



Original article

Exercise should be blue and green: Seasonal variation in how woodland and freshwater interact to enhance participation in active leisure events

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ABSTRACT

Models of physical activity assume exercise is dictated by characteristics of individuals, their environment and synergies between the two. Active leisure events utilise public green spaces such as parks to promote outdoor exercise among the relatively inactive to improve their health and wellbeing. They are a cheap and effective mechanism of reducing burdens placed upon healthcare systems. Understanding what components of the environment promote green exercise could increase their effectiveness. Previous studies have shown that the amount of woodland and freshwater along the routes of the active leisure events are positively associated with the return rates of new participants. However, few studies of green exercise have considered the impact of season. This study builds upon previous models of parkrun return rates by incorporating season. Higher return rates after attending a highly wooded event do not occur in winter. This suggests that woodland is associated with higher return rates only when deciduous trees are in leaf and that leaves could play a crucial role in the rewards gained from green exercise. Freshwater has a positive effect in winter. From April until October freshwater interacts with woodland to nearly double the increase in return rate associated with woodland. Thus, routes with high proportions of both woodland and freshwater have the highest return rates, but only when deciduous trees are in leaf. One explanation for this finding could be water reflecting the foliage on trees and so enhancing the amount of green present in the environment. Thus, the benefits of exercising in blue-green spaces appear to be greater than exercising in green spaces alone. This study has important implications for urban planners designing locations that will encourage people to engage in active leisure with green and blue spaces placed in close proximity seemingly creating the ideal setting for promoting exercise.

1. Introduction

Models of physical activity are determined by individual and environmental characteristics (Lee and Park, 2021; McLeroy et al., 1988). The environmental context includes at least three components, the societal environment, the physical environment and the political environment. Increasing numbers of people fail to meet the recommended levels of physical activity placing additional burdens upon healthcare systems and reducing our ability to achieve sustainable development goals (Bull et al., 2020). There are also existing inequalities in levels of exercise affecting individual characteristics, such as women and ethnic minorities, and those shaped by the socio-economic environment, with lower levels of access to green spaces and lower levels of physical activity in more deprived locations (Gage et al., 2023; Mitchell and Popham, 2008; O'Brien et al., 2017; Wolch et al., 2014). Furthermore, the COVID-19 pandemic has accentuated these inequalities (O'Connor et al., 2023; Quirk et al., 2022).

Many studies have suggested that outdoor activity can provide additional health and well-being benefits if the activity is undertaken in an area with green space (Li et al., 2022; Liu et al., 2021; Yang Liu et al., 2023) or blue space (Garrett et al., 2019; Grace et al., 2024; McDougall et al., 2021). This has led to the terms green exercise and blue exercise (Lahart et al., 2019; Loureiro et al., 2021). There is evidence that both the type and size of green spaces are important (Akpınar et al., 2016; Ha et al., 2022; Kim et al., 2020). Multiple studies have shown that green space encourages physical activity (Chen et al., 2021; Deelen et al., 2019; Jansen et al., 2017; Pietilä et al., 2015; Richardson et al., 2013; Stewart et al., 2016; Tsai et al., 2016) and is associated with better health as a result (Richardson et al., 2013). Proximity to blue spaces has also been found to be associated with frequency of running in an environment (Huang et al., 2023). Many studies have considered green spaces as a single component of the environment although some studies have now started to look at green space in more detail. For example, higher levels of physical activity and a measurable benefit to wellbeing

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have been identified from exercising in woodland specifically (Kajosaari and Pasanen, 2021; Petrunoff et al., 2022; Wolf et al., 2020). The associations between components of the environment and physical activity mean that interventions based upon manipulating the environment can be developed to promote levels of activity (Yong Liu et al., 2023). The more we understand about individual components of the environment and their interactions the greater chance we have of developing effective health interventions.

One growing form of intervention are active leisure events which encourage group exercise in outdoor spaces such as public parks (Hillman et al., 2021). These are increasingly involved in social prescribing (Fixsen and Barrett, 2022; Fleming et al., 2022; Haake et al., 2022), where health practitioners encourage patients who would benefit from increased levels of activity to engage with active leisure events. One excellent example is the parkrun practice which helps foster links between medical centres and local parkrun events (Haake et al., 2022). Participation data from active leisure events such as parkrun might provide ideal model systems for testing the impacts of the environment on the benefits of exercising in different outdoor environments due to the amount of data generated on levels of participation. The global scale of parkrun makes this a particularly useful model system. They organise weekly 5 km events across 22 countries in nearly 2000 different locations hosting approximately 200,000 events per year with the majority of events occurring in urban parks (www.parkrun.com). There is no requirement to run, with walking actively promoted (Haake et al., 2022). These events have generated a huge dataset on levels of participation at events in a wide range of different environments (Haake et al., 2022).

The results of all parkrun events are published including the event name, date, finishing time, age category and gender of participants and the number of parkrun events completed so new participants can be identified. Previous studies of parkrun have identified barriers to participation and factors that increase the likelihood of a new participant returning to parkrun. A study in Australia found that events with hard surfaces and close to water had higher growth rates in terms of numbers of participants (Grunseit et al., 2023). A study across several parkrun nations found that women, younger adults and the less physically fit were less likely to return to parkrun (Reece et al., 2022). This study also found an inconvenient start time and concerns about being too unfit to participate were barriers to engagement with parkrun. A study in Scotland found that slower first time participants were less likely to return to parkrun (Gilburn, 2023a). This study was also the first to relate landscape characteristics of parkrun routes to return rates and identified that both the proportion of woodland and freshwater along a parkrun route positively influence the likelihood of a new participant returning to a parkrun (Gilburn, 2023a).

One factor that has largely been ignored in the study of green exercise is season. One exception was a recent study that found seasonal variation in the levels of physical activity occurring in blue-green spaces with green spaces only promoting physical activity in summer (Zhou et al., 2022). Season has not yet been explored in the context of parkrun. One reason season might be important is that colour could play a key role in the benefits of green exercise (Akers et al., 2012; Zhang et al., 2023). A recent study has suggested that improvements in wellbeing associated with exposure to blue space can depend upon the surrounding green space hinting at potential interactions between the two (Grace et al., 2023). Deciduous trees will drop their leaves in autumn and not develop new leaves until the following spring, alternating their appearance between winter and summer from predominantly green to predominantly another colour determined by the hue of their bark. This colour change could create a differential benefit to green exercise with environments becoming less green in winter. The visual appearance of freshwater will also change seasonally with some water bodies becoming temporarily frozen during winter cold spells. There will also be changes in the amount of green vegetation in freshwater bodies.

Another factor that has generated rather mixed results with no

consistent trend is the association between gender and the benefits of green exercise (Li et al., 2023). Further studies are required to understand the potentially complex interactions between gender and different environmental components if we are to develop interventions that are effective for both men and women (Campos-Uscanga et al., 2022; Colley et al., 2019; Huber et al., 2022; Rosa et al., 2023). For example, woodland has been found to have a greater impact on the level of physical of girls in a study of Swedish children (Pagels et al., 2014).

The aim of this study is to develop a model of the return rate of new parkrun participants return incorporating season as a novel environmental factor. This will fill an important knowledge gap in relation to whether season impacts the beneficial effects of exposure to woodland and freshwater while participating in parkrun by increasing the return rates of new participants. The study will also investigate whether there is an interaction between season, the amount of woodland present on a route and the amount of freshwater on a route. Understanding how these factors shape individual decisions about partaking in physical activity by returning to an active leisure event will aid the design of outdoor spaces that promote activity levels and help fill the current knowledge gap in relation to seasonal impacts upon green exercise.

2. Methodology

The study included data from all existing 58 5 km parkrun course locations that held a parkrun event in Scotland between January 2019 and March 2020. The results pages for all events were processed using an Excel macro which extracted information about each participant including their age category, parkrun ID number, gender, finishing time and whether the participant was new to parkrun (Hoffman, 2023). The number of participants, date of the event and the event venue were also determined from the results pages. The results were harvested each week prior to the next set of events to be able to identify new participants from the number of runs completed, which is one of the variables extracted by the macro.

Gender is selected by participants rather than based upon genetically assigned sex. Age was determined by assigning the midpoint of the age range selected by the participant. Age ranges used by parkrun span 5-years apart from adult teenagers where a 2-year range is used. All adults with an assigned gender who participated at the first parkrun at one of the 58 different event locations over the study period were included. Whether or not the new participant returned to parkrun within a year was determined from their individual participation record available on www.parkrun.org.uk. The following explanatory variables were included: time of year, age, gender, finishing time, number of participants, proportion of new adult participants, the proportions of the area 30 m from the route made up of woodland and freshwater (Gilburn, 2023a). Time of year was separated into two (Apr-Oct and Nov-Mar) to denote the periods when deciduous trees are likely to be in leaf or bare. The proportions of the landscape consisting of woodland and freshwater surrounding each parkrun was determined by downloading the route maps from www.parkrun.org.uk in Keyhole Markup Language format and importing them into the GIS software package Digimap Edina (Gilburn, 2023a). Measuring tools within the aerial roam feature were used to mark out a 30 m distance from the route and the total area within the zone determined and recorded. How far a participant can see at any point will be highly variable depending upon the amount of tree cover. A wider distance than 30 m would include more land cover types that would be obscured from vision by trees. A narrower distance would mean excluding many land cover features that would be visible, so this is a compromise distance that has been used successfully to identify associations between behaviour and land cover types in previous studies (Gilburn, 2024, 2023a). The land cover types within the zones were classified using satellite imagery on Digimap and the proportion of each type within each zone determined. Land cover was classified into the following types: woodland, grassland and other as a previous study found that only freshwater and woodland were associated with return

Table 1

A GLMM with binomial error distribution of return rate to parkrun of adult first-time participants. All continuous explanatory variables were scaled. Season had two levels based upon whether or not deciduous trees were likely in lead with winter being November to March and foliage assumed to be present from April to October. The model formula coding used to generate rate the model is as follows: `glmer(Returned~Age+Season+Finishing.Time+Proportion.of.first.time-rs+Gender+Woodland+Freshwater+Woodland*Season+Woodland*Freshwater+Freshwater*Season+Gender*Freshwater+Woodland*Freshwater*Season+(1|Event.Name),family=binomial)`.

Parameter	Z	Estimate	Standard Error	P
Intercept	15.30	0.533	0.035	< 0.001
Age	9.09	0.124	0.014	< 0.001
Season(winter)	7.18	-0.196	0.027	< 0.001
Finishing time	5.70	-0.093	0.016	< 0.001
Proportion of first-timers	3.89	0.065	0.017	< 0.001
Gender(male)	3.55	0.101	0.028	< 0.001
Woodland	3.23	0.120	0.037	0.001
Freshwater	2.08	0.082	0.039	0.037
Woodland*Season(winter)	3.77	-0.118	0.031	< 0.001
Woodland*Freshwater	2.16	0.115	0.053	0.031
Freshwater*Season(winter)	2.11	-0.068	0.032	0.035
Gender(Male)*Freshwater	2.54	-0.076	0.030	0.011
Woodland*Freshwater*Season(winter)	2.72	-0.116	0.043	0.007

rates so only these two habitat classifications were included in this study (Gilburn, 2023a). Other included anything that could not be classified into these two land cover types and was used in the calculations of proportions of the routes surrounded by woodland and freshwater but was not included in the analyses. The proportion of woodland on the route ranged from 0 % to 98.9 % with a mean of 39.3 % and the proportion of freshwater ranged from 0 % to 30.4 % with a mean of 3.8 %. Six events lacked woodland and 28 of the 58 events lacked freshwater.

2.1. Statistical methodology

The dataset consisted of 25,933 adult participants made up of 14,662 females and 11,271 males and was analysed using R x64 4.1.1 (R Project 2023). A generalised linear mixed model (GLMM) with a binomial error distribution was used to model participants returning to parkrun. This was generated using the `glmer` function in the `lme4` package (Bates et al., 2015). Event venue was included as a random effect. All continuous explanatory variables were scaled to have a mean of zero and a standard deviation of one (Marquardt, 1980). This generates model coefficients that are directly comparable and makes interpretation easier. A backwards elimination model selection process was adopted with the least significant term being removed until only significant terms remained (Vu et al., 2015).

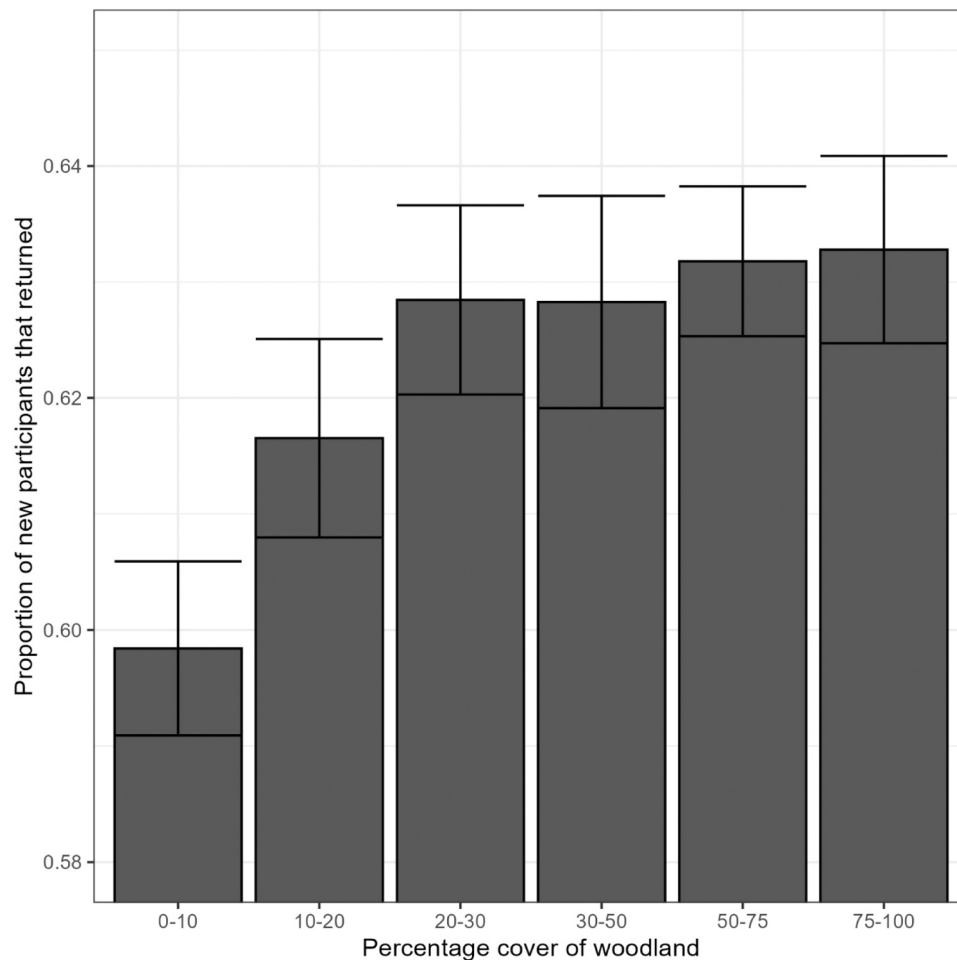


Fig. 1. The proportion of new participants returning to parkrun within one year after attending events with different percentage covers of woodland. Error bars display standard errors.

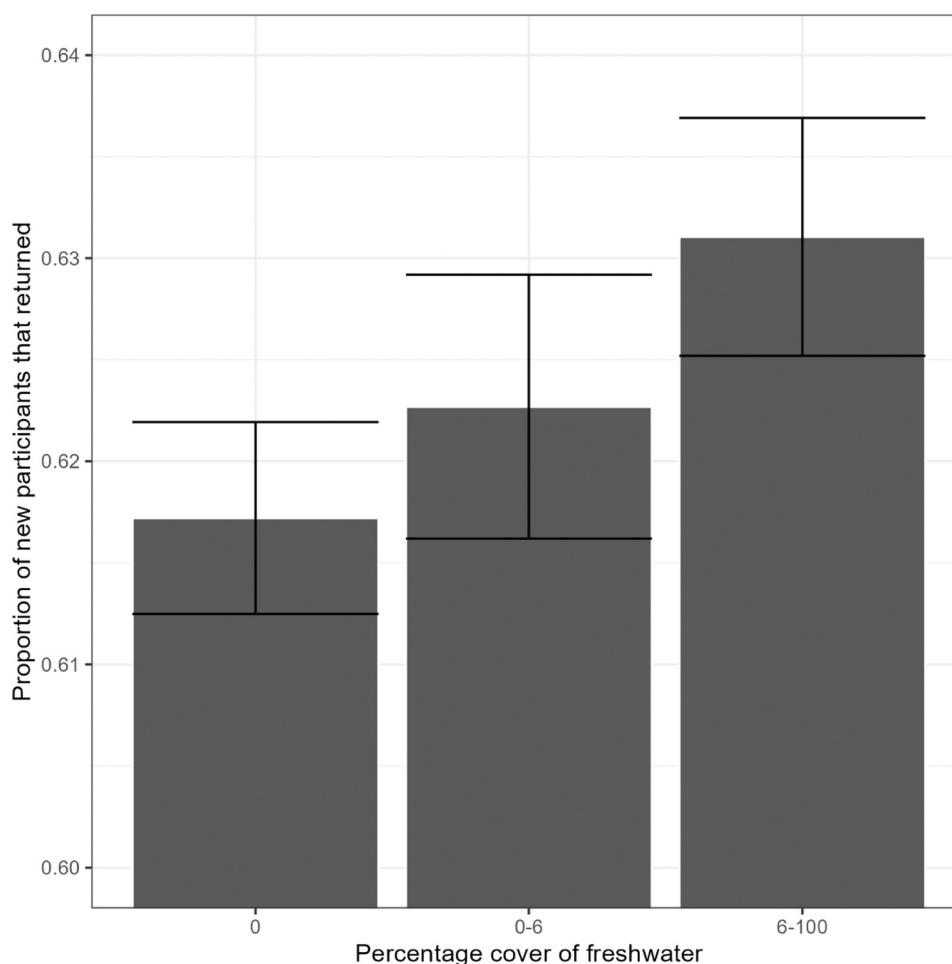


Fig. 2. The proportion of new participants returning to parkrun within one year after attending events with different percentage covers of freshwater. Error bars display standard errors.

3. Results

3.1. Is the return rate of First-Time participants associated with the percentage cover of woodland and freshwater?

The proportion of first-time participants that returned to parkrun within one year was 0.623 (s.e. = 0.003). The general linear mixed model identified that the percentage cover of both woodland and freshwater are both positively associated with the return rates of new participants (Table 1). Those events with less than 10 % woodland had return rates of below 0.6, whereas events with more than 20 % of woodland had return rates of around 0.63. There is evidence of a general increase in return rate with percentage cover of woodland (Fig. 1). Events with no freshwater have a mean return rate of 0.613. Events with up to 6 % coverage of freshwater had a return rate of 0.623 and events with more than 6 % coverage of freshwater had a return of 0.631, revealing a general increase in return rate with increasing cover of freshwater (Fig. 2).

3.2. The impact of season on the return rate of First-Time parkrun participants

Time of year was also significantly associated with return rates with lower rates occurring during winter (Nov-Mar) than the rest of the year (winter - 0.610, s.e. 0.004, N = 11,035; summer - 0.636, s.e. 0.005, N = 11,897). There was a highly significant interaction term between time of year and the proportion of woodland (Table 3). There is a clear

pattern of an increasing return rate with increasing percentage cover of woodland at parkrun events in summer but not in winter (Fig. 3). There were also interaction terms between woodland and freshwater, revealing an enhancement effect when present in combination. Furthermore, there was a three way-interaction between woodland, freshwater and time of year showing this enhancement effect only seemed to occur in summer (Fig. 4). Freshwater was associated with increasing return rates in winter. However, in summer the freshwater association with higher return rates only occurred in association with woodland (Fig. 4). There was also an interaction term between gender and freshwater showing higher return rates for women than men when more freshwater was present on the route (Table 1).

4. Discussion

Very few studies have investigated the impact of season on green exercise. This study revealed complex interactions between time of year, the proportion of woodland and the proportion of freshwater along a parkrun route in their associations with the return rate of new participants to parkrun. From November to March future participation levels are positively associated with the amount of freshwater present on a route suggesting that the blue space component within blue-green spaces is creating a benefit in winter. This is consistent with two studies that showed that running and exercise frequency were both positively associated with the amount of blue space in Helsinki (Huang et al., 2023; Kajosaari and Pasanen, 2021). During the rest of the year, the more woodland on a route the higher the return rates revealing a

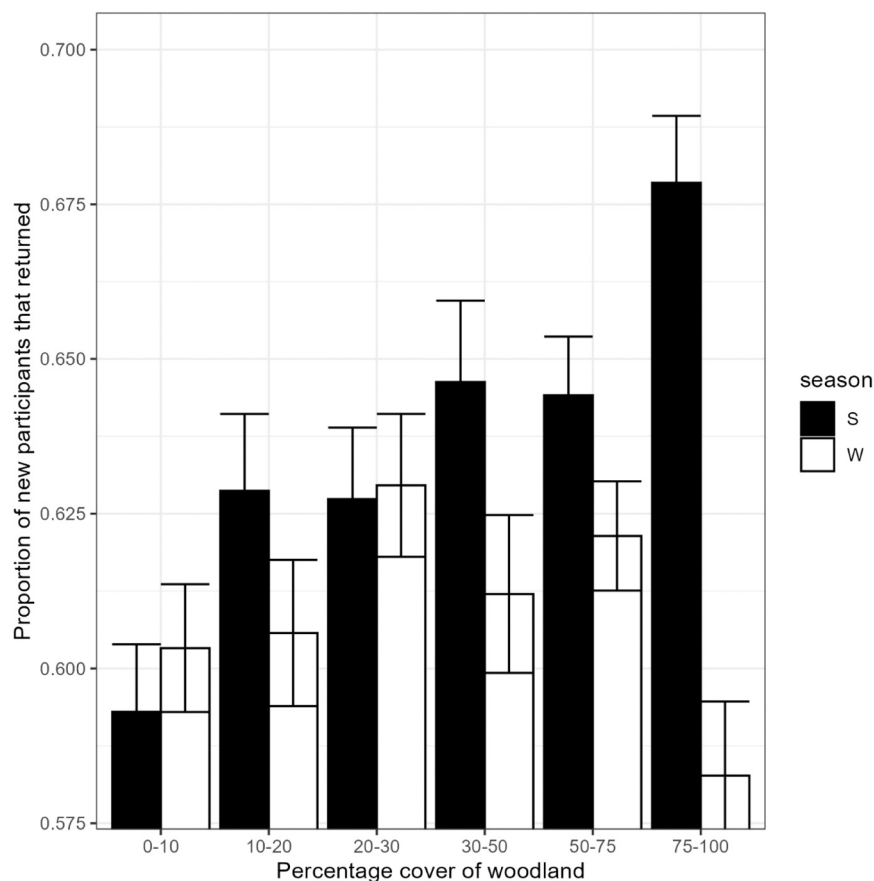


Fig. 3. The proportion of new participants returning to parkrun within one year after attending events with different percentage covers of woodland during summer (Apr-Oct) and winter (Nov-Mar). error bars display standard errors.

participation promotion effect whose timing matches the presence of leaves on deciduous trees. This concurs with a study conducted in Wuhan which found that green space only promoted physical activity in summer (Zhou et al., 2022). This suggests a summer green exercise effect could be associated with the colour green as green spaces are greener during the summer months. The association between woodland and return rates was stronger at events with more amount freshwater present. However, freshwater alone was not associated with an increase in return rates between April and October. This is a novel finding which suggests that there is no green exercise effect associated with freshwater in summer if few trees are present, but in the presence of trees freshwater is associated with higher return rates. One mechanism that could explain this would be the reflection of green trees on the surface of freshwater bodies turning part of the blue space green in colour. Thus, when deciduous trees are in leaf there appears to be a blue-green space exercise benefit gained by participating in a parkrun that has both woodland and freshwater in combination along its route.

Studies exposing participants to video footage with different colour filters applied revealed that the colour green was associated with better mood and a lower feeling of exertion which suggests that the colour green could play a role in the psychological benefits of green exercise (Akers et al., 2012; Zhang et al., 2023). The current study is consistent with hypothesis that one mechanism driving the benefit of green exercise is visual as it provides an explanation for the doubling of the benefit of trees when freshwater is also present. This suggests that an alternative explanation of this finding, the seasonal production of volatile organic compounds by trees believed to play a role in the benefits gained by forest bathing (Antonelli et al., 2020; Walker et al., 2023) is not likely to be driving the effect. A study of changes in wellbeing associated with different seasons when exposed to woodland found that the increase in

the colour green in Spring was associated with elevated mood which also supports the conclusions drawn by this study that the driver of the effect was visual (Kim and Lee, 2023).

The study identified gender differences in relation to freshwater with a greater increase on return rates seen in women. Overall studies of the impacts of gender on blue and green exercise have generated mixed results. One study has reported a stronger association between levels of physical activity and the presence of woodland in girls (Pagels et al., 2014). The current study has added to the complex picture by finding a positive impact of another environmental component, freshwater, on women. Further studies on the interactions between gender and physical environmental features are clearly required. It is encouraging that interventions that involve encouraging activity near freshwater might particularly encourage women to engage in activity as they are a higher priority group as they show overall lower levels of physical activity (Van Dyck et al., 2017).

The study was not an experiment but an analysis of an existing secondary dataset and as such the findings were entirely based upon identification of significant correlations, there the outcomes should be treated with some caution with respect to assigning any cause and effect. The study also did not measure any direct benefits to participants of taking part in parkrun events in different environmental settings as the green exercise benefit identified in this study is manifested by increasing the return rates of new parkrun participants. However, increased return rates to parkrun can be considered an indirect benefit associated with future health gains because the number of participations at parkrun has been found to be positively associated with future fitness gains (Gilburn, 2023b; Stevenson and Hickson, 2019). Therefore, the increased return rates observed in specific environmental settings do seem to potentially

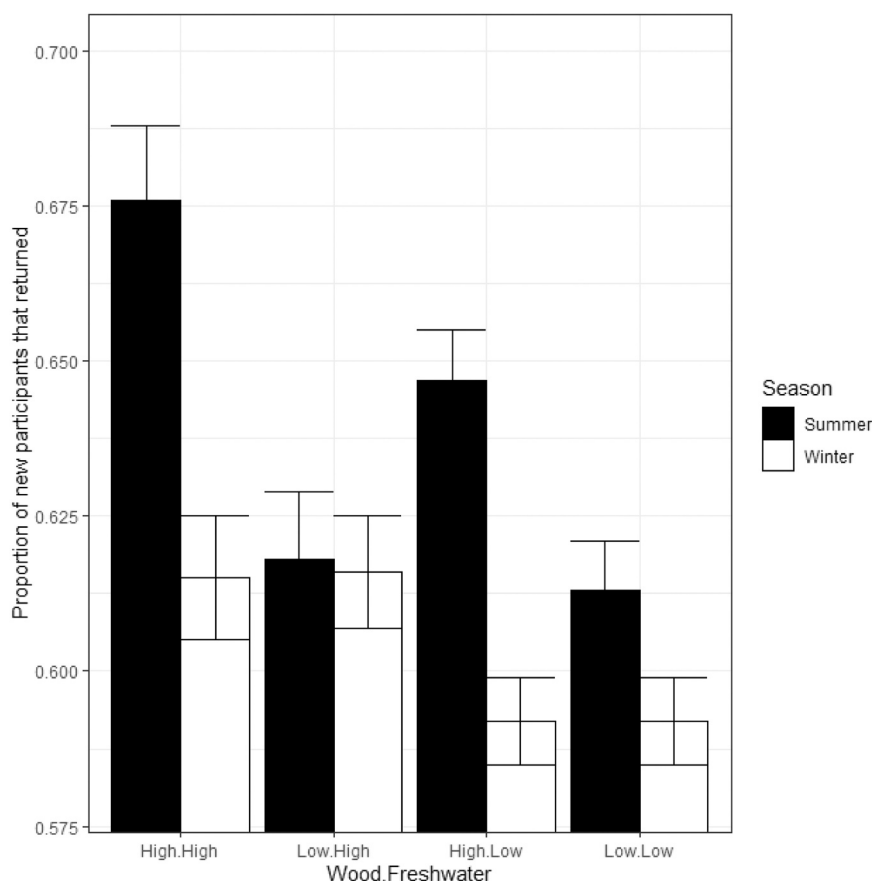


Fig. 4. The proportion of new participants returning to parkrun within one year after attending events with above and below average amounts of both woodland and freshwater during summer and winter. Error bars display standard errors.

provide an indirect benefit as exercise in blue-green spaces encourages future physical activity.

Another limitation of the study is it only focussed on first-time parkrun participants. A study of runners in the Netherlands found that green environments were more attractive and had greater restorative properties for novice runners compared to experienced runners (Deelen et al., 2019). This means that our study might have focussed on a cohort of participants most likely to display an association with components of the environment, although these are the cohort with the most to gain through the nature of the benefit considered in this study as it is an increase in future physical activity and fitness. It would be useful to also consider whether more experienced parkrun participants also respond to differently to variation in blue-green environments and measure the extent of this response.

A further limitation of the study was the level of classification of the blue and green-space. Green space was separated into grassland and woodland but the type of woodland was not determined. The explanation for the findings of this study relies on the loss of leaves during winter. The classification of woodlands into deciduous, mixed and coniferous in future studies would allow a test of the hypothesis generated by this study as the patterns observed would not be predicted to occur within coniferous woodland. Blue-space was only separated into freshwater and saltwater. How natural waterbodies appear has been found to be important (Grace et al., 2023) so a natural stream in good condition is likely to have a greater impact of return rates than a man-made reservoir, for example. Studies have also shown that the number and size of blue and green spaces and their heterogeneity can influence levels of physical activity (Ha et al., 2022; Jansen et al., 2017; Kim et al., 2020; Massoni et al., 2018; Petrunoff et al., 2022). Consequently, more detailed classifications based upon type and size of blue and green

spaces would be useful in future studies.

The study identified that during summer around 68 % of new participants returned to parkrun when doing events with relatively high proportions of cover of woodland and freshwater compared to only around 59 % at events with no freshwater and relatively little woodland. This means that the percentage of people who do not return is around 22 % higher at events lacking freshwater and with relatively little woodland. Consequently, the findings of the study have management implications for organisers of active leisure events who could prioritise the utilisation of routes that combine woodland and freshwater in summer, and which expose participants to freshwater during the winter months. For parkrun specifically, event directors might want to create a culture of gathering in an area before the event that combines woodland and freshwater as the benefits of being exposed to the blue-green space will still be accrued whether or not the participants are actively taking part in the event at the time of the expose. The study also has important implications for urban planners. Creating areas with a mixture of woodland and freshwater would provide the ideal setting for promoting levels of physical activity. Furthermore, placing trees specifically so they maximise the likelihood of creating green reflections, for example, by having treelined shorelines, might be particularly effective. It is also possible that the incorporation of evergreens might allow the summer blue-green exercise benefit might be extended into winter.

CRediT authorship contribution statement

Andre S.Gilburn: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

- Akers, A., Barton, J., Cossey, R., Gainsford, P., Griffin, M., Micklewright, D., 2012. Visual color perception in Green exercise: positive effects on mood and perceived exertion. *Environ. Sci. Technol.* 46, 8661–8666. <https://doi.org/10.1021/es301685g>.
- Akpinar, A., Barbosa-Leiker, C., Brooks, K.R., 2016. Does Green space matter? Exploring relationships between Green space type and health indicators. *Urban For. Urban Green.* 20, 407–418. <https://doi.org/10.1016/j.ufug.2016.10.013>.
- Antonelli, M., Donelli, D., Barbieri, G., Valussi, M., Maggini, V., Frenzuoli, F., 2020. Forest volatile organic compounds and their effects on human health: a State-of-the-Art review. *Int. J. Environ. Res. Public Health* 17, 6506. <https://doi.org/10.3390/ijerph17186506>.
- Bates, D., Mächler, M., Bolker, B., Walker, S., 2015. Fitting linear Mixed-Effects models using lme4. *J. Stat. Softw.* 67, 1–48. <https://doi.org/10.18637/jss.v067.i01>.
- Bull, F.C., Al-Ansari, S.S., Biddle, S., Borodulin, K., Buman, M.P., Cardon, G., Carty, C., Chaput, J.-P., Chastin, S., Chou, R., Dempsey, P.C., DiPietro, L., Ekelund, U., Firth, J., Friedenreich, C.M., Garcia, L., Gichu, M., Jago, R., Katzmarzyk, P.T., Lambert, E., Leitzmann, M., Milton, K., Ortega, F.B., Ranasinghe, C., Stamatakis, E., Tiedemann, A., Troiano, R.P., Ploeg, H.P., van der Wari, V., Willumsen, J.F., 2020. World health organization 2020 guidelines on physical activity and sedentary behaviour. *Br. J. Sports Med.* 54, 1451–1462. <https://doi.org/10.1136/bjsports-2020-102955>.
- Campos-Uscanga, Y., Reyes-Rincón, H., Pineda, E., Gibert-Isern, S., Ramirez-Colina, S., Argüelles-Nava, V., 2022. Running in natural spaces: gender analysis of its relationship with emotional intelligence, psychological Well-Being, and physical activity. *Int. J. Environ. Res. Public Health* 19, 6019. <https://doi.org/10.3390/ijerph19106019>.
- Chen, K., Zhang, T., Liu, F., Zhang, Y., Song, Y., 2021. How does urban Green space impact Residents' mental health: a literature review of mediators. *Int. J. Environ. Res. Public Health* 18, 11746. <https://doi.org/10.3390/ijerph182211746>.
- Colley, K., Currie, M.J.B., Irvine, K.N., 2019. Then and now: examining older People's engagement in outdoor recreation across the life course. *Leis. Sci.* 41, 186–202. <https://doi.org/10.1080/01490400.2017.1349696>.
- Deelen, I., Janssen, M., Vos, S., Kamphuis, C.B.M., Ettema, D., 2019. Attractive running environments for all? A cross-sectional study on physical environmental characteristics and runners' motives and attitudes, in relation to the experience of the running environment. *BMC Public Health* 19, 1–15. <https://doi.org/10.1186/s12889-019-6676-6>.
- Fixsen, A., Barrett, S., 2022. Challenges and approaches to Green social prescribing during and in the aftermath of COVID-19: a qualitative study. *Front. Psychol.* 13.
- Fleming, J., Wellington, C., Parsons, J., Dale, J., 2022. Collaboration between primary care and a voluntary, community sector organisation: practical guidance from the parkrun practice initiative. *Health Soc. Care Community* 30, e514–e523. <https://doi.org/10.1111/hsc.13236>.
- Gage, R., Mizdrak, A., Richards, J., Bauman, A., Mcleod, M., Jones, R., Woodward, A., Shaw, C., 2023. The epidemiology of Domain-Specific physical activity in New Zealand adults: a nationally representative Cross-Sectional survey. *J. Phys. Act. Health* 20, 909–920. <https://doi.org/10.1123/jpah.2022-0156>.
- Garrett, J.K., White, M.P., Huang, J., Ng, S., Hui, S., Leung, C., Tse, L.A., Fung, F., Elliott, L.R., Depledge, M.H., Wong, M.C.S., 2019. Urban blue space and health and wellbeing in Hong Kong: results from a survey of older adults. *Health Place* 55, 100–110. <https://doi.org/10.1016/j.healthplace.2018.11.003>.
- Gilburn, A.S., 2023a. Predictors of successful return to parkrun for first-time adult participants in Scotland. *PLOS Glob. Public Health* 3, e0001786. <https://doi.org/10.1371/journal.pgph.0001786>.
- Gilburn, A.S., 2023b. New parkrunners are slower and the attendance gender gap narrowing making parkrun more inclusive. *Int. J. Environ. Res. Public Health* 20, 3602. <https://doi.org/10.3390/ijerph20043602>.
- Gilburn, A., 2024. Green exercise, blue spaces and active leisure events: the performance of new participants is associated with their response to event characteristics. *J. Glob. Sport Manag.* 0 1–20. <https://doi.org/10.1080/24704067.2024.2327073>.
- Grace, M.J., Dickie, J., Bartie, P.J., Brown, C., Oliver, D.M., 2023. How do weather conditions and environmental characteristics influence aesthetic preferences of freshwater environments? *Sci. Total Environ.* 903, 166283. <https://doi.org/10.1016/j.scitotenv.2023.166283>.
- Grace, M., Dickie, J., Brown, C., Bartie, P., Oliver, D.M., 2024. Using solicited research diaries to assess the restorative potential of exposure to inland blue space across time. *Landsc. Urban Plan.* 241, 104904. <https://doi.org/10.1016/j.landurbplan.2023.104904>.
- Grunseit, A.C., Huang, B.-H., Merom, D., Bauman, A., Cranney, L., Rogers, K., 2023. Patterns and correlates of participation in a weekly mass participation physical activity event, parkrun, in Australia, 2011–2020. *J. Phys. Act. Health* 19. <https://doi.org/10.1123/jpah.2023-0532>.
- Ha, J., Kim, H.J., With, K.A., 2022. Urban Green space alone is not enough: a landscape analysis linking the spatial distribution of urban Green space to mental health in the city of Chicago. *Landsc. Urban Plan.* 218, 104309. <https://doi.org/10.1016/j.landurbplan.2021.104309>.
- Haake, S., Quirk, H., Bullas, A., 2022. Parkrun and the promotion of physical activity: insights for primary care clinicians from an online survey. *Br. J. Gen. Pr.* 72, e634–e640. <https://doi.org/10.3399/BJGP.2022.0001>.
- Hillman, P., Lamont, M., Scherrer, P., Kennelly, M., 2021. Reframing mass participation events as active leisure: implications for tourism and leisure research. *Tour. Manag. Perspect.* 39, 100865. <https://doi.org/10.1016/j.tmp.2021.100865>.
- Hoffman, 2023. parkrun statsgeek group. Version 4.6 of this macro that converts a parkrun results page into a useful and function rich Excel table | Facebook [WWW Document], n.d. URL <https://www.facebook.com/groups/parkrunstatsgeeks/permalink/3166888586881628> (accessed 4.12.23).
- Huang, D., Tian, M., Yuan, L., 2023. Sustainable design of running friendly streets: environmental exposures predict runnability by volunteered geographic information and multilevel model approaches. *Sustain. Cities Soc.* 89, 104336. <https://doi.org/10.1016/j.scs.2022.104336>.
- Huber, D., Mayr, M., Hartl, A., Sittenthaler, S., Traut-Mattausch, E., Weisböck-Erdheim, R., Freidl, J., 2022. Sustainability of hiking in combination with coaching in cardiorespiratory fitness and quality of life. *Int. J. Environ. Res. Public Health* 19, 3848. <https://doi.org/10.3390/ijerph19073848>.
- Jansen, F.M., Ettema, D.F., Kamphuis, C.B.M., Pierik, F.H., Dijst, M.J., 2017. How do type and size of natural environments relate to physical activity behavior? *Health Place* 46, 73–81. <https://doi.org/10.1016/j.healthplace.2017.05.005>.
- Kajosaari, A., Pasanen, T.P., 2021. Restorative benefits of everyday Green exercise: a spatial approach. *Landsc. Urban Plan.* 206, 103978. <https://doi.org/10.1016/j.landurbplan.2020.103978>.
- Kim, E., Lee, H., 2023. Seasonal forest changes of color and temperature: effects on the mood and physiological state of university students. *Int. J. Environ. Res. Public Health* 20, 6338. <https://doi.org/10.3390/ijerph20146338>.
- Kim, J., Park, D.-B., Seo, J.I., 2020. Exploring the relationship between forest structure and health. *Forests* 11, 1264. <https://doi.org/10.3390/f1121264>.
- Lahart, I., Darcy, P., Gidlow, C., Calogiuri, G., 2019. The effects of Green exercise on physical and mental wellbeing: a systematic review. *Int. J. Environ. Res. Public Health* 16, 1352. <https://doi.org/10.3390/ijerph16081352>.
- Lee, Y., Park, S., 2021. Understanding of physical activity in social ecological perspective: application of multilevel model. *Front. Psychol.* 12.
- Li, H., Ding, Y., Zhao, B., Xu, Y., Wei, W., 2023. Effects of immersion in a simulated natural environment on stress reduction and emotional arousal: a systematic review and meta-analysis. *Front. Psychol.* 13.
- Li, H., Zhang, X., Bi, S., Cao, Y., Zhang, G., 2022. Psychological benefits of Green exercise in wild or urban greenspaces: a meta-analysis of controlled trials. *Urban For. Urban Green.* 68, 127458. <https://doi.org/10.1016/j.ufug.2022.127458>.
- Liu, Yang, Kwan, M.-P., Wong, M.S., Yu, C., 2023. Current methods for evaluating people's exposure to Green space: a scoping review. *Soc. Sci. Med.* 338, 116303. <https://doi.org/10.1016/j.socscimed.2023.116303>.
- Liu, Yong, Li, Y., Yang, W., Hu, J., 2023. Exploring nonlinear effects of built environment on jogging behavior using random forest. *Appl. Geogr.* 156, 102990. <https://doi.org/10.1016/j.apgeog.2023.102990>.
- Liu, P., Liu, M., Xia, T., Wang, Y., Guo, P., 2021. The relationship between landscape metrics and facial expressions in 18 urban forest parks of Northern China. *Forests* 12, 1619. <https://doi.org/10.3390/f12121619>.
- Loureiro, N., Calmeiro, L., Marques, A., Gomez-Baya, D., Gaspar De Matos, M., 2021. The role of blue and Green exercise in planetary health and Well-Being. *Sustainability* 13, 10829. <https://doi.org/10.3390/su131910829>.
- Marquardt, D.W., 1980. Comment: you should standardize the predictor variables in your regression models. *J. Am. Stat. Assoc.* 75, 87–91. <https://doi.org/10.1080/01621459.1980.10477430>.
- Massoni, E.S., Barton, D.N., Rusch, G.M., Gundersen, V., 2018. Bigger, more diverse and better? Mapping structural diversity and its recreational value in urban Green spaces. *Ecosyst. Serv. Assess. Valuat. Recreat. Ecosyst. Serv.* 31, 502–516. <https://doi.org/10.1016/j.ecoser.2018.02.013>.
- McDougall, C., Hanley, N., Quilliam, R., Bartie, P., Robertson, T., Griffiths, M., Oliver, D., 2021. Neighbourhood blue space and mental health: a nationwide ecological study of antidepressant medication prescribed to older adults. *Landsc. Urban Plan.* 214, 104132. <https://doi.org/10.1016/j.landurbplan.2021.104132>.
- McLeroy, K., Bibeau, D., Steckler, A., Glanz, K., 1988. An Ecological Perspective on Health Promotion Programs [WWW Document]. URL <https://journals-sagepub-com.ezproxy-s2.stir.ac.uk/doi/10.1177/109019818801500401> (accessed 11.22.23).
- Mitchell, R., Popham, F., 2008. Effect of exposure to natural environment on health inequalities: an observational population study. *Lancet* 372, 1655–1660. [https://doi.org/10.1016/S0140-6736\(08\)61689-X](https://doi.org/10.1016/S0140-6736(08)61689-X).
- O'Brien, L., De Vreese, R., Atmiş, E., Stahl Olafsson, A., Sievänen, T., Brennan, M., Sánchez, M., Panagopoulos, T., de Vries, S., Kern, M., Gentin, S., Saraiva, G., Almeida, A., 2017. Social and environmental justice: diversity in access to and benefits from urban Green infrastructure – examples from Europe. In: Pearlmutter, D., Calfapietra, C., Samson, R., O'Brien, L., Krajter Ostoić, S., Sanesi, G., Alonso del Amo, R. (Eds.), *The Urban Forest: Cultivating Green Infrastructure for People and the Environment*, Future City. Springer International Publishing, Cham, pp. 153–190. https://doi.org/10.1007/978-3-319-50280-9_15.
- O'Connor, S., Bélanger-Gravel, A., study team, iC.A.R.E., 2023. Social determinants of long-term reported changes in physical activity and healthy eating during the COVID-19 pandemic in Canada: multiple cross-sectional surveys analysis from the

- iCARE study. *Appl. Physiol. Nutr. Metab.* <https://doi.org/10.1139/apnm-2023-0206>.
- Pagels, P., Raustorp, A., De Leon, A.P., Mårtensson, F., Kylin, M., Boldemann, C., 2014. A repeated measurement study investigating the impact of school outdoor environment upon physical activity across ages and seasons in Swedish second, fifth and eighth graders. *BMC Public Health* 14, 1–9. <https://doi.org/10.1186/1471-2458-14-803>.
- Petrunoff, N.A., Edney, S., Yi, N.X., Dickens, B.L., Joel, K.R., Xin, W.N., Sia, A., Leong, D., van Dam, R.M., Cook, A.R., Sallis, J.F., Chandrabose, M., Owen, N., Müller-Riemenschneider, F., 2022. Associations of park features with park use and park-based physical activity in an urban environment in Asia: a cross-sectional study. *Health Place* 75, 102790. <https://doi.org/10.1016/j.healthplace.2022.102790>.
- Pietilä, M., Neuvonen, M., Borodulin, K., Korpela, K., Sievänen, T., Tyrväinen, L., 2015. Relationships between exposure to urban Green spaces, physical activity and self-rated health. *J. Outdoor Recreat. Tour. SI Health Wellbeing* 10, 44–54. <https://doi.org/10.1016/j.jort.2015.06.006>.
- Quirk, H., Haake, S., Goyder, E., Bullas, A., Graney, M., Wellington, C., 2022. Change in health, wellbeing and physical activity levels during the COVID-19 pandemic: a longitudinal cohort of parkrun participants in the United Kingdom. *Health Promot. Int.*, daac012 <https://doi.org/10.1093/heapro/daac012>.
- Reece, L.J., Owen, K., Graney, M., Jackson, C., Shields, M., Turner, G., Wellington, C., 2022. Barriers to initiating and maintaining participation in parkrun. *BMC Public Health* 22, 83. <https://doi.org/10.1186/s12889-022-12546-w>.
- Richardson, E.A., Pearce, J., Mitchell, R., Kingham, S., 2013. Role of physical activity in the relationship between urban Green space and health. *Public Health* 127, 318–324. <https://doi.org/10.1016/j.puhe.2013.01.004>.
- Rosa, C.D., Larson, L.R., Silvia Collado, Cloutier, S., Profice, C.C., 2023. Gender differences in connection to nature, outdoor preferences, and Nature-Based recreation among college students in Brazil and the United States. *Leis. Sci.* 45, 135–155. <https://doi.org/10.1080/01490400.2020.1800538>.
- Stevinson, C., Hickson, M., 2019. Changes in physical activity, weight and wellbeing outcomes among attendees of a weekly mass participation event: a prospective 12-month study. *J. Public Health* 41, 807–814. <https://doi.org/10.1093/pubmed/fty178>.
- Stewart, O.T., Moudon, A.V., Fesinmeyer, M.D., Zhou, C., Saelens, B.E., 2016. The association between park visitation and physical activity measured with accelerometer, GPS, and travel diary. *Health Place* 38, 82–88. <https://doi.org/10.1016/j.healthplace.2016.01.004>.
- R.: The R Project for Statistical Computing [WWW Document], n.d. URL <https://www.r-project.org/> (accessed 4.12.23).
- Tsai, W.-L., Floyd, M.F., Leung, Y.-F., McHale, M.R., Reich, B.J., 2016. Urban vegetative cover fragmentation in the U.S. *Assoc. Phys. Act. Bmi. Am. J. Prev. Med.* 50, 509–517. <https://doi.org/10.1016/j.amepre.2015.09.022>.
- Van Dyck, D., Cardon, G., De Bourdeaudhuij, I., De Ridder, L., Willem, A., 2017. Who participates in running events? Socio-demographic characteristics, psychosocial factors and barriers as correlates of Non-Participation—A pilot study in Belgium. *Int. J. Environ. Res. Public Health* 14, 1315. <https://doi.org/10.3390/ijerph14111315>.
- Vu, D.H., Muttaqi, K.M., Agalgaonkar, A.P., 2015. A variance inflation factor and backward elimination based robust regression model for forecasting monthly electricity demand using climatic variables. *Appl. Energy* 140, 385–394. <https://doi.org/10.1016/j.apenergy.2014.12.011>.
- Walker, H., Jena, A., McEwan, K., Evans, G., Campbell, S., 2023. Natural volatile organic compounds (NVOCs) are greater and more diverse in UK forests compared with a public garden. *Forests* 14, 92. <https://doi.org/10.3390/f14010092>.
- Wolch, J.R., Byrne, J., Newell, J.P., 2014. Urban Green space, public health, and environmental justice: the challenge of making cities 'just Green enough. *Landsc. Urban Plan.* 125, 234–244. <https://doi.org/10.1016/j.landurbplan.2014.01.017>.
- Wolf, K.L., Lam, S.T., McKeen, J.K., Richardson, G.R.A., van den Bosch, M., Bardekjian, A.C., 2020. Urban trees and human health: a scoping review. *Int. J. Environ. Res. Public Health* 17, 4371. <https://doi.org/10.3390/ijerph17124371>.
- Zhang, D., Jin, X., Wang, L., Jin, Y., 2023. Form and color visual perception in Green exercise: positive effects on attention, mood, and self-esteem. *J. Environ. Psychol.* 88, 102028. <https://doi.org/10.1016/j.jenvp.2023.102028>.
- Zhou, Y., Yang, L., Yu, J., Guo, S., 2022. Do seasons matter? Exploring the dynamic link between blue-Green space and mental restoration. *Urban For. Urban Green.* 73, 127612. <https://doi.org/10.1016/j.ufug.2022.127612>.