Canadian Journal on Aging / La Revue canadienne du vieillissement

www.cambridge.org/cjg

Neighbourhood Walkability and Greenness Exhibit Different Associations with Social Participation in Older Males and Females: An Analysis of the CLSA

Irmina Klicnik[1], Andrew Putman[1], David Rudoler[1], Michael J. Widener[2] and Shilpa Dogra[1]

[1]Ontario Tech University, Faculty of Health Science, Oshawa, ON L1G 0C5, Canada and [2]University of Toronto, Department of Geography and Planning, Toronto, ON M5S 3G3, Canada

Article

Cite this article: Klicnik, I., Putman, A., Rudoler, D., Widener, M.J., & Dogra, S. (2024). Neighbourhood Walkability and Greenness Exhibit Different Associations with Social Participation in Older Males and Females: An Analysis of the CLSA. *Canadian Journal on Aging / La Revue canadienne du vieillissement* https://doi.org/10.1017/S0714980824000369

Received: 01 November 2023
Accepted: 26 May 2024

Keywords:
active ageing; neighbourhood; longitudinal; loneliness; LEAAF

Mots-clés:
vieillissement actif; quartier; longitudinale

Corresponding author:
Irmina Klicnik;
Email: irmina.klicnik@ontariotechu.net

Abstract

We explored the relationship between neighbourhood and social participation among older adults using a Living Environments and Active Aging Framework. This prospective cohort study used baseline data from the Canadian Longitudinal Study on Aging (CLSA) with a 3-year follow-up. Three aspects of social participation were the outcomes; walkability and greenness at baseline were exposure variables. The sample consisted of 50.0% females (n=16,735, age 72.9 ± 5.6 years). In males, higher greenness was associated with lower loneliness and less variety in social activities. No significant associations between greenness and social participation were found in females. High walkability was related to a higher variety of social activity and higher loneliness in males but not females, and less desire for more social activity in both sexes. Greenness and walkability impact social participation among older adults. Future research should include sex and gender-based analyses.

Résumé

Nous avons utilisé le cadre « Living Environments and Active Aging » (milieux de vie et vieillissement actif) pour explorer les liens entre le quartier de résidence et la participation sociale des personnes âgées. Cette étude de cohorte prospective a utilisé les données de base de l'Étude longitudinale canadienne sur le vieillissement (ELCV) avec un suivi de trois ans. Les paramètres d'évaluation étaient trois aspects de la participation sociale; la facilité de déplacement à pied et la verdure étaient les variables d'exposition. L'échantillon était composé à 50 % de femmes (n = 16 735, âge 72,9 ± 5,6 ans). Chez les hommes, une verdure plus étendue était associée à une plus faible solitude et à une moins grande variété d'activités sociales. Aucune association significative entre la verdure et la participation sociale n'a été trouvée chez les femmes. Une grande facilité de déplacement à pied était liée à une plus grande variété d'activités sociales et à une plus grande solitude chez les hommes, mais pas chez les femmes, ainsi qu'à un désir moindre d'activités sociales chez les deux sexes. La verdure et la facilité de déplacement à pied ont un impact sur la participation sociale des personnes âgées. Les recherches futures devraient inclure des analyses à ce sujet basées sur le sexe et le genre.

Introduction

Population ageing is a global phenomenon, with projections indicating that by 2050, 16% of the world's population will be aged 65 years and older (United Nations, 2019). In Canada, older adults are expected to make up 25% of the total population by 2036 (Statistics Canada, 2015). As the proportion of Canadians older than 65 grows each year, it is concerning that close to a quarter of this cohort reports being socially isolated (Tam, 2017). Social isolation refers to an objective state of being alone. This can further translate into a sense of loneliness, which is a subjective state of being socially isolated regardless of any actual social contact one may have (de Jong Gierveld et al., 2006). The latter often requires individual treatment, while the former requires structural and societal intervention.

The subjective nature of loneliness makes standardizing interventions and measurement difficult (Fakoya et al., 2020). On the other hand, social isolation is easier to measure, but interventions generally conclude that only a small number are effective (Poscia et al., 2018). This is because they are labour-intensive, and not easily transferable between contexts. As such, examining social behaviour may be a more effective method to gain insight into the social health

of older adults. However, social behaviour patterns and preferences vary between older men and women (Levasseur et al., 2020; Naud et al., 2019). For example, a study on gendered employment patterns, that is, length and type of employment as dictated by gender norms, found that these patterns can contribute to differences in how older men and women engage in social behaviour (Cohn-Schwartz & Naegele, 2023). Similarly, a study found that spousal education is associated with more time spent in physical activity among women (Cohn-Schwartz & Naegele, 2023).

Social isolation among older adults can have serious consequences for health and well-being, such as depression, cardiovascular disease, reduced cognitive function, and increased risk of mortality (Cacioppo & Cacioppo, 2014; Courtin & Knapp, 2017). As such, strategies to address social isolation are imperative in the promotion of healthy, active ageing. Active ageing, that is, engagement with life through both physical activity and social participation, plays a pivotal role in fostering compressed morbidity (Fries, 1996), thereby enabling individuals to enjoy a greater number of disability-free years and better quality of life. Nonetheless, it is worth noting that not everyone achieves the optimal level of physical activity (Guthold et al., 2018) or social participation (de Koning et al., 2021) required to reap these advantages. Socioeconomic status, accessibility of resources, and community design often dictate an individual's capacity to engage in physical and social activities (Eime et al., 2015). These structural factors, along with social determinants of health such as gender, education, employment, and social support networks (Hsu et al., 2019), can significantly influence disparities in engagement, underscoring the need for an equity-focused approach that shifts blame away from the individual. For example, older women are more motivated by social interaction when choosing to pursue physical activity than men are (Van Uffelen et al., 2017), while men prefer one-to-one activities (Windt et al., 2023). Both need to be considered in large-scale interventions to address active ageing.

The inter-relationship between physical activity and social participation has been discussed in the context of healthy ageing (Dogra et al., 2022). It is suggested that there may be a bidirectional association such that physical activity, or lack thereof, often includes social activity (e.g. walking with a friend, or sedentary social activities such as Bingo), and social activities often require physical activity (e.g. incidental physical activity from going to senior's centre to play cards) or adequate physical function (e.g. being mobile enough to meet with friends) (Lindsay Smith et al., 2017). Unfortunately, the vast majority of studies aimed at understanding how to improve physical activity and sedentary time in older adults have not leveraged this association with social participation (Douglas et al., 2017). Similarly, research interventions aimed at reducing social isolation may have had limited success in specific populations because they are aimed at addressing individual factors such as income (Menec et al., 2019) but rarely consider behaviours such as physical activity. Importantly, approaches involving educational or psychological components and group interventions have been found to yield greater effectiveness compared to one-on-one interventions (Fakoya et al., 2020; Poscia et al., 2018), emphasising the point that to impact active ageing, we cannot simply focus on individual behaviour change.

Using the social–ecological approach, which recognizes that individuals are embedded within contexts which include relationships, community environments, and societal structures that shape their behaviours (de Koning et al., 2021), another gap that may be limiting our success with intervening in social isolation in older adults pertains to the neighbourhood environment. From research on physical activity, it is well established that characteristics such as greenness and walkability significantly impact movement and health among older adults (Chaudhury et al., 2016; Crouse et al., 2017; Klicnik et al., 2021) and that the environment moderates the relationship between physical activity and health (Putman et al., 2023). There is some evidence to suggest that the neighbourhood also influences mental health outcomes among older adults. For example, in a study of 270 community-dwelling older adults, path analysis revealed that active living can lead to better mental health, but this relationship is mediated by a sense of connectedness and solidarity within a group, commonly known as neighbourhood cohesion (Gan et al., 2022). This suggests that there may also be an effect of neighbourhood characteristics on social participation outcomes through engagement in regular physical activity. A prominent example of this was shown in a study of perceived neighbourhood greenness, where recreational walking *and* social connectedness in areas of higher perceived greenness were associated with improved mental health (Sugiyama et al., 2008). Another study, which looked at objectively measured neighbourhood greenness and walkability, and self-rated mental health among other outcomes (n=15339), found that self-rated mental health was higher among those living in areas of higher greenness. Due to the known associations between mental health and social participation (Mackenzie & Abdulrazaq, 2021), these findings necessitate a more nuanced exploration of how various aspects of the living environment contribute to social engagement while considering physical activity engagement.

To conceptualize this work, we used a simple framework which shows that social participation is influenced by the living environment, and both of these are impacted by a multitude of factors. Figure 1 illustrates this framework and alludes to the potential mechanistic links between the living environment and social participation. The purpose of this study, therefore, was to explore the relationship between neighbourhood characteristics and social participation outcomes using this framework in a sample of community-dwelling older adults, as their living environment is more variable than those living in congregate or assisted living settings. Specifically, we investigated associations of neighbourhood greenness, and walkability, with social participation outcomes in older adults. Based on the framework and previous research, we hypothesized that regardless of greenness and walkability, older women would report higher social participation (Cohn-Schwartz & Naegele, 2023; Levasseur et al., 2020; Naud et al., 2019), while older men would report more social participation in neighbourhoods with lower walkability but higher greenness (Klicnik et al., 2021). We also hypothesized that physical activity and social participation would be highly correlated, and that this would differ between males and females (Lindsay Smith et al., 2017; Van Uffelen et al., 2017; Windt et al., 2023).

Methods

Data source and participants

The Canadian Longitudinal Study on Aging (CLSA) is a nationally representative, stratified random sample of Canadian adults (n=51 388 at baseline), aged 45–85 years at baseline (2011-2015). The purpose of the CLSA is to track individuals at three-year intervals to understand the ageing process using a comprehensive battery of questions and measures. The sample is comprised of a Tracking cohort (n=21 000) and a Comprehensive cohort (n=30 000), with the latter participating in in-home interviews and physical

https://doi.org/10.1017/S0714980824000369 Published online by Cambridge University Press

assessments in addition to the questionnaires completed by the entire sample. Follow-up data are collected every three years. The present study uses data from baseline (2011-2015) and from the first follow-up (2015-2018, dataset versions 4.1 and 3.0). Participants have been linked by a 3-character forward sortation area with measurements of the Canadian Active Living Environment [Can-ALE] and Normalized Difference Vegetation Index from the Canadian Urban Environmental Health Research Consortium (Brook et al., 2018).

Participants randomly selected by telephone across all 10 provinces comprised the tracking cohort, while the comprehensive cohort included participants from 7 provinces living within 25-50 km of 11 data collection sites. Individuals residing in the territories, on reserves, or those who are in the armed forces were not eligible to participate. Full details on participants, sampling strategy, and study protocol have been published in previous work (Raina et al., 2019). Only participants aged 65 or older, who had the same postal code during the follow-up period were included.

The protocol of the CLSA has been reviewed and approved by 13 research ethics boards across Canada. Changes to the CLSA protocol are reviewed annually, and written consent is obtained from all participants. The Ontario Tech University Research Ethics Board approved secondary analysis of the CLSA dataset (REB # 16480).

Outcome variables

1. **Total physical activity (at follow-up)** – This variable was derived from a modified version of the Physical Activity Scale for the Elderly (PASE), a retrospective questionnaire used to collect information on movement behaviour. The PASE was developed for a community-dwelling population, with good test-retest reliability (Washburn et al., 1993). Participants were asked how many times in the past 7 days they took part in light, moderate, and strenuous activity, exercise, or walking. Response options included: 1-never, 2-seldom (1-2 days), 3-sometimes (3-4 days), and 4-often (5-7 days). For each of the 5 intensities, they were also asked how many hours per day they spent for each movement (less than 30 mins, 30 minutes but less than 1 hour, 1 hour but less than 2 hours, 2 hours but less than 4 hours, and 4 hours or more). To calculate total physical activity, the number of days was multiplied by the number of minutes (converted from the midpoint of each category) to arrive at total weekly minutes of physical activity, then divided by 60 to yield a count of total hours of physical activity per week.
2. **Social Participation (at follow-up):** Three variables were used to assess social participation. First, variety of weekly social activities was calculated from the question that asked, 'In the past 12 months, how often did you participate in activities with family and friends out of the household, religious activities, clubs or fraternal organization activities, educational or cultural activities, association activities, other recreational activities, sports or physical activities with others, and volunteer or charity work.' Response options were on a 5-point ordinal scale (1-at least once a day, 2-at least once a week, 3-at least once a month, 4-at least once a year, and 5-never). Those who responded 'at least once a day' or 'at least once a week' were given a score of 1; those who responded with other response options were coded as 0. Responses (1 or 0) for each of the 8 questions were summed to create a score of 0-8. Second, loneliness was assessed using the question "How often do you feel lonely?" with a 4-point Likert scale (1-rarely or never, 2-some of the time, 3-occasionally, and 4- every day). Finally, to understand the desire for more social activity, participants were asked 'In the past 12 months, have you felt like you wanted to participate in more social, recreational, or group activities?'. Response options were yes or no.

Exposure variables: Walkability and greenness (at baseline)

Walkability

The Canadian Active Living environments (Can-ALE, from CANUE) index is a measure of intersection density, dwelling density, and points of interest (Ross et al., 2018). The index captures what is colloquially referred to as 'walkability.' The index assigns a ranking of favourability of the environment from 1 to 5, corresponding to very low, low, moderate, high, or very high favourability. The Can-ALE measures for 2016 were derived from 1 km circular buffers based on dissemination areas from Statistics Canada. A cluster analysis (k-medians approach) was performed to assign each dissemination area to one of the 5 levels described above (Ross et al., 2018). The Can-ALE specifically, and community walkability in general, have been correlated with physical activity levels (Klicnik et al., 2021), and social participation (Levasseur et al., 2015) among older adults. Due to a limited number of CLSA participants living in high or very high-ranked neighbourhoods, these groups were collapsed to create a total of 4 levels of Can-ALE.

Greenness

The mean of annual mean Normalized Difference Vegetation Index (NDVI) within a 500 m buffer for 2011 and 2013 was used to evaluate greenness in participant neighbourhoods (*CanMap Postal Code Suite* v2015.3. *[computer file] DMTI Spatial Inc.*, 2015; Gorelicket al. 2017; Landsat 5 TM Annual Greenest-Pixel TOA Reflectance Composite, 1984-2012; Landsat 8 Annual Greenest-Pixel TOA Reflectance Composite, 2013-2015; USGS Landsat 5 TM TOA Reflectance (Orthorectified) & 2011 (n.d.); USGS Landsat 8 TOA Reflectance (Orthorectified) n.d.). The NDVI is the most used metric for green vegetation on the ground (Crouse et al., 2017) and uses a scale of 0 to 1 to identify areas of barrenness or water (values closer to 0) and dense vegetation (values closer to 1). Buffers between 500 and 1000 m are the most commonly used for health research (Browning & Lee, 2017). Greenness values are typically presented as quartiles specific to each data set.

Covariates

Self-reported sex was reported as male or female. Household income was reported in categories of <$20,000, $20,000-$50, 000, $50, 000-$100, 000, $100, 000-$150, 000, and >$150, 000. Highest levels of personal education were reported in 11 categories (<Grade 8, Grade 9 or 10, Grades 11 to 13, High school Graduate, Some Post-Secondary, Trade Certificate/Diploma, College/CEGEP Diploma, University Non-Degree Certificate, Bachelor's Degree, Graduate Degree, and Other). These responses were combined to classify participants as less than secondary school graduation, secondary school graduation, no post-secondary education, some post-secondary education, or post-secondary degree/diploma.

https://doi.org/10.1017/S0714980824000369 Published online by Cambridge University Press

Statistical analysis

All statistical analysis was computed using *R* version 4.2.0 (R Core Team, 2022). Prior to imputation, categorical variables were described using counts and percentages, and continuous variables were described using means and standard deviations. Preliminary testing for the presence of associations between physical activity and each of the three social participation variables was assessed visually using plots and by calculation through Kendall's tau (variety of weekly social activities and loneliness) and Mann-Whitney U (desire for more social participation) tests. These associations were then further assessed through regression modelling, controlling for self-reported sex, household income, and education. Sample and analytic weights provided by the CLSA (Raina et al., 2019) were used.

Associations between the environmental exposures and each social participation outcome were assessed with regression modelling. Specifically, we employed Poisson regression models to examine the relationships between total physical activity, greenness, or walkability and a participant's *variety of weekly social activities*, binary logistic regression models to explore the relationships with an individuals' *desire to participate in more activities*, and ordinal logistic regression models to assess relationships with *loneliness.* Missing data (< 2.1% of analytic sample) were imputed via Multiple Imputation by Chained Equations, and all coefficient values were exponentiated into odds ratios for interpretation.

Results

Sample characteristics are presented in Table 1, with additional demographic information in Supplementary Table 1. Further descriptive analyses of physical activity hours per week for each response category are presented in Figure 2. The overall sample included 16 735 older adults. Fifty percent were female, with an average age of 73.0 ± 5.7 for females and 72.9 ± 5.6 for males. On average, total physical activity in females was 6.0 ± 6.2 hours per week compared to males who reported 7.4 ± 7.4 hours per week.

The association between physical activity and social participation variables are presented in Table 2 along with the analysis type. Results for males and females followed similar trends. All associations between physical activity and social participation variables were statistically significant, except for physical activity and loneliness for males. For the combined sample of males and females, ***each hour of increased physical activity*** was associated with a 2.4% increase in variety of social activities they participated in, a 1.6% increase in the likelihood of wanting to engage in more social activity, and 1.3% lower likelihood of rarely/never feeling lonely. Due to this association between physical activity and our outcomes, physical activity was not included in the modelling of neighbourhood characteristics and social participation outcomes.

Table 1. Sample characteristics

	Male	Female
n	8363	8372
Age (mean (SD))	72.9 (5.6)	73.0 (5.7)
Total physical activity, hours per week (mean (SD))	7.4 (7.4)	6.0 (6.2)
Variety of weekly social activities (mean (SD))	2.2 (1.7)	2.5 (1.8)
Desire for more social activities, No (%)	5523 (67.6)	5157 (63.3)
Loneliness (number (%))		
Rarely or never	6418 (79.5)	5711 (71.0)
Some of the time	835 (10.3)	1173 (14.6)
Occasionally	634 (7.9)	915 (11.4)
Everyday	181 (2.2)	244 (3.0)

Additional characteristics is presented in Suppl. Table 1

Results for the relationship between greenness, walkability, and the social participation variables are shown in Table 3. Among males, residing in the 4th quartile of *greenness* was associated with a decrease in variety of social activities (IRR = 0.935 (95%CI: 0.885, 0.987, p<0.05) and lower likelihood of reporting feeling lonely (OR = 0.715 (95%CI: 0.583, 0.877, p<0.01). There were no significant associations between greenness and any of the social participation variables among females. For *walkability*, being in the highest quartile of *walkability* was associated with higher variety of social activity (IRR = 1.080 (95%CI: 1.021, 1.141, p<0.01) and higher likelihood of reporting feeling lonely (OR = 1.405 (95%CI: 1.146, 1.722, p<0.01), and a lower likelihood of reporting a desire for more social activity among males (OR = 0.830 (95%CI: 0.698, 0.987, p<0.05). In females, there was a significant relationship across all levels of walkability, such that being in the 2nd, 3rd, or 4th quartile of walkability was associated with a decreased likelihood of desire for more social activity compared to the first quartile. Associations between walkability and loneliness were not significant for females in this sample.

Discussion

This study sought to examine whether neighbourhood characteristics are associated with social participation in older adults. We hypothesized that social participation would be associated with the neighbourhood environment with differences by sex, and that physical activity and social participation would be highly correlated. Both of our hypotheses were confirmed. First, we found sex differences in the associations between the neighbourhood environment and social participation outcomes. Specifically, it appears that greenness may be important for loneliness among older males, and that higher walkability may be more important for higher variety of social activity among older males. Among older females, walkability appears to be more important than greenness. Second, we found a consistent association between physical activity with desire for more social activity and variety of weekly social activities. These data provide large-scale quantitative evidence to support existing literature that has found associations between physical activity and social participation in smaller samples (Schrempft et al., 2019). These findings have important implications for work aimed at understanding and improving physical activity and social health among older adults, particularly with regard to how we design our neighbourhoods.

Our finding that total physical activity was related to desire for more social activity, variety of weekly social activity, and loneliness (males only) is novel as it is the first study to assess these associations using large-scale Canadian data. It is consistent with previous research linking physical activity to social participation (Decloe et al., 2009; Schrempft et al., 2019). For example, previous research on Flemish older adults (n= 50,000+) found that perceived social environment – defined as frequency of contact with neighbours, neighbourhood support and involvement, and participation – was significantly associated with higher odds of walking for

https://doi.org/10.1017/S0714980824000369 Published online by Cambridge University Press

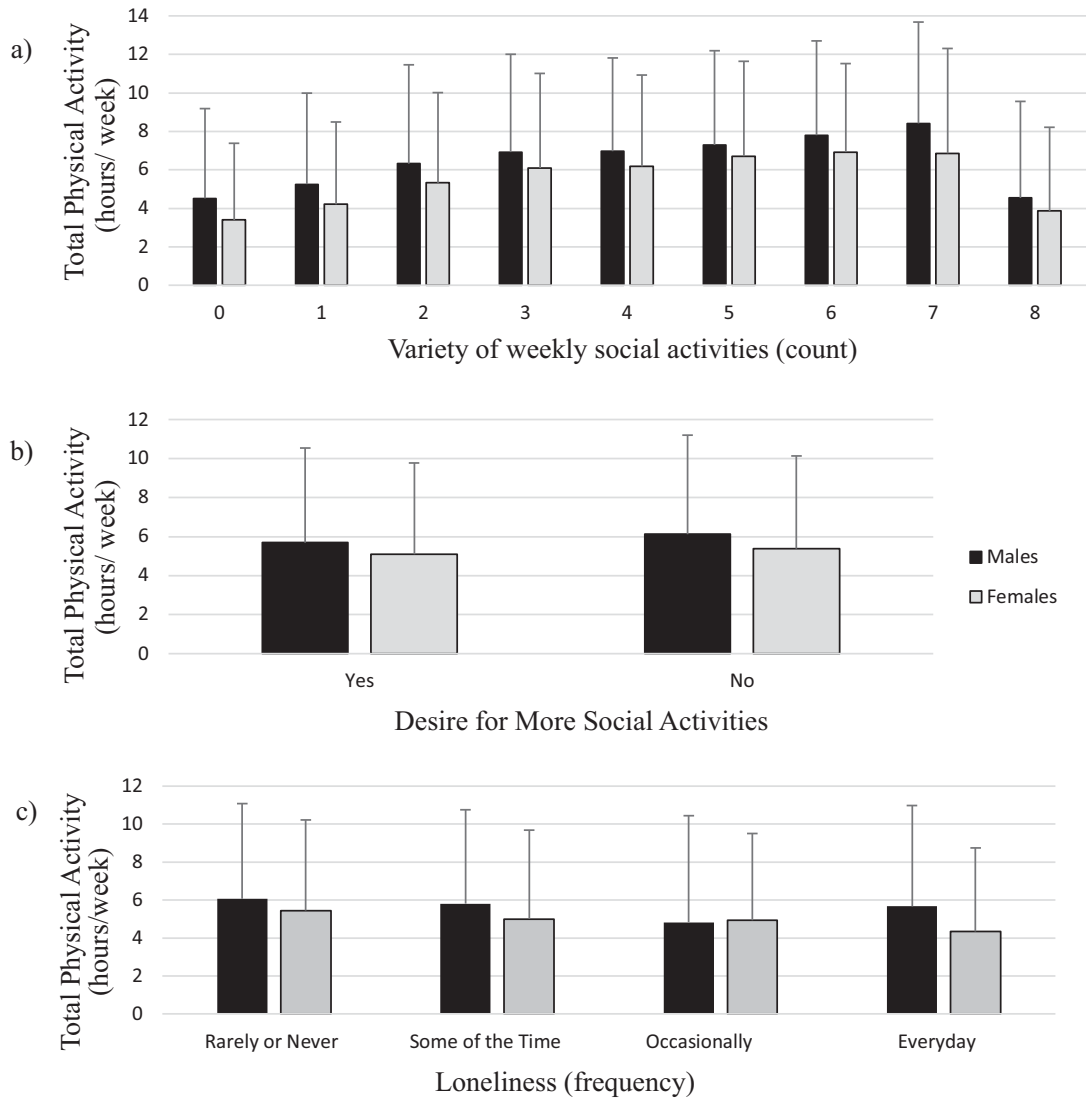

Figure 1. The *Living Environment and Active Aging Framework (LEAAF).* Characteristics of the living environment are theorized to influence movement and social behaviours separately but also influence the inter-relationship between movement and social behaviours (active ageing).

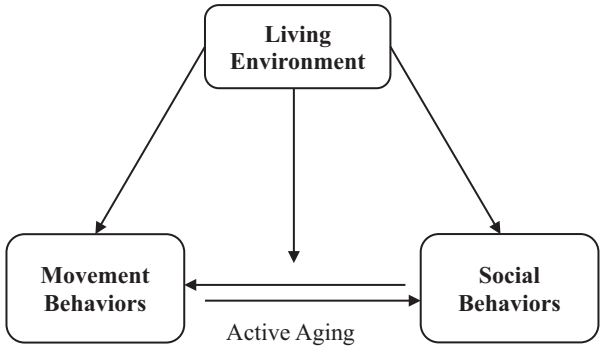

Figure 2. Mean hours of total physical activity by each social participation outcome.

transportation (Van Cauwenberg et al., 2014). Recently, in a sample of Japanese older adults (n=1925), it was found that older adults experienced reduced social contact due to COVID-19, with those reporting the largest reductions in social contact also exhibiting lower physical activity and higher sedentary behaviour levels (Otaki et al., 2022). These findings, along with ours, suggest that social participation and physical activity are strongly associated with older adults and that this association likely has a bidirectional component to it. For example, a study of Italian older adults (n=163) who participated in a 16-week dance program found significant improvements in dual-task performance *and* social engagement (Brustio et al., 2018). Thus, we recommend that future research explore the evaluation of physical activity and social participation jointly as components of a unified 'active ageing' construct, rather than treating them as distinct factors in older adults' well-being. Such an approach could offer a more comprehensive understanding of the interplay between these activities and their collective impact on the well-being of the ageing population.

Data from the analyses including walkability and greenness variables indicated that greenness may be associated with lower levels of loneliness and that walkability may be associated with higher levels of loneliness. This was an interesting finding because previous research has shown that higher walkability is associated with lower levels of deprivation within a neighbourhood or community (Sallis et al., 2012), and that a lower level of deprivation is

https://doi.org/10.1017/S0714980824000369 Published online by Cambridge University Press

Table 2. Association between physical activity and social participation variables

	Total	Males	Females
Variety of social activities[1]	1.024 (95% CI: 1.021–1.027)***	1.021 (95% CI: 1.017–1.025)***	1.026 (95% CI: 1.023–1.030)***
Desire for more social activity[2]	1.016 (95%CI: 1.007–1.025)***	1.015 (95%CI: 1.003–1.028)*	1.015 (95%CI: 1.003–1.028)*
Loneliness[3]	0.987 (95% CI: 0.977–0.997)**	0.995 (95%CI: 0.980–1.010)	0.980 (95%CI: 0.967–0.993)**

*$p<0.05$
**$p<0.01$
***$p<0.000$
[1]*Poisson regression*
[2]*logistic regression*
[3]*ordinal logistic regression.*

Table 3. Associations between neighborhood factors and social participation outcomes.

	Variety of social activity (Poisson regression, *IRR*)		Desire for more activity (Logistic regression, OR)		Loneliness (Ordinal logistic regression, *OR*)	
	Male	Female	Male	Female	Male	Female
Greenness						
2nd	0.965 (0.912, 1.021)	1.025 (0.977, 1.076)	1.043 (0.873, 1.245)	0.933 (0.798, 1.090)	0.945 (0.773, 1.156)	0.907 (0.770, 1.068)
3rd	0.954 (0.903, 1.008)	0.999 (0.952, 1.049)	1.036 (0.870, 1.233)	1.048 (0.895, 1.227)	0.747 (0.608, 0.919)**	0.948 (0.804, 1.117)
4th	0.935 (0.885, 0.987)*	0.979 (0.931, 1.029)	1.093 (0.920, 1.299)	1.109 (0.944, 1.302)	0.715 (0.583, 0.877)**	0.873 (0.737, 1.035)
Walkability						
2nd	1.063 (1.009, 1.120)*	1.048 (0.998, 1.100)	0.900 (0763, 1.061)	0.758 (0.647, 0.889)**	1.138 (0.931, 1.390)	1.102 (0.932, 1.303)
3rd	1.081 (1.025, 1.140)**	1.059 (1.008, 1.112)*	0.955 (0.806, 1.130)	0.674 (0.575, 0.790)***	1.143 (0.932, 1.402)	1.081 (0.914, 1.279)
4th	1.080 (1.021, 1.141)**	1.026 (0.976, 1.079)	0.830 (0.698, 0.987)*	0.689 (0.586, 0.810)***	1.405 (1.146, 1.722)**	1.125 (0.949, 1.334)

Fully adjusted models (age, household income, education), Poisson and ordinal logistic regression coefficients have been exponentiated to IRRs and ORs above.
*$p<0.05$
**$p<0.01$
***$p<0.001$.

associated with a lower prevalence loneliness (Victor & Pikhartova, 2020). Similarly, though greenness is sometimes higher in rural areas, it is not a proxy for rurality, which means that higher greenness in urban (less deprived) areas is also important for loneliness. However, the mechanistic pathways to this association need further exploration. For example, neighbourhood greenness may be protective against harm from environmental exposures associated with urban living (Browning et al., 2022). Nevertheless, walkability was also associated with lower desire for more social activities, indicating that perhaps a more walkable neighbourhood provides greater opportunity for participation. This is consistent with previous research which has shown that older adults living in more walkable neighbourhoods experience more incidental social interaction due to their time spent mobilizing around their neighbourhoods (Van Holle et al., 2016). It is important to note however, that we found some interesting sex differences in these associations.

In our sample, older females living in highly walkable neighbourhoods were less likely to report the desire for more social activities, indicating that perhaps there was an alignment between available activities and their preferences, or that older females are resourceful and motivated to find the social activities they enjoy. There was a smaller association for males, and only at the highest levels of walkability. Furthermore, for older males, higher greenness and lower walkability were associated with a lower likelihood of reporting feeling lonely. These data suggest that age-friendly neighbourhood design must take a sex and gender-responsive approach to ensure the health and engagement of all older adults. These findings are also in line with previous research from older males and females that indicates the presence of sex differences in activity preference. For example, while males may be more likely to participate in outdoor activities such as golf and gardening, females may be more likely to participate in indoor activities such as yoga and aerobic dancing (Li et al., 2017). A key limitation of our analysis, therefore, was that information on indoor vs. outdoor activity was not assessed. This may have impacted our findings especially for females, who may prefer to be active indoors (Li et al., 2017) and as such, may not be as impacted by the presence of greenness, especially if they choose to drive to the indoor locations where they carry out social activity.

This study has some notable strengths and limitations. The large national sample with longitudinal data (exposures from baseline; physical activity and social participation outcomes from follow-up (3 years apart)) and the link to objective environmental data was a major strength. To our knowledge, this is also the first study of the relationship between neighbourhood factors, physical activity, and social participation in the Canadian context. One of the primary limitations of this study is the reliance on self-reported measures of physical and social activity. For example, the self-reported PASE scale was used as the primary measure of physical activity in this study, as device-based measures of physical activity were not available at baseline or at first follow-up in the CLSA. While the PASE scale has been validated in older adults (Washburn et al., 1993), there are known limitations to using self-report without the corroboration of objective measures or observation (Welk et al., 2023). Additionally, although NDVI was used to measure greenness in this study, it does not distinguish between recreational spaces

https://doi.org/10.1017/S0714980824000369 Published online by Cambridge University Press

and dense, unusable vegetation, suggesting a need for a more nuanced analysis of greenspace. Since most people carry out only part of their social and physical activities within their neighbourhood (Browning & Lee, 2017), we cannot assume that objective neighbourhood data is spatially matched to their behaviour patterns with total accuracy. However, the presence of these associations across such a varied geographical area as Canada is indicative of the need for further research into these associations at larger buffer sizes.

Another limitation of this analysis is our reliance on self-reported sex to gauge gender identity and expression, which unfortunately are not captured adequately in the CLSA. Specifically, it is possible that for social outcomes, gender plays a vital role such that gender norms affect behaviour. Gendered roles may have outsized effects on socializing along gender lines beyond what sex differences would indicate. To illustrate, research indicates that older females tend to report having larger social networks (Hosseini et al., 2020). However, it remains plausible that older males also desire extensive social engagement, but societal expectations of masculine behaviour could potentially hinder them from actively pursuing such social connections (McKenzie et al., 2018). Thus, future research using gender is needed to better understand how we can encourage active ageing by creating more inclusive communities.

In conclusion, we found that the observed associations between neighbourhood factors and social activity differ by sex. Neighbourhood greenness is associated with loneliness in older males but not in older females, while walkability appears to be more relevant for females in terms of variety of social activity. Our findings highlight the need for sex and gender-based analyses in active ageing research beyond sex stratification. It is crucial for researchers to extend inclusivity by incorporating more nuanced sex and gender-based analysis, better acknowledge the role of culture and countries, and fully understand and support the unique needs of older adults. Overall, these findings can help researchers to better understand the mechanisms by which our environment shapes our health, by considering social participation along with physical activity when developing interventions. Further research of this nature is also needed with equity-seeking populations, and people with varying health status, to address the disparities between neighborhoods in the pursuit of active ageing for all people.

Supplementary material. The supplementary material for this article can be found at http://doi.org/10.1017/S0714980824000369.

Acknowledgements. This research was made possible using the data/biospecimens collected by the Canadian Longitudinal Study on Aging (CLSA). Funding for the Canadian Longitudinal Study on Aging (CLSA) is provided by the Government of Canada through the Canadian Institutes of Health Research (CIHR) under grant reference: LSA 94473 and the Canada Foundation for Innovation, as well as the following provinces, Newfoundland, Nova Scotia, Quebec, Ontario, Manitoba, Alberta, and British Columbia. This research has been conducted using the CLSA Tracking Baseline V3.5, Comprehensive Baseline V4.1, Tracking Follow up 1 V2.1, and Comprehensive Follow up 1 V3.0 under Application Number 20CA011. The CLSA is led by Drs. Parminder Raina, Christina Wolfson and Susan Kirkland.

The Normalized Difference Vegetation Index and the Canadian Active Living Environments z-scores (Can-ALE), indexed to DMTI Spatial Inc. postal codes were provided by CANUE (Canadian Urban Environmental Health Research Consortium, www.canue.ca).

Financial support. This research was supported by the Social Sciences and Humanities Research Council (SSHRC).

References

Brook, J. R., Setton, E. M., Seed, E., Shooshtari, M., Doiron, D., & Consortium, C. T. C. U. E. H. R. (2018). The Canadian Urban Environmental Health Research Consortium - a protocol for building a national environmental exposure data platform for integrated analyses of urban form and health. *BMC Public Health*, **18**(1), 114. https://doi.org/10.1186/s12889-017-5001-5

Browning, M., & Lee, K. (2017). Within what distance does "greenness" best predict physical health? A systematic review of articles with GIS buffer analyses across the lifespan. *International Journal of Environmental Research and Public Health*, **14**(7), 675. https://doi.org/10.3390/ijerph14070675

Browning, M. H., Rigolon, A., & McAnirlin, O. (2022). Where greenspace matters most: A systematic review of urbanicity, greenspace, and physical health. *Landscape and Urban Planning*, **217**, 104233.

Brustio, P. R., Liubicich, M. E., Chiabrero, M., & Rabaglietti, E. (2018). Dancing in the golden age: A study on physical function, quality of life, and social engagement. *Geriatric Nursing*, **39**(6), 635–639.

Cacioppo, J. T., & Cacioppo, S. (2014). Older adults reporting social isolation or loneliness show poorer cognitive function 4 years later. *Evidence-Based Nursing*, **17**(2), 59–60. https://doi.org/10.1136/eb-2013-101379

CanMap Postal Code Suite v2015.3. *[computer file] DMTI Spatial Inc.* In. (2015).

Chaudhury, H., Campo, M., Michael, Y., & Mahmood, A. (2016). Neighbourhood environment and physical activity in older adults. *Social Science & Medicine*, **149**, 104–113. https://doi.org/10.1016/j.socscimed.2015.12.011

Cohn-Schwartz, E., & Naegele, L. (2023). *Employment over the life course and post-retirement social networks: A gendered perspective*. International Psychogeriatrics, 1–11.

Courtin, E., & Knapp, M. (2017). Social isolation, loneliness and health in old age: A scoping review. *Health & Social Care In the Community*, **25**(3), 799–812.

Crouse, D. L., Pinault, L., Balram, A., Hystad, P., Peters, P. A., Chen, H., van Donkelaar, A., Martin, R. V., Menard, R., Robichaud, A., & Villeneuve, P. J. (2017). Urban greenness and mortality in Canada's largest cities: A national cohort study. *Lancet Planet Health*, **1**(7), e289–e297. https://doi.org/10.1016/S2542-5196(17)30118-3

de Jong Gierveld, J., Van Tilburg, T., & Dykstra, P. A. (2006). *Loneliness and social isolation*. In *Cambridge handbook of personal relationships*. Cambridge University Press. 485–500.

de Koning, J., Richards, S. H., Wood, G. E. R., & Stathi, A. (2021). Profiles of loneliness and social isolation in physically active and inactive older adults in rural England. *International Journal of Environmental Research and Public Health*, **18**(8), 3971. https://doi.org/10.3390/ijerph18083971

Decloe, M. D., Kaczynski, A. T., & Havitz, M. E. (2009). Social participation, flow and situational involvement in recreational physical activity. *Journal of Leisure Research*, **41**(1), 73–90. https://doi.org/10.1080/00222216.2009.11950160

Dogra, S., Dunstan, D. W., Sugiyama, T., Stathi, A., Gardiner, P. A., & Owen, N. (2022). Active aging and public health: Evidence, implications, and opportunities. *Annual Review of Public Health*, **43**(1), 439–459. https://doi.org/10.1146/annurev-publhealth-052620-091107

Douglas, H., Georgiou, A., & Westbrook, J. (2017). Social participation as an indicator of successful aging: An overview of concepts and their associations with health. *Australian Health Review*, **41**(4), 455–462.

Eime, R. M., Charity, M. J., Harvey, J. T., & Payne, W. R. (2015). Participation in sport and physical activity: Associations with socio-economic status and geographical remoteness. *BMC Public Health*, **15**, 1–12.

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

Fries, J. F. (1996). Physical activity, the compression of morbidity, and the health of the elderly. *Journal of the Royal Society of Medicine*, **89**(2), 64–68.

Gan, D. R. Y., Cheng, G. H. L., Ng, T. P., Gwee, X., Soh, C. Y., Fung, J. C., & Cho, I. S. (2022). Neighborhood makes or breaks active ageing? Findings from Cross-sectional path analysis. *International Journal of Environmental Research and Public Health*, **19**(6), 3695. https://doi.org/10.3390/ijerph19063695

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment*, **202**, 18–27. https://doi.org/10.1016/j.rse.2017.06.031

Guthold, R., Stevens, G. A., Riley, L. M., & Bull, F. C. (2018). Worldwide trends in insufficient physical activity from 2001 to 2016: A pooled analysis of 358 population-based surveys with 1.9 million participants. *Lancet Glob Health*, **6**(10), e1077–e1086. https://doi.org/10.1016/S2214-109X(18)30357-7

Hosseini, Z., Veenstra, G., Khan, N. A., & Conklin, A. I. (2020). Associations between social connections, their interactions, and obesity differ by gender: A population-based, cross-sectional analysis of the Canadian longitudinal study on aging. *PloS One*, **15**(7), e0235977. https://doi.org/10.1371/journal.pone.0235977&type=printable

Hsu, H.-C., Liang, J., Luh, D.-L., Chen, C.-F., & Wang, Y.-W. (2019). Social determinants and disparities in active aging among older Taiwanese. *International Journal of Environmental Research and Public Health*, **16**(16), 3005.

Klicnik, I., Cullen, J. D., Doiron, D., Barakat, C., Ardern, C. I., Rudoler, D., & Dogra, S. (2021). Leisure sedentary time and physical activity are higher in neighbourhoods with denser greenness and better built environments: An analysis of the Canadian Longitudinal Study on Aging. *Applied Physiology, Nutrition, and Metabolism*, **47**(3), 278–286. https://doi.org/10.1139/apnm-2021-0438

Landsat 5 TM Annual Greenest-Pixel TOA Reflectance Composite. (1984-2012). Retrieved July from https://explorer.earthengine.google.com/#detail/LANDSAT%2FLT5_L1T_ANNUAL_GREENEST_TOA

Landsat 8 Annual Greenest-Pixel TOA Reflectance Composite. (2013-2015). Retrieved July from https://explorer.earthengine.google.com/#detail/LANDSAT%2FLC8_L1T_ANNUAL_GREENEST_TOA

Levasseur, M., Généreux, M., Bruneau, J.-F., Vanasse, A., Chabot, É., Beaulac, C., & Bédard, M.-M. (2015). Importance of proximity to resources, social support, transportation and neighborhood security for mobility and social participation in older adults: results from a scoping study. *BMC Public Health*, **15**(1), 503–503. https://doi.org/10.1186/s12889-015-1824-0

Levasseur, M., Naud, D., Bruneau, J.-F., & Généreux, M. (2020). Environmental characteristics associated with older adults' social participation: The contribution of sociodemography and transportation in metropolitan, urban, and rural areas. *International Journal of Environmental Research and Public Health*, **17**(22), 8399. https://doi.org/10.3390/ijerph17228399

Li, W., Churchill, L., Procter-Gray, E., Kane, K., Cheng, J., Clarke, A., & Ockene, J. (2017). Sex differences in physical activity among older adults living in urban and rural neighborhoods. Innovation in Aging, **1**(suppl_1), 1092–1092. https://doi.org/10.1093/geroni/igx004.4005

Lindsay Smith, G., Banting, L., Eime, R., O'Sullivan, G., & van Uffelen, J. G. Z. (2017). The association between social support and physical activity in older adults: A systematic review. *The International Journal of Behavioral Nutrition and Physical Activity*, **14**(1), 56–56. https://doi.org/10.1186/s12966-017-0509-8

Mackenzie, C. S., & Abdulrazaq, S. (2021). Social engagement mediates the relationship between participation in social activities and psychological distress among older adults. *Aging & Mental Health*, **25**(2), 299–305. https://doi.org/10.1080/13607863.2019.1697200

McKenzie, S. K., Collings, S., Jenkin, G., & River, J. (2018). Masculinity, social connectedness, and mental health: Men's diverse patterns of practice. *American Journal of Men's Health*, **12**(5), 1247–1261. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6142169/pdf/10.1177_1557988318772732.pdf

Menec, V. H., Newall, N. E., Mackenzie, C. S., Shooshtari, S., & Nowicki, S. (2019). Examining individual and geographic factors associated with social isolation and loneliness using Canadian Longitudinal Study on Aging (CLSA) data. *PLoS One*, **14**(2), e0211143. https://doi.org/10.1371/journal.pone.0211143

Naud, D., Généreux, M., Bruneau, J.-F., Alauzet, A., & Levasseur, M. (2019). Social participation in older women and men: differences in community activities and barriers according to region and population size in Canada. *BMC Public Health*, **19**(1), 1124–1124. https://doi.org/10.1186/s12889-019-7462-1

Otaki, N., Yokoro, M., Yano, M., Imamura, T., Akita, M., Tanino, N., & Fukuo, K. (2022). Social contact impacts physical activity and sedentary behavior among older adults in Japan due to COVID-19. *BMC Geriatrics*, **22**(1), 491–491. https://doi.org/10.1186/s12877-022-03188-z

Poscia, A., Stojanovic, J., La Milia, D. I., Duplaga, M., Grysztar, M., Moscato, U., Onder, G., Collamati, A., Ricciardi, W., & Magnavita, N. (2018). Interventions targeting loneliness and social isolation among the older people: An update systematic review. *Experimental gerontology*, **102**, 133–144.

Putman, A., Klicnik, I., & Dogra, S. (2023). Neighbourhood greenness moderates the association between physical activity and geriatric-relevant health outcomes: An analysis of the CLSA. *BMC Geriatrics*, **23**(1), 317.

R Core Team. (2022). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing. https://www.R-project.org/

Raina, P., Wolfson, C., Kirkland, S., Griffith, L. E., Balion, C., Cossette, B., Dionne, I., Hofer, S., Hogan, D., van den Heuvel, E. R., Liu-Ambrose, T., Menec, V., Mugford, G., Patterson, C., Payette, H., Richards, B., Shannon, H., Sheets, D., Taler, V., … Young, L. (2019). Cohort profile: The Canadian Longitudinal Study on Aging (CLSA). *International Journal of Epidemiology*, **48**(6), 1752–1753j. https://doi.org/10.1093/ije/dyz173

Ross, N., Wasfi, R., Herrmann, T., & Gleckner, W. (2018). *Canadian Active Living Environments Database (Can-ALE) user manual & technical document*. Geo-Social Determinants of Health Research Group, Department of Geography, McGill University.

Sallis, J. F., Floyd, M. F., Rodríguez, D. A., & Saelens, B. E. (2012). Role of built environments in physical activity, obesity, and cardiovascular disease. *Circulation*, **125**(5), 729–737.

Schrempft, S., Jackowska, M., Hamer, M., & Steptoe, A. (2019). Associations between social isolation, loneliness, and objective physical activity in older men and women. *BMC Public Health*, **19**(1), 74. https://doi.org/10.1186/s12889-019-6424-y

Statistics Canada. (2015). Population count and population growth in Canada. Retrieved from https://www150.statcan.gc.ca/n1/pub/91-520-x/2010001/aftertoc-aprestdm1-eng.htm

Sugiyama, T., Leslie, E., Giles-Corti, B., & Owen, N. (2008). Associations of neighbourhood greenness with physical and mental health: do walking, social coherence and local social interaction explain the relationships? *Journal of Epidemiology & Community Health*, **62**(5), e9–e9.

Tam, T. (2017). The chief public health officer's report on the state of public health in Canada 2017: Designing healthy living. Retrieved from https://www.canada.ca/content/dam/phac-aspc/documents/services/publications/chief-public-health-officer-reports-state-public-health-canada/2017-designing-healthy-living/PHAC_CPHO-2017_Report_E.pdf

United Nations. (2019). World population prospects 2019: Highlights. Department of Economic and Social Affairs (DESA). https://population.un.org/wpp/Publications/Files/WPP2019_10KeyFindings.pdf

USGS Landsat 5 TM TOA Reflectance (Orthorectified) & 2011. (n.d.) Retrieved July from https://explorer.earthengine.google.com/#detail/LANDSAT%2FLT5_L1T_TOA

USGS Landsat 8 TOA Reflectance (Orthorectified). (n.d.) Retrieved July from https://explorer.earthengine.google.com/#detail/LANDSAT%2FLC8_L1T_TOA

Van Cauwenberg, J., De Donder, L., Clarys, P., De Bourdeaudhuij, I., Buffel, T., De Witte, N., Dury, S., Verte, D., & Deforche, B. (2014). Relationships between the perceived neighborhood social environment and walking for transportation among older adults. *Social Science & Medicine*, **104**, 23–30. https://doi.org/10.1016/j.socscimed.2013.12.016

Van Holle, V., Van Cauwenberg, J., De Bourdeaudhuij, I., Deforche, B., Van de Weghe, N., & Van Dyck, D. (2016). Interactions between neighborhood social environment and walkability to explain belgian older adults' physical activity and sedentary time. *International Journal of Environmental Research and Public Health*, **13**(6), 569. https://doi.org/10.3390/ijerph13060569

Van Uffelen, J. G., Khan, A., & Burton, N. W. (2017). Gender differences in physical activity motivators and context preferences: A population-based study in people in their sixties. *BMC Public Health*, **17**, 1–11.

Victor, C. R., & Pikhartova, J. (2020). Lonely places or lonely people? Investigating the relationship between loneliness and place of residence. *BMC Public Health*, **20**(1), 1–12.

Washburn, R. A., Smith, K. W., Jette, A. M., & Janney, C. A. (1993). The Physical Activity Scale for the Elderly (PASE): Development and evaluation. *Journal of Clinical Epidemiology*, **46**(2), 153–162. https://doi.org/10.1016/0895-4356(93)90053-4

Welk, G., Lamoureux, N. R., Zeng, C., Zhu, Z., Berg, E., Wolff-Hughes, D. L., & Troiano, R. P. (2023). Equating NHANES monitor based physical activity to self-reported methods to enhance ongoing surveillance efforts. *Medicine and*

Science in Sports and Exercise, *Publish Ahead of Print*. https://doi.org/10.1249/MSS.0000000000003123

Windt, S., Sims-Gould, J., Mackey, D. C., & McKay, H. (2023). Older mens' experiences with and preferences for physical activity. *Canadian Journal on Aging/La Revue canadienne du vieillissement*, **42**(4), 576–590. https://www.cambridge.org/core/services/aop-cambridge-core/content/view/9AF2824AB75EDF26349C66D9D3B57E90/S0714980823000211a.pdf/div-class-title-older-mens-experiences-with-and-preferences-for-physical-activity-div.pdf

https://doi.org/10.1017/S0714980824000369 Published online by Cambridge University Press