RCT: costs correct at time of writing (April 2024)

Item	Price Ex VAT (£)
HUR Premium Line SmartTouch RT Equipment	
STE5530-Hi5 Leg Extension / Curl Rehab Electrically Adjustable	13,056
STE5540-Hi5 Leg Press Rehab Electrically Adjustable:	12,147
ST5520-Hi5 Adduction / Abduction Rehab	9,988
STE5175-Hi5 Optimal Rhomb Rehab Electrically Adjustable	10,783
STE5140-Hi5 Chest Press Rehab Electrically Adjustable	11,124
9200 Performance Recorder	2,409
Compressor	2,290
Software	
ST01-C Cloud SmartTouch 1-year license	1,500 (1-year license)
ST00-C Startup fee for the cloud setup (includes RFID reader)	500 (one off set-up)
Total	63,797

If a multicentre RCT was implemented, each site would require the equipment and software listed in Table 5.2. Instructor hours would be a further important cost consideration. Hourly rate would be dependent on skills/expertise, with the current average London-based hourly rate reported to be £18.77 (http://uk.indeed.com). Required hours for delivery per group (n=6 due to number of machines), given a 24-week RT intervention with three one-hour sessions per week would be estimated at 72 hours. This gives an estimated instructor cost per group of £1351.44. Extra provision may need to be factored in for travel costs. The overall cost of intervention delivery is somewhat uncertain, in part due to location and supply and demand of qualified, experienced instructors. Local delivery cost estimates are recommended.

While it is beyond the scope of this thesis to offer a full evaluation of cost-effectiveness, it is important to note that substantial health care costs are associated with frailty and weakness (Coelho-Junior et al., 2021). RT interventions to slow or reverse frailty and reduce the prevalence of muscle weakness among older adults may have a substantial beneficial impact on the cost of UK health and social care (Pinedo-Villanueva et al., 2019). Full economic evaluation of PA interventions for older adults are urgently required (Pinheiro et al., 2023).

Given the costings identified in Table 5.2, affordability is a reasonable concern. It is of note that while cost was not established as a critical factor in the feasibility trials reported in this thesis (Chapters Two and Three), it can often be a definitive ruling criteria, regardless of the other feasibility outcomes. There are several possible options to reduce initial outlay including shared ownership or leasing equipment, reducing the number of RT items, and/or incorporating other modalities such as free weights, weight stack machines, resistance bands and bodyweight. On-going costs may be offset by fee-paying access to the RT equipment to the wider community and/or other healthy ageing initiatives supported by local health services. As indicated in Chapter Three, the care home involved in the trial did purchase some of the equipment as an on-going investment into staff and residents' multidimensional health and well-being: the equipment is specifically designed for active ageing, inclusive wellness, and lifelong strength. While the technology and design of the equipment undoubtedly contribute to its higher price tag, these features do provide easier set-up, smart touch use, stepless pneumatic resistance adjustment and high safety standards. Given these features, particularly the computerised system which automatically adjusts sets, reps and load, there are potential cost-savings in relation to intervention delivery and wider use, such that, with appropriate training, care staff and family may be able to assist both during the trial and longer term thus supporting sustainability. Further, findings reported in Chapter Four indicated that maximal isometric lower limb strength could be reliably evaluated using a portable measuring device (Performance Recorder) on-site with the equipment. Valid and reliable strength assessments are a cornerstone of the RT intervention, and this is a valuable and unique feature of the training equipment used.

5.5 Practical Implications

The findings from this thesis strongly support the feasibility of RT interventions with frail and pre-frail older adults in residential care settings and, notwithstanding the limited sample size, indicate the positive impact of RT on multidimensional health and physical function. As reported, RT can positively impact strength and functional ability (Chapter Two) and perceived positive changes in mood, vitality and movement confidence can be rapid and life-enhancing (Chapter Two and Three). Further, maximal isometric lower limb and handgrip strength testing can be safely and reliably assessed with frail and pre-frail older adults in residential care with no prior testing or RT experience.

Several revisions and amendments have been proposed, and are fully documented in Chapters Two, Three and Four, and summarised in the 'Revisions and Amendments' section of this chapter (Chapter Five). While *a priori* progression criteria were not established, the

assessment of feasibility was robust and included consideration of all feasibility criteria, both qualitative and quantitative data, and input from relevant stakeholders. Subsequently, there is now a requirement to consider whether to proceed with the delivery of a full RCT, inclusive of these refinements, if appropriate funding can be secured. Sample size calculations would need to be finalised based upon advisory group co-production input specifically in relation to revised measures and recruitment strategies, revised RT intervention duration, desired clinical meaningful differences in health outcomes and possible logistics of a multicentre cluster-randomised RCT.

5.6 Recommendations for Future Research

The findings from this thesis offer direction for future research. As discussed in Chapter Two and Three future studies could extend the intervention duration and assess the longer-term impact of RT on markers of multidimensional health and physical function. Doing so would also support the examination of longer-term attendance and adherence, including barriers and facilitators for frail older adults participating in RT. A natural progression of this work would be to examine longer-term adherence, sustainability, and expansion alongside a full evaluation of cost-effectiveness. Further, while both feasibility trials (Chapter Two and Three) were inclusive and ethical approval was in place they did not comprise any participants with a lack of cognitive capacity to consent. A possible explanation for this may have been limited researcher time contact with those in the specialised dementia support unit and heightened caution from care staff to recruit due to an increased need for support and associated time burden. However, as some participants did have diagnosed and undiagnosed dementia but full capacity to consent, it is reasonable to suggest that the RT intervention is feasible for those with mild cognitive impairment but not yet known in those lacking capacity.

Future work could usefully explore the effects of RT on frail, older adults with cognitive dysfunction (i.e., any stage of Alzheimer's disease and related dementias) and lacking capacity to consent. This would need to include consideration of recruitment strategies given the above, potentially an increased level of support for care staff and participants and may also need to evaluate and revise some measures or allow completion with a nominated person. As noted in Chapter Two, the potential effect of RT in the prevention of frailty progression would also be interesting to examine. Chapter Three, with pre-frail participants, took some steps towards a better understanding of this but further research is needed to better understand effective RT prescription.

Findings highlighted in Chapter Three raised further questions in relation to social interaction, including support from the instructor, peers, family and friends, and 'exercise champions.' Strategies to enhance engagement could usefully consider ways to increase positive social interaction and build social cohesion through wider care home use and involving family and friends with an interest in health and wellness. This would be a fruitful area of further research and address the impact of peer-leaders and workout partners on attendance and adherence and assess the impact of moving toward independent exercising. The role of the instructor in successful intervention delivery is also a fascinating research question which could be usefully explored by examining how older adult fitness instructors' personal characteristics play a role in building group cohesion and enjoyment.

Future studies into the reliability and appropriateness of maximal isometric strength testing with frail and pre-frail older adults, as discussed in Chapter Four, could expand to a larger scale, and test a different number of practice trials and actual trials. It would be of interest to include older adults with cognitive dysfunction, particularly as little current evidence exists with this population. Further it would be worthwhile to establish minimal clinically important change values for muscle strength in these populations.

More broadly, as discussed in Chapters Two and Three, a better understanding of cost effectiveness and long-term sustainability of future RT interventions needs to be developed. As part of this there is a need to test whether suitably trained care staff and activity coordinators could successfully deliver RT interventions, particularly given the ease of use of the specialised equipment used in this thesis.

5.7 Overall Conclusion

This PhD expands our knowledge of what is known about RT for frail and pre-frail older adults living in residential care, specifically in relation to its impact on multidimensional health. It challenges previously held views that frail and pre-frail older adults with no previous experience of RT may not adhere to, engage with, or enjoy a structured progressive training programme. It further challenges perceived barriers to older adults' use of RT equipment and technology, and the demands of integrating this into an established residential care facility. This PhD also sought to evaluate the reliability of field-based maximal isometric strength testing with frail and pre-frail older adults with no previous experience of training or testing in their first testing session. The findings clearly demonstrated that isometric hand grip and lower limb strength measures were appropriate, with high within-session reliability.

This thesis serves to move RT research with frail and pre-frail older adults towards a multidimensional approach to health and well-being with consideration for cognitive,

psychological, emotional, social, physiological, and physical function. It contributes to the literature by supporting RT as an effective strategy to enhance well-being, combat age-related loss of strength and function, and slow the progression of or reverse physical frailty in care home residents. Moreover, it clearly indicates that frailty is not a contraindication to progressive RT and that engaging in structured, group RT can have a transformative effect on people's quality of life, whatever their age and ability. However, the challenge remains to fully integrate RT into the care of frail and pre-frail older adults in residential care and include an appropriate individualised RT prescription in all personal healthcare recommendations.

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Appendix A

CONSORT 2010 Checklist

This appendix consists of supplementary material (available online) from study one (Chapter Two), and is reported in line with CONSORT 2010 guidelines for reporting randomised pilot and feasibility trials (Eldridge et al., 2016). Page numbers have been amended in line with this thesis.

Table A. 1.

CONSORT 2010 Checklist, Study One

CONSORT 2010 Checklist of Information to Include When Reporting a Pilot or Feasibility Trial

Section/Topic	Item No	Checklist Item	Reported on Page No
Title and abstract			
	1a	Identification as a pilot or feasibility randomised trial in the title	49
	1b	Structured summary of pilot trial design, methods, results, and conclusions (for specific guidance see CONSORT abstract extension for pilot trials)	49
Introduction			
Background and objectives	2a	Scientific background and explanation of rationale for future definitive trial, and reasons for randomised pilot trial	50-51
	2b	Specific objectives or research questions for pilot trial	51-52
Methods			
Trial design	3a	Description of pilot trial design (such as parallel, factorial) including allocation ratio	54, 57
	3b	Important changes to methods after pilot trial commencement (such as eligibility criteria), with reasons	57

Participants	4a	Eligibility criteria for participants	52
	4b	Settings and locations where the data were collected	52
	4c	How participants were identified and consented	52-53
Interventions	5	The interventions for each group with sufficient details to allow replication, including how and when they were actually administered	57-66
Outcomes	6a	Completely defined prespecified assessments or measurements to address each pilot trial objective specified in 2b, including how and when they were assessed	58-62, Table 2.3 (p.59)
	6b	Any changes to pilot trial assessments or measurements after the pilot trial commenced, with reasons	61-66
	6c	If applicable, prespecified criteria used to judge whether, or how, to proceed with future definitive trial	N/A
Sample size	7a	Rationale for numbers in the pilot trial	53
	7b	When applicable, explanation of any interim analyses and stopping guidelines	N/A
Randomisation:			
Sequence generation	8a	Method used to generate the random allocation sequence	57
	8b	Type of randomisation(s); details of any restriction (such as blocking and block size)	57
Allocation concealment	9	Mechanism used to implement the random allocation sequence (such as sequentially numbered containers), describing any	57

mechanism		steps taken to conceal the sequence until interventions were assigned	
Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions	57
Blinding	11a	If done, who was blinded after assignment to interventions (for example, participants, care providers, those assessing outcomes) and how	57
	11b	If relevant, description of the similarity of interventions	N/A
Statistical methods	12	Methods used to address each pilot trial objective whether qualitative or quantitative	66-67, Table 2.3
Results			
Participant flow (a diagram is strongly recommended)	13a	For each group, the numbers of participants who were approached and/or assessed for eligibility, randomly assigned, received intended treatment, and were assessed for each objective	69, Fig.2.1
	13b	For each group, losses, and exclusions after randomisation, together with reasons	69, Fig.2.1
Recruitment	14a	Dates defining the periods of recruitment and follow-up	54-56, Tables 2.1, 2.2
	14b	Why the pilot trial ended or was stopped	52-53
Baseline data	15	A table showing baseline demographic and clinical characteristics for each group	70, Table 2.5

Numbers analysed	16	For each objective, number of participants (denominator) included in each analysis. If relevant, these numbers should be by randomised group	71, 72, 81-84, Tables 2.6, 2.7, 2.8
Outcomes and estimation	17	For each objective, results including expressions of uncertainty (such as 95% confidence interval) for any estimates. If relevant, these results should be by randomised group	81-84, Table 2.8
Ancillary analyses	18	Results of any other analyses performed that could be used to inform the future definitive trial	73-80
Harms	19	All important harms or unintended effects in each group (for specific guidance see CONSORT for harms)	90
	19a	If relevant, other important unintended consequences	N/A
Discussion			
Limitations	20	Pilot trial limitations, addressing sources of potential bias and remaining uncertainty about feasibility	94
Generalisability	21	Generalisability (applicability) of pilot trial methods and findings to future definitive trial and other studies	95,96
Interpretation	22	Interpretation consistent with pilot trial objectives and findings, balancing potential benefits and harms, and considering other relevant evidence	91-95
	22a	Implications for progression from pilot to future definitive trial, including any proposed amendments	96-97

Other information			
Registration	23	Registration number for pilot trial and name of trial registry	55
Protocol	24	Where the pilot trial protocol can be accessed, if available	55
Funding	25	Sources of funding and other support (such as supply of drugs), role of funders	2, Declaration section (in thesis), Acknowledgements section in publication
	26	Ethical approval or approval by research review committee, confirmed with reference number	55

Appendix B

CONSORT 2010 Checklist

This appendix consists of supplementary material (available online) from study two (Chapter Three), and is reported in line with CONSORT 2010 guidelines for reporting randomised pilot and feasibility trials (Eldridge et al., 2016). Page numbers have been amended in line with this thesis.

Table B. 1.

CONSORT 2010 Checklist, Study Two

CONSORT 2010 Checklist of Information to Include When Reporting a Pilot or Feasibility Trial

Section/Topic	Item No	Checklist item	Reported on page No
Title and abstract			
	1a	Identification as a pilot or feasibility randomised trial in the title	97
	1b	Structured summary of pilot trial design, methods, results, and conclusions (for specific guidance see CONSORT abstract extension for pilot trials)	97
Introduction			
Background and objectives	2a	Scientific background and explanation of rationale for future definitive trial, and reasons for randomised pilot trial	98-101
	2b	Specific objectives or research questions for pilot trial	101-102
Methods			
Trial design	3a	Description of pilot trial design (such as parallel, factorial) including allocation ratio	103-104
	3b	Important changes to methods after pilot trial commencement (such as eligibility criteria), with reasons	107
Participants	4a	Eligibility criteria for participants	102
	4b	Settings and locations where the data were collected	102

	4c	How participants were identified and consented	102-103
Interventions	5	The interventions for each group with sufficient details to allow replication, including how and when they were actually administered	105,106, Table 3.1., 110-112
Outcomes	6a	Completely defined prespecified assessments or measurements to address each pilot trial objective specified in 2b, including how and when they were assessed	108, 109
	6b	Any changes to pilot trial assessments or measurements after the pilot trial commenced, with reasons	107
	6c	If applicable, prespecified criteria used to judge whether, or how, to proceed with future definitive trial	N/A
Sample size	7a	Rationale for numbers in the pilot trial	103
	7b	When applicable, explanation of any interim analyses and stopping guidelines	N/A
Randomisation:			
Sequence generation	8a	Method used to generate the random allocation sequence	107
	8b	Type of randomisation(s); details of any restriction (such as blocking and block size)	107
Allocation concealment mechanism	9	Mechanism used to implement the random allocation sequence (such as sequentially numbered containers), describing any steps taken to conceal the sequence until interventions were assigned	107
Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions	107

Blinding	11a	If done, who was blinded after assignment to interventions (for example, participants, care providers, those assessing outcomes) and how	107
	11b	If relevant, description of the similarity of interventions	N/A
Statistical methods	12	Methods used to address each pilot trial objective whether qualitative or quantitative	112, 113
Results			
Participant flow (a diagram is strongly recommended)	13a	For each group, the numbers of participants who were approached and/or assessed for eligibility, randomly assigned, received intended treatment, and were assessed for each objective	114, Figure 3.1
	13b	For each group, losses, and exclusions after randomisation, together with reasons	114, Figure 3.1
Recruitment	14a	Dates defining the periods of recruitment and follow-up	105, Table 3.1
	14b	Why the pilot trial ended or was stopped	103
Baseline data	15	A table showing baseline demographic and clinical characteristics for each group	115, Table 3.3
Numbers analysed	16	For each objective, number of participants (denominator) included in each analysis. If relevant, these numbers should be by randomised group	123, 124, Table 3.4
Outcomes and estimation	17	For each objective, results including expressions of uncertainty (such as 95% confidence interval) for any estimates. If relevant, these results should be by randomised group	115-122, 123, 124, Table 3.4
Ancillary analyses	18	Results of any other analyses performed that could be used to inform the future definitive trial	N/A

Harms	19	All important harms or unintended effects in each group (for specific guidance see CONSORT for harms)	122
	19a	If relevant, other important unintended consequences	N/A
Discussion			
Limitations	20	Pilot trial limitations, addressing sources of potential bias and remaining uncertainty about feasibility	131
Generalisability	21	Generalisability (applicability) of pilot trial methods and findings to future definitive trial and other studies	131-133
Interpretation	22	Interpretation consistent with pilot trial objectives and findings, balancing potential benefits and harms, and considering other relevant evidence	125-131
	22a	Implications for progression from pilot to future definitive trial, including any proposed amendments	131-133
Other information			
Registration	23	Registration number for pilot trial and name of trial registry	103
Protocol	24	Where the pilot trial protocol can be accessed, if available	103
Funding	25	Sources of funding and other support (such as supply of drugs), role of funders	2, Declaration section (in thesis), Acknowledgements section in publication
	26	Ethical approval or approval by research review committee, confirmed with reference number	103

Appendix C

Analysis of Health and Functional Outcomes

This appendix includes analyses of health and functional outcomes from study two (Chapter Three) which were not included in the published journal article. Table C.1 and Figures C.1-C.5 were available as online supplementary material.

Health and Functional Outcomes

ITT analyses of pre- to post-intervention compared with the wait-list control indicated no significant differences across all variables, bar one measure of emotional health, the GDS, such that the control group had a significant worsening of depressive symptoms relative to the intervention group who had no significant change. Due to the feasibility nature of this study, mean difference, 95% CI and effect sizes are also presented (Table C.1).

Post-hoc sensitivity analysis on completers only was performed to explore the impact of non-completion. Per-protocol analyses were robust and consistent in reporting significant improvements in left and right knee extension strength, gait speed and SPPB functional capacity in the intervention group. Significant improvements in hip adduction but worsening on the GDS and PSS were observed among the wait-list controls. However, the sensitivity analysis also indicated further significant differences in change pre- to post-intervention between groups for some measures of physical function. These results differ from ITT analyses (Table C.1) and are reported here for completeness as pre- to post- means for each group and mean group difference. The results included Fried frailty walk test speed in the intervention group (M = 0.25, SD = 0.05) compared to the wait-list control (M = 0.08, SD = 0.10), a mean group difference of 0.17 [95% CI 0.03, 0.29] m/s, $t_{(7)} = 3.00$, p = .02, Hedges' *g* = 1.79; the SPPB gait speed in the intervention group (M = 0.19, SD = 0.11) compared to wait-list control (M = 0.03, SD = 0.05], with a mean group difference of 0.16 [95% CI 0.03, 0.29] m/s, $t_{(7)} = 2.87$, p = .03, Hedges' *g* = 1.71; and SPPB total score in the intervention group (M = 2.00, SD = 0.82) compared to the wait-list control (M = 0.00, SD = 1.00), a mean group difference of 2.00 [95% CI 0.53, 3.47], $t_{(7)} = 3.22$, p = .02, Hedges' *g* = 1.92.

Changes over time in walking speed and functional capacity in those who completed the intervention also indicate clinically important change (Kwon et al., 2009). Figures C.1-C.5 show changes over time in functional capacity and strength, physiological, cognitive, and

emotional health, and social support measures on all participants, including ITT. The follow-up timepoint is included for completeness.

Table C. 1.

Effects Table: Within and Between-Group Changes from Baseline to Follow-up, ITT Analyses

	Intervention					Control				Mean difference in changes between groups		
Outcome measure	**n**	**Pre mean (SD)**	**Post mean (SD)**	**Mean Difference [95% CI]**	**p**	**n**	**Pre mean (SD)**	**Post mean (SD)**	**Mean Difference [95% CI]**	**p**	**Mean Difference [95% CI]**	**p**	**Effect size (Hedges' *g*)**
Knee extension left, peak torque (N·m)	6	78.78 (20.90)	96.54 (11.85)	17.76 [3.16, 32.36)	.02*	5	82.63 (41.80)	90.62 (38.30)	7.99 [-22.64, 10.98]	.29	9.77 [-11.43, 30.97]	.31	0.57
Knee extension right, peak torque (N·m)	6	86.28 (25.05)	101.79 (24.49)	15.51 [2.25, 28.76]	.03*	5	83.85 (28.04)	81.25 (28.52)	-2.60 (-17.11, 11.92)	.70	18.10 [-1.56, 37.76]	.07	1.15
Knee flexion left, peak torque (N·m)	6	41.74 (9.48)	41.44 (12.62)	-0.30 [-7.01, 6.42]	.92	5	39.85 (15.74)	46.98 (11.10)	7.13 [-0.23, 14.49]	.06	-7.42 [-17.39, 2.54]	.13	-0.93
Knee flexion right, peak torque N·m)	6	42.51 (13.27)	42.48 (12.32)	-0.04 [-5.47, 5.40]	.99	5	47.93 (24.54)	50.02 (18.38)	2.09 [-3.86, 8.04]	.45	-2.12 [-10.18, 5.93]	.57	-0.33
Hip adduction, peak torque (N·m)	6	107.49 (18.38)	109.73 (19.50)	2.23 [-5.61, 10.07]	.54	5	114.97 (35.15)	124.46 (41.27)	9.49 [0.90, 18.08]	.03*	-7.26 [-18.89, 4.37]	.19	-0.78
Hip abduction, peak torque (N·m)	6	79.93 (27.03)	82.54 (27.21)	2.62 [-7.24, 12.48]	.56	5	113.62 (41.91)	107.21 (31.24)	-6.41 [-17.21, 4.40]	.21	9.02 [-8.15, 26.20]	.24	0.77

	Intervention					Control				Mean difference in changes between groups		
Outcome measure	**n**	**Pre mean (SD)**	**Post mean (SD)**	**Mean Difference [95% CI]**	**p**	**n**	**Pre mean (SD)**	**Post mean (SD)**	**Mean Difference [95% CI]**	**p**	**Mean Difference [95% CI]**	**p**	**Effect size (Hedges' *g*)**
SPPB Balance test (0-4)	6	3.67 (0.52)	3.83 (0.41)	0.17 [-0.23, 0.56]	.36	5	3.60 (0.55)	3.40 (0.55)	-0.20 [-0.63, 0.23]	.32	0.37 [-0.22, 0.95]	.19	0.79
SPPB Gait speed test (0-4)	6	2.50 (1.05)	3.17 (0.75)	0.67 [-0.10, 1.43]	.08	5	3.20 (0.45)	3.40 (0.89)	0.20 [-0.64, 1.04]	.60	0.47 [-0.66, 1.60]	.37	0.52
SPPB Gait speed ($m \cdot s^{-1}$)	6	0.67 (0.19)	0.79 (0.15)	0.13 [0.03-0.22]	.02*	5	0.75 (0.07)	0.79 (0.09)	0.03 [-0.07, 0.14]	.51	0.09 [-0.04-0.23]	.15	0.84
SPPB Chair stand test (0-4)	6	1.17 (0.41)	1.50 (0.84)	0.33 [-0.23, 0.90]	.25	5	1.00 (0.71)	1.00 (0.00)	0.00 [-0.62, 0.62]	1.00	0.33 [-0.50, 1.17]	.39	0.50
SPPB Total points (0-12)	6	7.33 (1.63)	8.67 (1.75)	1.33 [0.30, 2.37]	.02*	5	7.80 (1.30)	7.80 (1.30)	0.00 [-1.14, 1.14]	1.00	1.33 [-0.20, 2.87]	.08	0.84
Katz ADL (0-6)	6	6.00 (0.00)	6.00 (0.00)	0.00 [0.00, 0.00]	1.00	5	6.00 (0.00)	6.00 (0.00)	0.00 [0.00, 0.00]	1.00	0.00 [0.00, 0.00]	1.00	0.00
Fried frailty, weight loss (0-1)	6	0.00 (0.00)	0.00 (0.00)	0.00 [0.00, 0.00]	1.00	5	0.00 (0.00)	0.00 (0.00)	0.00 [0.00, 0.00]	1.00	0.00 [0.00, 0.00]	1.00	0.00
Fried frailty 2a, depression (0-3)	6	0.83 (1.17)	0.50 (1.22)	-0.33 [-1.12, 0.45]	.36	5	1.00 (1.22)	0.60 (0.89)	-0.40 [-1.26, 0.46]	0.32	0.07 [-1.10, 1.23]	.90	0.07
Fried frailty 2b, depression (0-3)	6	0.67 (0.82)	0.33 (0.82)	-0.33 [-0.78, 0.12]	.13	5	0.40 (0.55)	0.20 (0.45)	-0.20 [-0.69, 0.29]	.38	-0.13 [-0.80, 0.53]	.66	-0.25

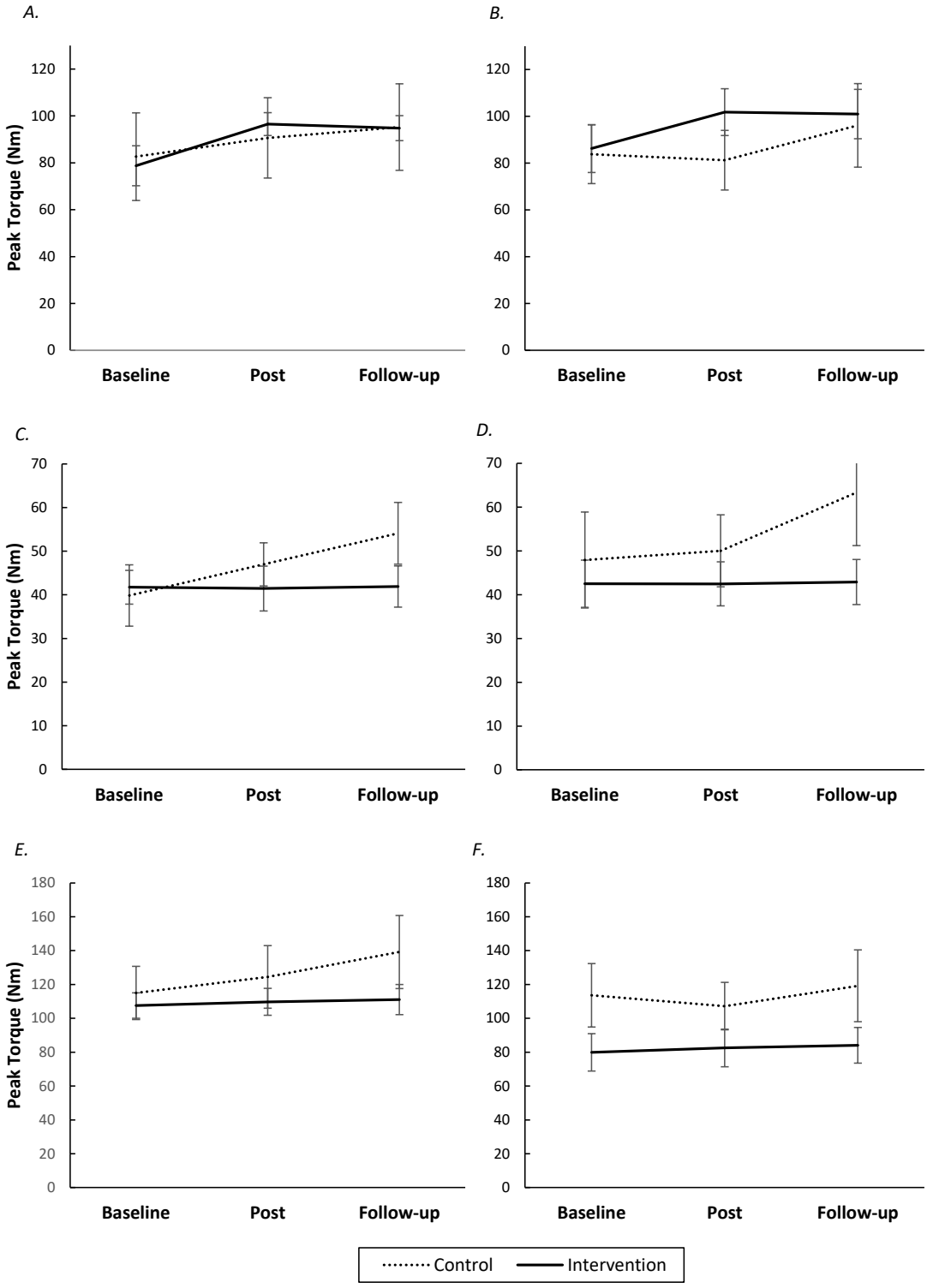
	Intervention					Control				Mean difference in changes between groups		
Outcome measure	**n**	**Pre mean (SD)**	**Post mean (SD)**	**Mean Difference [95% CI]**	**p**	**n**	**Pre mean (SD)**	**Post mean (SD)**	**Mean Difference [95% CI]**	**p**	**Mean Difference [95% CI]**	**p**	**Effect size (Hedges' *g*)**
Fried frailty, grip strength (kg)	6	28.13 (7.24)	27.42 (6.24)	-0.72 [-2.17, 0.74]	.29	5	28.56 (8.84)	27.46 (9.86)	-1.10 [-2.69, 0.49]	.15	0.38 [-1.77, 2.54]	.70	0.22
Fried frailty, walk test (s)	6	7.00 (2.33)	5.47 (1.29)	-1.53 [-2.75, -0.30]	.02*	5	5.84 (0.51)	5.35 (0.92)	-0.49 [-1.83, 0.85]	.43	-1.04 [-2.85, 0.77]	.23	-0.72
Fried frailty, walk speed ($m \cdot s^{-1}$)	6	0.71 (0.22)	0.88 (0.24)	0.17 [0.06, 0.29]	.01**	5	0.79 (0.07)	0.87 (0.14)	0.08 [-0.04, 0.21]	.17	0.09 [-0.08, 0.26]	.28	0.64
Fried MLTAQ ($kcal \cdot wk^{-1}$)	6	582.18 (625.41)	514.43 (577.90)	-67.75 [-213.01, 77.50]	.32	5	255.62 (251.97)	153.85 (118.95)	-101.77 [-260.89, 57.35]	.18	34.02 [-181.43, 249.47]	.73	0.20
Fried frailty Total (0-5)	6	1.33 (0.52)	1.00 (0.63)	-0.33 [-0.96, 0.29]	.26	5	1.40 (0.55)	1.60 (0.55)	0.20 [-0.49, 0.89]	.53	-0.53 [-1.46, 0.39]	.23	-0.72
GDS (0-30)	6	4.33 (3.27)	3.67 (3.61)	-0.67 [-1.65, 0.31]	.16	5	4.60 (2.19)	5.80 (1.92)	1.20 [0.13, 2.27]	.03*	-1.87 [-3.32, -0.41]	.02*	-1.61
HADS anxiety (0-21)	6	1.67 (1.75)	2.83 (1.47)	1.17 [-1.53, 3.86]	.35	5	5.40 (4.28)	5.40 (6.19)	0.00 [-2.76, 2.76]	1.00	1.17 [-2.57, 4.90]	.50	0.39
HADS depression (0-21)	6	1.67 (1.86)	2.67 (1.51)	1.00 [-0.33, 2.33]	.12	5	3.00 (1.22)	3.80 (2.59)	0.90 [-0.66, 2.26]	.25	0.20 [-1.78, 2.18]	.82	0.13
PSS total (0-40)	6	4.83 (2.40)	5.50 (2.74)	0.67 [-3.93, 5.27]	.75	5	5.80 (3.56)	12.80 (9.88)	7.00 [1.96, 12.04]	.01**	-6.33 [-15.35, 2.69]	.13	-1.16

	Intervention					Control				Mean difference in changes between groups		
Outcome measure	**n**	**Pre mean (SD)**	**Post mean (SD)**	**Mean Difference [95% CI]**	**p**	**n**	**Pre mean (SD)**	**Post mean (SD)**	**Mean Difference [95% CI]**	**p**	**Mean Difference [95% CI]**	**p**	**Effect size (Hedges' *g*)**
SMMSE total (0-30)	6	28.83 (1.17)	28.50 (0.84)	-0.33 [-1.41, 0.74]	.50	5	29.40 (0.89)	29.60 (0.89)	0.20 [-0.97, 1.37]	.71	-0.53 [-2.12, 1.06]	.47	-0.42
ISEL appraisal (0-12)	6	11.33 (0.82)	11.50 (0.84)	0.17 [-0.35, 0.68]	.49	5	11.80 (0.45)	11.80 (0.45)	0.00 [-0.57, 0.57]	1.00	0.17 [-0.62, 0.96]	.61	0.27
ISEL belonging (0-12)	6	10.67 (1.37)	11.17 (1.17)	0.50 [-0.14, 1.14]	.11	5	10.00 (3.39)	10.20 (3.49)	0.20 [-0.50, 0.90]	.53	0.30 [-0.65, 1.25]	.49	0.40
ISEL tangible (0-12)	6	11.00 (1.26)	11.33 (1.21)	0.33 [-0.29, 0.96]	.26	5	11.40 (1.34)	11.20 (1.79)	-0.20 [-0.89, 0.49]	.53	0.53 [-0.39, 1.46]	.23	0.72
MNA total (0-14)	6	13.33 (1.21)	13.67 (0.52)	0.33 [-0.54, 1.21]	.41	5	13.20 (1.30)	13.40 (0.55)	0.20 [-0.76, 1.16]	.65	0.13 [-1.17, 1.44]	.82	0.13
Cortisol (ng/mL)	6	129.74 (35.57)	122.33 (29.99)	-7.41 [-41.41, 26.58]	.63	5	116.60 (40.42)	130.19 (67.22)	13.58 [-23.65, 50.82]	.43	-21.00 [-71.42, 29.42]	.37	-0.52
DHEAS (ng/mL)	6	563.38 (330.94)	573.60 (299.04)	10.22 [-53.71, 74.14]	.73	5	580.63 (409.90)	624.32 (399.67)	43.69 [-26.34, 113.72]	.19	-33.47 [-128.29, 61.34]	.45	-0.44
Cortisol:DHEAS	6	0.30 (0.18)	0.29 (0.19)	-0.02 [-0.16, 0.13]	.80	5	0.55 (0.76)	0.44 (0.55)	-0.11 [-0.27, 0.04]	.14	0.10 [-0.18, 0.38]	.63	0.57

Note. ADL = Activities of Daily Living, DHEAS = Dehydroepiandrosterone Sulphate, GDS = Geriatric Depression Scale, HADS = Hospital Anxiety and Depression Scale, ISEL = Interpersonal Support Evaluation List, MLTAQ = Minnesota Leisure Time Activity Questionnaire Shortened Version, MNA = Mini Nutritional Assessment, PSS = Perceived Stress Scale, SMMSE = Standardised Mini Mental State Examination, SPPB = Short Physical Performance Battery, TNFa = Tumour Necrosis Factor alpha. * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$, differences indicated by independent t-tests.

Figure C. 1.

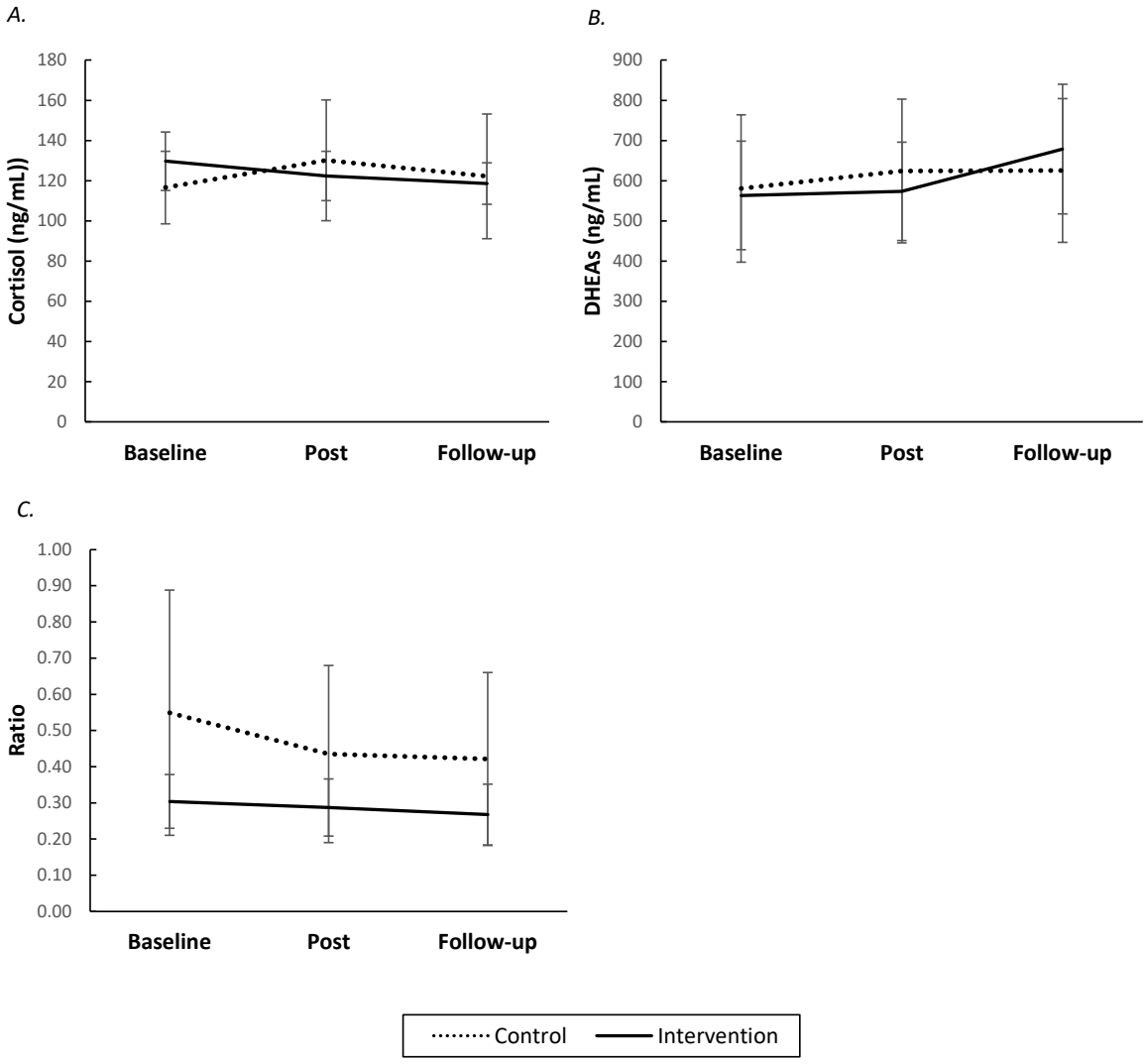
Strength Measures



Note. Peak torque measures (Nm) over time in intervention and control groups. Panel A: Left knee extension. Panel B: Right knee extension. Panel C: Left knee flexion. Panel D: Right knee flexion. Panel E: Hip adduction. Panel F: Hip abduction. Error bars represent standard error.

Figure C. 2.

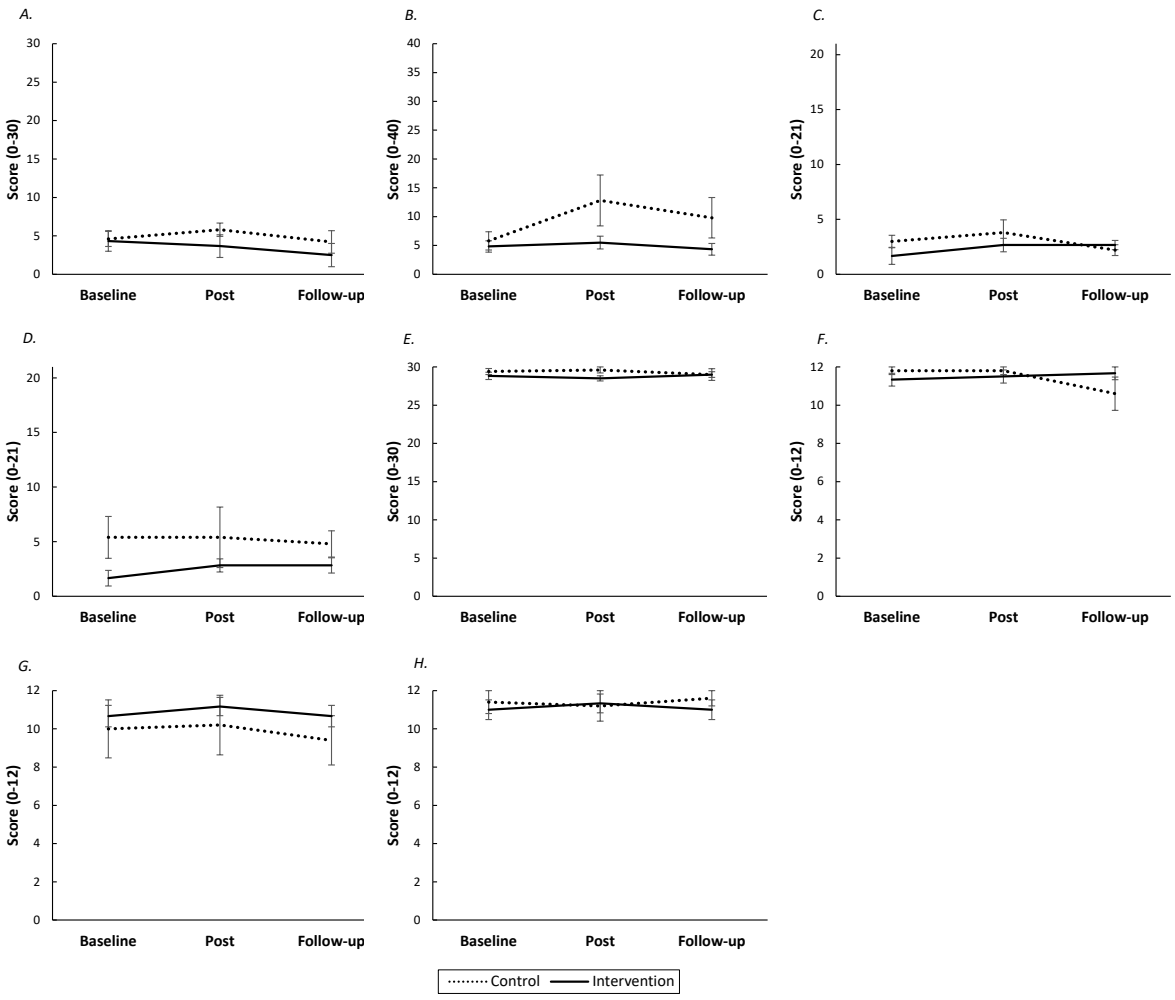
Physiological Measures



Note. Blood measures over time in intervention and control groups. Panel A: Cortisol. Panel B: Dehydroepiandrosterone Sulphate (DHEAS). Panel C: Cortisol:DHEAS. Error bars represent standard error.

Figure C. 3.

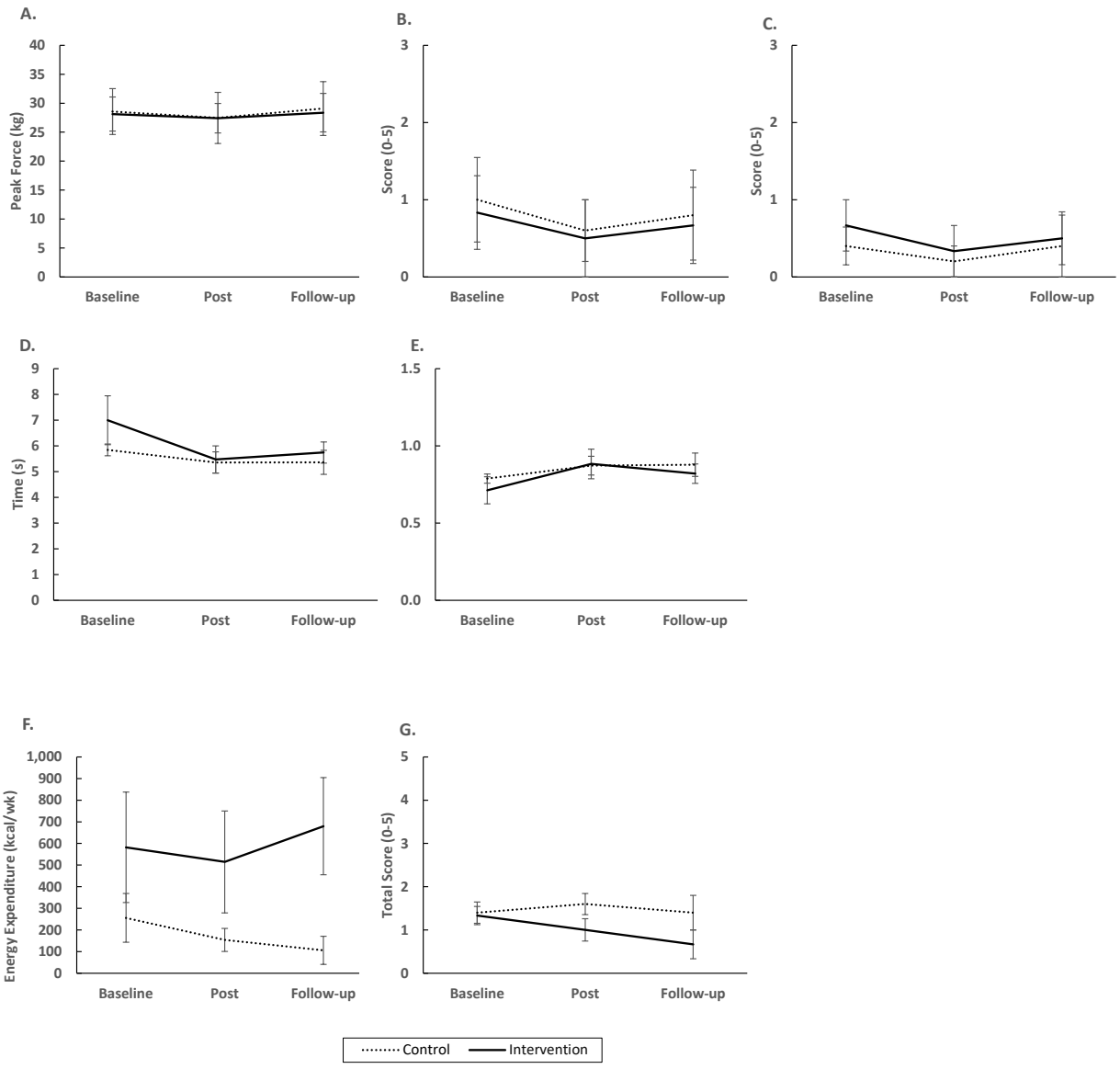
Psychological, Emotional, Cognitive and Social Support Measures



Note. Psychological, Emotional, Cognitive and Social Support measures over time in intervention and control groups. Panel A: Geriatric Depression Scale (GDS). Panel B: Perceived Stress Scale (PSS). Panel C: Hospital and Anxiety Depression Scale (Depression). Panel D: Hospital and Anxiety Depression Scale (Anxiety). Panel E: Standardised Mini Mental State. Panel F: Interpersonal Support Evaluation List (Appraisal). Panel G: Interpersonal Support Evaluation List (Belonging). Panel H: Interpersonal Support Evaluation List (Tangible). Error bars represent standard error.

Figure C. 4.

Eligibility Screening and Functional Capacity Measures

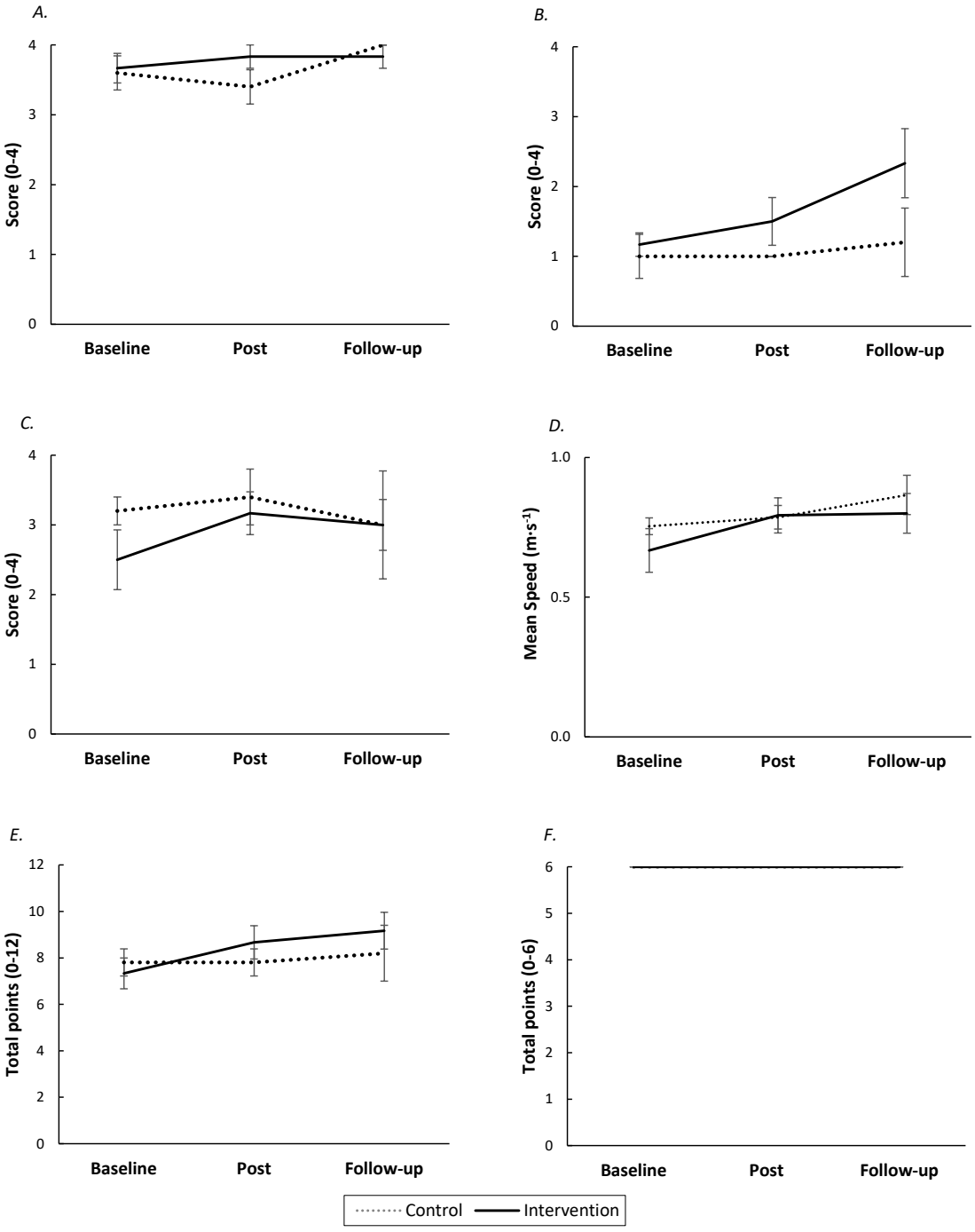


Note. Fried frailty phenotype measures over time in intervention and control groups. Panel A: Grip strength. Panel B: Centre for Epidemiological Studies Depression scale (CES-D) question 1. Panel C: CES-D question 2. Panel D: Mean walk test time. Panel E: Mean walk test speed. Panel F: Minnesota Leisure Time Activity Questionnaire (MLTAQ) Shortened Version. Panel G: Fried frailty Total Score. Error bars represent standard error.

[a] Fried frailty self-reported unintentional weight loss question not shown here: all participants scored zero, with no reported change at postintervention or follow-up.

Figure C. 5.

Functional Capacity Measures



Note. Functional Capacity measures over time in intervention and control groups. Panel A: Short Physical Performance Battery (SPPB) Balance test. Panel B: SPPB Chair stand test. Panel C: SPPB Gait speed

test. Panel D: SPPB mean gait speed. Panel E: SPPB total score. Panel F: Katz Index of Independence in Activities of Daily Living[a] (Katz ADL). Error bars represent standard error.

[a]All participants scored six for Katz ADL, with no reported change at postintervention or follow-up.