Change in GPS-assessed walking locations following a cluster-randomized controlled physical activity trial in older adults, results from the MIPARC trial

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Abstract

This study employed novel GPS methods to assess the effect of a multilevel physical activity (PA) intervention on device-measured walking locations in 305 community dwelling older adults, ages 65+ (mean age = 83, 73% women). Retirement communities were randomized to a 1-year PA intervention that encouraged neighborhood walking, or to a healthy aging control condition. Total time and time spent walking in four life-space domains were assessed using GPS and accelerometer devices. The intervention increased the time spent walking as a proportion of total time spent in the Campus, Neighborhood and Beyond Neighborhood domains. Intervention effects on walking location were observed in both genders and across physical and cognitive functioning groups. Results demonstrate that an intervention providing individual, social and environmental support for walking can increase PA in larger life-space domains for a broad spectrum of older adults.

Keywords

Aging; GPS; Life-space; Mobility patterns; Exercise/physical activity; Intervention

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1. Background

There is much interest in understanding the mobility patterns of older adults and developing interventions that can maintain health and independence across aging populations (Johnson et al., 2020; Matthews and Yang, 2013; Shareck et al., 2014; Taylor et al., 2019). Life-space and activity space measures describe the frequency and degree to which individuals move between geographically distinct domains that extend from within one's home to beyond the neighborhood in which they live and have been related to mobility, physical activity (PA), falls, physical and cognitive function, nursing home admissions, and mortality in older adults (Baker et al., 2003; Hirsch et al., 2016; James et al., 2011; Johnson et al., 2020; Mackey et al., 2016; 2014; May et al., 1985; Peel et al., 2005; Portegijs et al., 2015; Schenk et al., 2011; Stalvey et al., 1999a; Takemoto et al., 2015; Taylor et al., 2019; H.-W Wahl et al., 2013). A larger life-space could also lead to more time spent outdoors, which has been linked to reduced loneliness, depressive symptoms, and fear of falling, as well as greater autonomy, PA and physical functioning (Abraham et al., 2010; Kerr et al., 2012a, 2012c; Portegijs et al., 2014; Rantakokko et al., 2014; Van Dyck et al., 2012). Globally, the older adult population is expected to double by 2050 (World Population Ageing, 2019 Highlights, 2019). Given this growth, PA interventions that target mobility in larger life-spaces could provide a valuable strategy to maintain health and autonomy in aging adults.

Retirement communities are an important housing option for the older adult population. Their campuses provide an additional life-space domain that allows residents to safely walk in well-maintained areas, without being exposed to neighborhood hazards outside of the property (Kerr et al., 2011). Most older adults, however, prefer to walk for a purpose and to a destination as opposed to simply walking for exercise (Winters et al., 2014; Yen IH, Shim JK, 2012) and walkable neighborhoods can support such purposeful activity (King et al., 2011). Life-space is typically assessed by self-report, though recent studies have successfully used mobile devices, like accelerometers and GPS, to measure life-space and out of home mobility objectively (Fillekes et al., 2019; Hirsch et al., 2016; 2014; Jansen et al., 2018; Liddle et al., 2014; Schenk et al., 2011; Shoval et al., 2011; Tsai et al., 2015; H.W. Wahl et al., 2013; Wan et al., 2013). Modifiable factors associated with life-space have been identified (Kuspinar et al., 2020) and studies have examined how the walkability of environments can moderate the effectiveness of PA interventions (Consoli et al., 2020; Kerr et al., 2010; Lo et al., 2019; Perez et al., 2018). However, no study has used validated GPS methods to investigate whether a PA intervention promoting neighborhood walking can increase walking in larger life-space domains.

The purpose of this study was to use accelerometer and GPS data from the Multilevel Intervention for Physical Activity in Retirement Communities (MIPARC) study to assess both the total time and *walking* time in four life-space domains (Home, Retirement Community Campus, Neighborhood, Beyond Neighborhood) in a 1-year PA intervention delivered in retirement communities. Since the ability to drive and access to transportation are strongly associated with larger life-spaces (Fillekes et al., 2019; Kuspinar et al., 2020; Shah et al., 2012), it is important to differentiate between active and passive (i.e. as a vehicle driver or passenger) time in different life-space domains. Previous findings from this cohort detected a significant increase and less decline in PA among the intervention group over time

(Kerr et al., 2018). Since the intervention encouraged campus and neighborhood walking, we hypothesized that participants spent less time walking at home and more time walking in further life-space domains compared to the control condition participants. An exploratory objective was to examine whether the effect of the intervention on walking locations differed by gender, as we previously found that men in the intervention group had a greater increase in PA, compared to women (Kerr et al., 2018). We additionally explored whether baseline physical and cognitive function modified the effect of the intervention on walking location, as associations between these factors and mobility have been previously identified (Johnson et al., 2020; Kuspinar et al., 2020). We hypothesized that men and those with higher physical and cognitive functioning at baseline would have a greater increase in time walking beyond the Home and Campus domains, as a result of the PA intervention.

2.   Methods

The institutional review board of the University of California, San Diego (UCSD) approved the study. All participants provided written informed consent and completed a post-consent comprehension test to rule out serious cognitive impairment. An independent data and safety monitoring officer reviewed all adverse events. The study was conducted according to the study protocol published elsewhere (Kerr et al., 2012b).

Using a cluster randomized study design, a total of 11 retirement communities were randomized to the intervention or attention control condition. Sites that met study criteria, agreed to either condition and signed a memorandum of understanding prior to being randomized. Eligible participants were at least 65 years old, completed a 'timed up and go' walking test in less than 30 s, were able to walk 20 m without human assistance, had not had a fall in the previous 12 months that resulted in hospitalization, were able to talk over the phone, and had no plans to move in the next year. The study was conducted between 2010 and 2014.

The intervention employed techniques from the Social Cognitive Theory and applied them in an Ecological framework with intervention activities occurring at the individual, interpersonal, and community level in and around the retirement communities (Bandura, 1986; Brawley et al., 2003; Sallis et al., 2006) as described previously (Kerr et al, 2012b, 2018). In addition to group education sessions and individual phone counseling, intervention participants received pedometers, educational materials, step counts for walking to common locations around their campus, and walking maps for their local community. The maps were created to reflect walks of varying lengths to different destinations in the neighborhood, e.g., parks or shops. At the start of the program, participants were encouraged to begin walking indoors and outdoors on their campus. By 6 weeks, neighborhood maps were distributed, and participants began group walks into the surrounding neighborhoods. The intervention was most intense in the first 6 months when all study components were co-led by UCSD staff and resident peer leaders, with the resident leaders continuing the walks during the subsequent 6-month follow up period. Resident leaders completed a walk audit with the pedestrian advocacy organization 'Circulate San Diego' and received training to advocate for improvement requests with local policy makers and city officials to ensure participants had safe walking routes in local neighborhoods. Community improvements

included extending crosswalk times, adding auditory and visual traffic signals at busy intersections, clearing pedestrian paths of hazards, adding wheel stops to prevent cars from parking over a sidewalk, and adding walking paths to a retirement community redevelopment plan. Participants in the control condition received similar levels of attention via group meetings and counseling calls as intervention participants, though their sessions focused on topics related to successful aging, like nutrition and sleep, and the counseling calls asked about their general health. They did not receive pedometers, walking maps, nor any information related to PA or walking.

2.1. Measurement

Participants were measured at 5 time points: baseline, 3, 6, 9 and 12 months. Participants wore Qstarz GPS devices (BT-Q1000XT) attached to a belt worn on the waist, which can accurately differentiate indoor and outdoor time (Lam et al., 2013). Walking time was assessed using a triaxial accelerometer (GT3X+, ActiGraph) worn on the same belt as the GPS. At each measurement time point, participants wore both devices for 6 days during waking hours. Participants were asked to re-wear devices if they were not worn for a minimum of 10 h per day on at least 4 days. They were instructed to charge the GPS device overnight.

The GPS data were processed and joined to the accelerometer data using the Personal Activity and Location Measurement System (PALMS) (Carlson et al., 2015). Data were aggregated and merged at the minute level. For this study, activity was classified into intensity defined categories of walking (760 counts per minute (cpm)) and not walking (<760 cpm). The 760 cpm threshold has been shown to accurately measure moderate to vigorous intensity activities in older adults (Matthews, 2005; Matthews et al., 2013; Rejeski et al., 2016). The intervention targeted an increase in daily step counts, and did not focus on the intensity of walking, thus this threshold was deemed most appropriate to capture all walking, especially given the older age of the study population. Non-wear time was determined using a modified Choi algorithm in which 90 consecutive minutes of zero counts with a 2-min spike tolerance was screened as non-wear (Choi et al., 2011). Missing GPS data was imputed using a validated algorithm (Meseck et al., 2016). After consideration of non-wear time and missing GPS data, valid wear days were defined as days with a minimum of 600 min of combined accelerometer and GPS data.

2.2. Time in life-space domains

Four domains were defined: Home, Retirement Community Campus (Campus), Neighborhood, and Beyond Neighborhood to represent the original life-space survey (Baker et al., 2003). Home address for each participant was determined by taking the centroid mean of all GPS coordinates at 3am for each day. This calculation was performed to give a precise home location on large campuses, rather than using a retirement community street address, which would generalize all participants for a given retirement community to one geocoded point at the street level. The Home domain was defined spatially by creating a 45 m radial buffer around the participant's home location to account for the home footprint as well as a small GPS scatter buffer. The Campus domain was defined manually using satellite imagery to create a polygon outline of each of the MIPARC site campuses with

the accuracy reviewed by a UCSD staff member familiar with each site. The Neighborhood domain was defined spatially by creating an 800 m radial buffer from each participant's home location, similar to a study using smartphones to assess life-space (Wan et al., 2013). Neighborhood is commonly defined by a 10–20 min walk in older adult studies (Barnett et al., 2017). In this sample, the average time to complete a 400 m walk test (Vestergaard et al., 2009) was 7.4 min, thus we estimated that an 800 m buffer would meet the 10–20 min neighborhood definition, a distance supported by prior research (Boruff et al., 2012; Mavoa et al., 2019). The Beyond Neighborhood domain was defined as any point beyond the 800 m Neighborhood buffer. While many built environment studies use local street network buffers, street networks typically do not include sidewalks and other formal or informal walking paths, so radial buffers were employed to capture all space in relatively close proximity to the participants' home and to effectively model the mutually exclusive life space framework (Fig. 1).

GPS, accelerometer, and spatial domain data were loaded into a HIPAA compliant PostgreSQL geodatabase. Python and SQL commands were used to spatially join each GPS and accelerometer point to a life-space domain, and participant data were aggregated to average total daily minutes and total daily walking minutes in each domain for each time point. We calculated percent total time (time in each domain out of total awake time) and percent time spent walking in each domain (minutes walking in a domain out of total time in the domain) for each participant.

2.3. Covariates

Age, gender, education level (college and above vs. less than college) and marital status (married/not married) were assessed by self-report. Baseline physical and cognitive functioning were assessed as potential effect modifiers as both continuous and categorical variables. The Short Physical Performance Battery (SPPB) was used to objectively measure physical function as it is predictive of disability (Guralnik et al, 1994, 2000). The total score was calculated (possible range 0–12) and a dichotomous variable created to indicate low (0–9) or high (10–12) functioning (Bandinelli et al., 2006; Guralnik et al., 1994).

Cognitive function was measured using the Trail Making Test (TMT) – Parts A and B, which assesses cognitive flexibility and executive function, and the Wechsler Adult Intelligence Scale – IV Symbol Search Test, to assess visual scanning and psychomotor speed. Both have been shown to vary with PA (Barha et al., 2017; Chen et al., 2018; Sanders et al., 2019; Vidoni et al., 2015; Zlatar et al., 2019). The TMT was scored in time (seconds) to completion with higher scores representing worse cognitive functioning. The Symbol Search Test allowed 120 s for completion and higher scores were indicative of better functioning. We averaged z-scores from all 3 cognitive tests to create a composite score. Trails A and B scores were multiplied by −1 so that a positive score would represent better cognition, thus higher scores on the cognitive composite reflect better cognitive performance. We also split the composite score into 3 categories: "low" indicated a composite score −1 standard deviation (SD) from the group mean (n = 23, 10%), "middle" between −1 and +1 SD (n = 186, 81%), and "high" +1 SD (n = 20, 9%) and tested effect modification using both continuous and categorical variables.

2.4. Statistical analyses

The study sample was described using means for continuous variables and frequencies for categorical variables, with *t*-test or chi square tests assessing statistical differences between intervention and control groups at baseline. We quantified the difference in outcomes by intervention status across time using mixed effects linear regression models. First, we assessed change in daily time (min/day) in non-home domains (i.e., sum of Campus, Neighborhood and Beyond Neighborhood time), total daily walking (across all domains) and walking in Non-home domains. The total time and time spent walking (both as daily minutes and as a proportion of time spent in the domain) were analyzed as separate outcomes for each life-space domain. Multiple measurement days were nested within participants, and a random participant-level intercept was included in the model. Condition (intervention versus control), time, and a two-way interaction effect, condition x time (i.e., the intervention effect), were included as fixed effects. To account for retirement community clustering, study site was entered as a fixed effect.

We obtained and plotted the marginal effect for each measurement time point by condition, which averages the predicted values of the dependent variables by time point and condition for all observations, accounting for all other covariates (Williams, 2012). Three-way interactions assessed whether the intervention impact on walking in the 4 life-space domains differed based on gender or baseline physical and cognitive function, using both continuous and categorical physical and cognitive functioning variables in separate models to test sensitivity. Categorical variables were used in margins plots to aid visualization. All analyses were conducted in Stata SE 14.2 (StataCorp, College Station, TX).

2.5. Inverse probability of treatment weighting (IPTW)

Randomization occurred at the retirement community level and, as is common when the number of clusters is low, randomization did not achieve balance across all covariates at the participant level (Moerbeek, 2005; Moerbeek and Van Schie, 2016). We used IPTW to adjust for covariate imbalance between the intervention and control groups at baseline and any residual confounding. We first modeled participants' probability of being in the intervention group (i.e. the propensity score (PS)) (Leyrat et al., 2013). We considered baseline demographic characteristics, many of which were imbalanced (age, gender, education, marital status, baseline PA, physical and cognitive functioning) (Amaducci et al., 1998; Leveille et al., 2000; Matthews et al., 2005), or covariates that were thought to potentially influence the outcomes as follows (Brookhart et al., 2006; Rosenbaum and Rubin, 1983). The Falls Efficacy Scale - International (FES-I) assessed fear of falling, which has been associated with PA and outdoor time in older adults (Kempen et al., 2008; Kerr et al., 2012a; Rantakokko et al., 2009). Self-reported functional performance and disability was assessed using the Late Life Functioning Disability Instrument (LLFDI) (Beauchamp et al., 2014; Sayers et al., 2004). The 6 item short form of the PROMIS Pain Interference Scale assessed the degree to which pain impacted life activities (Amtmann et al., 2010). The time to complete the 400 Meter Walk Test (MWT) assessed cardiorespiratory fitness (Anton et al., 2011). Device-based covariates included accelerometer-assessed average daily moderate-to-vigorous PA (MVPA) minutes (1952 counts per minute), sedentary minutes

(<100 counts per minute) and device wear time (mins/day) at baseline. The categorical physical and cognitive functioning variables were also included in the PS.

A weight was then calculated using the PS values and included in regression models. IPTW removes confounding by creating a pseudopopulation in which every participant has an equal probability of receiving the intervention and control. Standardized Mean Differences (SMD) for each covariate included in the PS were computed to assess balance between the intervention and control groups before and after weighting. A threshold of SMD <0.1 was used to determine acceptable balance (see Appendix 1) (Austin and Stuart, 2015) and to choose which covariates to include in the final PS model to calculate weights. The final weighted outcome regression models additionally adjusted for age, gender, marital status, education, study site and categorical baseline physical and cognitive function variables, making our estimation doubly robust.

3. Results

There were 305 participants in total with 150 and 155 participants in the intervention and control arms, respectively. Table 1 provides descriptive statistics for the MIPARC sample at baseline. Participants in the intervention arm were younger, more likely to be married, and had higher physical function scores. Intervention participants spent less time at Home and Campus and more time in the Neighborhood and Beyond at baseline. On average, intervention participants had more daily walking at baseline, with more minutes walking in the Neighborhood and Beyond Neighborhood domains, compared to controls.

Results of the mixed effects linear regression models are presented as plots of the marginal estimates by condition across study time points in Fig. 2. Confidence intervals on the margin plots indicate precision of the estimates at that time point, whereas estimates of the condition by time interaction are presented with regression coefficients and 95% confidence intervals in the appendices. Overall, we did not observe any intervention effect on overall time spent in non-home domains (Fig. 2). The intervention group increased their daily walking from baseline to 3 months by 21.48 min/day (CI: 12.0, 31.0, Appendix 2), compared to controls, and maintained greater daily walking levels throughout the remainder of the study, whereas there was no change in walk time among the control group (Fig. 2). A significant increase in daily time spent walking in non-home domains was also observed among intervention participants at 3 months (coef = 11.48, 95% CI: 1.7, 21.3), and remained higher, compared to controls, though estimates were imprecise (Appendix 2).

Fig. 3 shows marginal estimates of the proportion of time spent in each life-space domain (out of overall awake time). We did not observe differences between groups in the percent of time spent in any life-space domain, except that intervention participants had greater time in the neighborhood domain at 6 and 9 months, compared to control participants. In general, there were not any significant differences in trends over time between groups (Appendix 3).

Out of the total time spent in each domain, intervention participants spent a greater percentage of time walking than controls across all domains and time points, though baseline differences between groups were imprecise in most domains (Fig. 4). The most

sustained change occurred in the Campus domain where intervention participants increased their percent walking time from baseline at all time points, compared to controls (Appendix 4). The intervention group had a large increase in percent time spent walking in both the Neighborhood and Beyond Neighborhood (6% and 8%, respectively) domains at 3 months (Appendix 4), with differences remaining at 12 months in Beyond Neighborhood walking. See Appendix 5 for marginal estimates and 95% confidence intervals for % time walking in life-space domains.

We additionally assessed total minutes walking in each domain to explore how each domain contributed to overall walking time (Fig. 5). Most walking, in absolute minutes, occurred in the Home and Campus domains. The intervention group had greater walking minutes in the Neighborhood at 3, 6 and 9 months, compared to controls, whereas differences between groups were not observed at any time point in other domains. Regression outputs and marginal estimates for minutes of walking by time point and condition are presented in Appendices 6 and 7.

We did not observe notable differences in the intervention effect on percent time walking by gender or physical and cognitive function levels. In the intervention group, we found greater Beyond Neighborhood walking by females at 3 months while men had more Campus walking at 6 months, however interaction term coefficients were imprecise and general trends were similar by gender (Appendix 8).

In general, we observed a greater percentage of time spent walking by those with better physical function in both intervention and control participants (Appendix 9). Intervention participants with both low and high physical function had a trend of increased walking that was maintained over time in the Campus, Neighborhood and Beyond Neighborhood, compared to controls. Those with low function returned to near baseline levels by 12 months in the furthest domains, though maintained higher campus walking. The high functioning group sustained walking gains over the 12-month period, especially in the Campus and Neighborhood domains.

Generally, intervention participants with the highest cognitive function had more walking than the other cognitive groups in non-home domains, though the mid and low functioning groups also showed an increase in walking outside the home at 3 months (Appendix 10). Among controls, the high cognition group also generally had more walking than other groups, though the pattern was less clear.

4. Discussion

Our main finding was that intervention participants increased their total walking in the Campus, Neighborhood and Beyond Neighborhood domains, compared to the control group. The intervention did not appear to affect overall time spent in life-space domains. These results indicate that the intervention was effective specifically in increasing PA in further life-space domains.

Increased walking as a percentage of Campus time was sustained by intervention participants across the entire 12-month period, while walking in the Neighborhood and

Beyond Neighborhood domains had the greatest increase at 3 months and then declined over time. The termination of UCSD staff's role in the intervention after 6 months may have contributed to these observed declines. Intervention participants did spend more time, both walking and in general, in the Neighborhood domain than the control group. It may be that the increased exposure to neighborhood destinations (i.e. new parks or shops) gained in the walking intervention led participants to increase time there, both for walking or other activities (Kerr et al., 2012a; Winters et al., 2014).

We did not find that men in the intervention group increased their walking in further life-space domains more than women, as hypothesized. These findings are unexpected given that we observed a greater increase in MVPA among men in a separate analysis of this cohort (Kerr et al., 2018). It may be that men increased the proportion of their overall activity that was at higher intensity (i.e., MVPA), but the location of that activity did not differ. Studies have found gender differences in environmental perceptions and confidence to walk in local environments, with women walking less in neighborhoods (Dyck et al., 2012; Gallagher et al., 2014; Merom et al., 2015). The social support and group walks provided by the intervention may have been successful in overcoming the barriers experienced by women that lead to these differences.

One unexpected finding was that in the Neighborhood and Beyond Neighborhood domains, both those with high and low physical function had a large increase in walking at 3 months that tapered off, though more drastically in the lower functioning group. This is an important finding given that, in baseline analyses in this cohort, we found the frequency, distance and duration of pedestrian trips were positively associated with better physical functioning (Takemoto et al., 2015). Our findings suggest that programs providing individual, social and environmental support for walking may mitigate the decline in walking and life-space mobility that may otherwise occur due to low physical functioning, though future studies should explore how to maintain gains over a longer term.

In line with results from this analysis, we did not find cross-sectional associations between cognitive function and walking in prior analyses of this cohort (Takemoto et al., 2015). Nor were associations found in a 2-year study assessing cognitive decline and life-space mobility (Béland et al., 2018). A recent review found evidence that those with limited life-spaces were more likely to develop mild cognitive impairment (De Silva et al., 2019), which we did not assess. That said, we found that intervention participants with higher cognitive function spent more time walking in non-home domains, compared to the other cognitive groups. This suggests that individuals with better cognitive function may benefit more from PA interventions that target walking in further life-space domains while more specific intervention strategies would be needed for a more cognitively impaired sample to ensure comfort and safety with walking further into their surrounding environment. This is important to explore given that, for older adults with cognitive decline, maintaining out-of-home life-space has been shown to positively impact satisfaction and independence as well as a sense of autonomy and identity (Kerr et al., 2012a; Portegijs et al., 2014; Rantakokko et al., 2014).

Our study is the first to use GPS to assess changes in where individuals walk, based on an intervention that addressed the walkability of local environments. Webber et al. suggested that the determinants of older adult mobility are influential at the individual, social and environmental levels (Webber et al., 2010). Our lack of observed effect modification by physical or cognitive function align with results from a recent large study that showed driving status, social support, and gait speed were the most significant determinants of life-space mobility, while balance and cognitive factors, like memory and executive function, were less important (Kuspinar et al., 2020). Our study demonstrates that a multilevel intervention to increase PA, that includes a focus on both supportive social and built environments, can increase PA in larger life-space domains, at least temporarily. Future research is needed to understand how to maintain mobility gains, especially in more vulnerable groups.

While this study had many strengths, including a novel multilevel intervention and device-measured PA and location, the small number of retirement communities resulted in lower statistical precision and environmental variability. Accessible life-space may have varied since some sites were close to the ocean and we did not test the sensitivity of the neighborhood buffer size. Studies should further investigate what environmental predictors may affect walking in life-space domains. The two most common life-space assessments in community dwelling populations range from 3 days to 4 weeks, whereas our measure was for one week (Baker et al., 2003; Stalvey et al., 1999b). Though shorter in duration than the University of Alabama Life-Space Assessment (UAB-LSA), self-reported measures require more recall, which may be difficult in an older adult population. The combination of GPS and accelerometer data provide an objective measure of frequency, duration and PA in various life-space domains. However, some questionnaires additionally capture the degree of independence when traveling in life-space domains. While the study population was ambulatory without human assistance, participants may have used assistive devices for walking, which was not considered in this analysis. Further, we did not attempt to generate a single life-space mobility score, as is the goal with questionnaires, though this could be explored in future work. Though driving, a key life-space determinant, was not specifically addressed, this cohort had access to transportation for recreation and shopping trips through their retirement communities that likely mitigated the importance of this factor. Our cognition classification was based on a limited set of assessments and we had very few participants with high or low scores, which may have limited our ability to detect any moderating effects, though no effect was observed using either the continuous or categorical cognition score.

5. Conclusions and implications

In community dwelling residents, maintaining life-space mobility is critically important to avoid physical and cognitive decline, risk of falls, and possible transition to a care facility. Maintaining independence and PA may help to reduce healthcare costs, living costs, and give elderly residents a greater sense of autonomy. While maintaining older adults' life-space mobility can be supported by medications, vision and hearing tests, and transportation options, our results indicate a walking program could increase PA in larger life-space domains, providing the additional physical and psychological health benefits associated with

PA and outdoor time. There was no difference in the number of adverse events between intervention and control participants, so participants remained safe despite walking in more challenging environments.

This study provides evidence that mobility patterns can be changed, even in quite elderly adults, through a targeted intervention with strategies specifically aimed at providing social support and introducing new walking environments. These elements may explain why the effect of the intervention did not differ by gender, physical function and cognition as expected, indicating that the many older adults, regardless of functional status, may benefit. Campus was the only domain where walking continued to increase across the length of the study period, highlighting the importance of those spaces that are most accessible to home locations. The findings that the largest increases occurred at 3 months followed by a decline highlight the importance of developing effective ongoing intervention strategies.

Funding

Appendix

Appendix 1.

Standardized Mean Differences (SMD) of propensity score covariates between intervention and control groups, before and after weighting

	SMD Before Weighting	SMD After Weighting
Age	−0.59437	−0.00205
Gender	−0.20831	0.022834
Education	0.089714	0.023482
Marital status	0.258244	−0.01542
Avg. daily wear time	−0.19829	−0.03121
Average daily MVPA	0.292411	0.030082
Physical function (SPPB)	0.473672	0.003744
Composite cognitive score	0.410389	−0.03931
Age x SPPB	0.411539	0.014921
Age x gender	−0.22189	0.017945
Fear of falling	−0.42693	−0.08352
Fear of falling x age	−0.53473	−0.07322
Avg. daily sedentary time	−0.38379	−0.025
Disability	0.522758	−0.03109
Pain	−0.17361	0.065103
400 MWT	−0.54127	0.084759

Appendix 2.

Regression estimates for non-home time, total walking time and walking time in Non-home domains (min/day)

	Non-home time		Total walk time		Non-home walking	
	Coef	95% CI	coef	95% CI	coef	95% CI
Intervention condition	−17.4	[−192.5,157.8]	−10.1	[−36.2,16.1]	−9.0	[−24.3,6.3]
Time point (Ref)						
3 mos	60.3[*]	[1.0,119.5]	−1.1	[−7.4,5.3]	6.7	[−0.9,14.3]
6 mos	36.0[*]	[0.2,71.8]	−2.0	[−9.2,5.1]	4.1	[−2.7,10.8]
9 mos	54.9[*]	[15.9,94.0]	−0.3	[−11.5,10.9]	6.4	[−4.9,17.7]
12 mos	29.8	[−4.4,64.0]	−4.1	[−13.8,5.6]	3.1	[−6.0,12.3]
Condition x time						
Intervention x 3 mos	−26.2	[−93.0,40.7]	21.5[*]	[12.0,31.0]	11.5[*]	[1.7,21.3]
Intervention x 6 mos	9.4	[−38.0,56.8]	8.5	[−1.6,18.6]	7.3	[−1.5,16.1]
Intervention x 9 mos	−14.3	[−65.5,36.8]	0.8	[−12.0,13.6]	0.9	[−11.5,13.3]
Intervention x 12 mos	−11.9	[−64.7,40.9]	8.0	[−4.5,20.5]	6.1	[−4.7,16.9]

95% confidence intervals in brackets.

[*] $p < 0.05$.

Appendix 3.

Regression estimates for percent time spent in each domain out of total awake time

	Home		Campus		Neighborhood		Beyond Neighborhood	
	coef	95% CI	coef	95% CI	coef	95% CI	coef	95% CI
Intervention condition	0.01	[−0.22,0.23]	−0.16	[−0.32,0.00]	0.03	[−0.02,0.08]	0.13[*]	[0.02,0.24]
Time point (Ref)								
3 mos	−0.09[*]	[−0.16,−0.03]	0.03	[−0.04,0.10]	0.04	[−0.02,0.10]	0.02	[−0.05,0.09]
6 mos	−0.06[*]	[−0.10,−0.02]	0.05[*]	[0.02,0.09]	0.01	[−0.01,0.03]	−0.00	[−0.03,0.02]
9 mos	−0.08[*]	[−0.12,−0.04]	0.03	[−0.01,0.08]	0.01	[−0.01,0.03]	0.04[*]	[0.01,0.07]
12 mos	−0.04	[−0.08,0.00]	0.02	[−0.01,0.06]	0.01	[−0.02,0.04]	0.00	[−0.03,0.04]
Condition x time								
Intervention x 3 mos	0.07	[−0.01,0.14]	−0.00	[−0.08,0.07]	−0.02	[−0.08,0.04]	−0.04	[−0.12,0.03]
Intervention x 6 mos	0.01	[−0.04,0.07]	0.00	[−0.05,0.06]	−0.00	[−0.03,0.03]	−0.01	[−0.06,0.03]
Intervention x 9 mos	0.05	[−0.01,0.11]	−0.01	[−0.07,0.04]	0.03	[−0.01,0.07]	−0.06[*]	[−0.11,−0.02]
Intervention x 12 mos	0.05	[−0.01,0.11]	−0.04	[−0.09,0.01]	−0.03	[−0.06,0.01]	0.02	[−0.03,0.06]

95% confidence intervals in brackets.

[*] $p < 0.05$.

Appendix 4.

Regression estimates for percent time walking in each domain out of total time in the domain

	Home		Campus		Neighborhood		Beyond Neighborhood	
	coef	95% CI	coef	95% CI	coef	95% CI	coef	95% CI
Intervention condition	0.02	[−0.02,0.06]	−0.01	[−0.10,0.07]	−0.01	[−0.07,0.04]	−0.05	[−0.13,0.03]
Time point (Ref)								
3 mos	0.01	[−0.01,0.02]	0.00	[−0.04,0.04]	−0.00	[−0.03,0.02]	−0.00	[−0.02,0.02]
6 mos	0.02	[−0.03,0.06]	−0.00	[−0.02,0.02]	−0.02	[−0.05,0.02]	0.01	[−0.01,0.04]
9 mos	0.01	[−0.00,0.02]	−0.01	[−0.03,0.01]	0.01	[−0.03,0.04]	0.02	[−0.02,0.06]
12 mos	0.00	[−0.01,0.02]	−0.01	[−0.02,0.01]	0.02	[−0.03,0.06]	0.00	[−0.03,0.03]
Condition x time								
Intervention x 3 mos	−0.01	[−0.03,0.01]	0.04	[−0.01,0.09]	0.06*	[0.02,0.10]	0.08*	[0.04,0.12]
Intervention x 6 mos	−0.02	[−0.07,0.02]	0.05*	[0.02,0.09]	0.04	[−0.00,0.08]	−0.00	[−0.04,0.04]
Intervention x 9 mos	−0.02*	[−0.04,−0.01]	0.04*	[0.01,0.07]	0.00	[−0.04,0.05]	−0.01	[−0.06,0.04]
Intervention x 12 mos	−0.01	[−0.04,0.01]	0.06*	[0.03,0.09]	0.01	[−0.04,0.06]	0.01	[−0.03,0.05]

Appendix 5.

Marginal estimates and 95% confidence intervals for % time walking in life-space domains

Time Point x Condition	Marginal estimate (%)	95% CI
Home domain		
Baseline Control	0.101	0.086–0.117
Baseline Intervention	0.119	0.108–0.130
3-month Control	0.107	0.089–0.124
3-month Intervention	0.120	0.106–0.134
6-month Control	0.109	0.082–0.136
6-month Intervention	0.120	0.105–0.135
9-month Control	0.100	0.084–0.115
9-month Intervention	0.106	0.095–0.117
12-month Control	0.099	0.085–0.113
12-month Intervention	0.112	0.097–0.127
Campus domain		
Baseline Control	0.157	0.133–0.182
Baseline Intervention	0.151	0.134–0.167
3-month Control	0.159	0.129–0.190
3-month Intervention	0.193	0.172–0.215
6-month Control	0.154	0.135–0.173
6-month Intervention	0.204	0.177–0.232

Time Point x Condition	Marginal estimate (%)	95% CI
9-month Control	0.141	0.122–0.161
9-month Intervention	0.180	0.156–0.203
12-month Control	0.152	0.128–0.176
12-month Intervention	0.205	0.178–0.232
Neighborhood domain		
Baseline Control	0.108	0.088–0.129
Baseline Intervention	0.123	0.103–0.143
3-month Control	0.106	0.080–0.131
3-month Intervention	0.184	0.158–0.211
6-month Control	0.092	0.057–0.126
6-month Intervention	0.148	0.126–0.170
9-month Control	0.113	0.081–0.144
9-month Intervention	0.133	0.110–0.156
12-month Control	0.124	0.079–0.169
12-month Intervention	0.149	0.123–0.175
Beyond neighborhood domain		
Baseline Control	0.115	0.094–0.136
Baseline Intervention	0.160	0.136–0.184
3-month Control	0.115	0.093–0.136
3-month Intervention	0.242	0.208–0.276
6-month Control	0.129	0.108–0.151
6-month Intervention	0.175	0.144–0.206
9-month Control	0.133	0.101–0.165
9-month Intervention	0.167	0.143–0.192
12-month Control	0.114	0.093–0.135
12-month Intervention	0.175	0.152–0.199

Appendix 6.

Regression estimates for time spent walking in each domain (min/day)

	Total walk minutes at home		Total walk minutes on campus		Total walk minutes in neighborhood		Total walk minutes beyond neighborhood	
Intervention condition	−1.40	[−25.3,22.6]	−12.93[*]	[−22.4,−3.5]	−1.86	[−6.6,2.9]	5.88	[−2.9,14.6]
Time point (Ref)								
3 mos	−8.16[*]	[−14.6,−1.7]	1.49	[−4.9,7.9]	1.57	[−2.5,5.7]	3.60	[−4.8,12.0]
6 mos	−6.66[*]	[−10.8,−2.5]	4.12	[−1.4,9.6]	−0.20	[−2.4,2.01]	0.16	[−3.0,3.3]
9 mos	−7.08[*]	[−11.1,−3.0]	0.81	[−3.2,4.8]	1.14	[−2.7,5.0]	4.42	[−1.5,10.3]
12 mos	−7.31[*]	[−11.3,−3.4]	−0.21	[−3.9,3.5]	0.55	[−3.3,4.4]	2.78	[−1.6,7.2]
Condition x time								

	Total walk minutes at home		Total walk minutes on campus		Total walk minutes in neighborhood		Total walk minutes beyond neighborhood					
Intervention x 3	10.79*	[3.0,18.6]	10.18*	[2.3,18.1]	3.65	[−1.3,8.6]	−2.28	[−11.3,6.7]				
Intervention x 6	2.71	[−3.6,9.0]	4.83	[−2.2,11.9]	3.19	[−0.2,6.5]	−0.64	[−4.9,3.7]				
Intervention x 9	0.99	[−4.8,6.8]	5.10	[−0.7,10.9]	2.57	[−2.7,7.8]	−6.73*	[−13.2,−0.2]				
Intervention x 12	3.04	[−3.5,9.6]	5.49	[−0.1,11.1]	−0.42	[−4.7,3.9]	1.13	[−4.6,6.9]				

95% confidence intervals in brackets.

*
$p < 0.05$.

Appendix 7.

Marginal estimates and 95% confidence intervals for time spent walking (min/day) in life-space domains

Time Point x Condition	Marginal estimate (min/day)	95% CI
Home domain		
Baseline Control	42.112	37.115–47.108
Baseline Intervention	42.779	37.350–48.208
3-month Control	34.052	27.550–40.554
3-month Intervention	44.701	38.320–51.082
6-month Control	35.225	30.549–39.901
6-month Intervention	37.927	31.556–44.298
9-month Control	34.801	29.945–39.657
9-month Intervention	35.569	30.346–40.793
12-month Control	34.450	29.495–39.405
12-month Intervention	37.754	31.707–43.800
Campus domain		
Baseline Control	22.944	19.294–26.594
Baseline Intervention	19.234	16.155–22.312
3-month Control	25.196	18.139–32.252
3-month Intervention	29.967	25.551–34.384
6-month Control	27.375	21.761–32.988
6-month Intervention	26.869	22.694–31.044
9-month Control	23.773	19.205–28.340
9-month Intervention	23.861	20.130–27.593
12-month Control	23.697	19.200–28.194
12-month Intervention	23.732	19.854–27.610
Neighborhood domain		
Baseline Control	6.996	4.516–9.476

Time Point x Condition	Marginal estimate (min/day)	95% CI
Baseline Intervention	9.515	7.412–11.618
3-month Control	8.127	4.721–11.533
3-month Intervention	15.893	13.007–18.779
6-month Control	6.074	2.598–9.551
6-month Intervention	14.444	11.456–17.432
9-month Control	6.796	3.948–9.645
9-month Intervention	15.176	11.731–18.621
12-month Control	6.424	3.851–8.997
12-month Intervention	10.842	8.164–13.520
Beyond neighborhood domain		
Baseline Control	11.055	8.470–13.640
Baseline Intervention	14.727	12.063–17.391
3-month Control	14.980	6.528–23.433
3-month Intervention	16.893	13.911–19.876
6-month Control	10.962	7.486–14.438
6-month Intervention	15.193	11.926–18.460
9-month Control	14.534	10.163–18.904
9-month Intervention	13.523	10.603–16.444
12-month Control	13.562	10.152–16.971
12-month Intervention	19.190	14.969–23.412
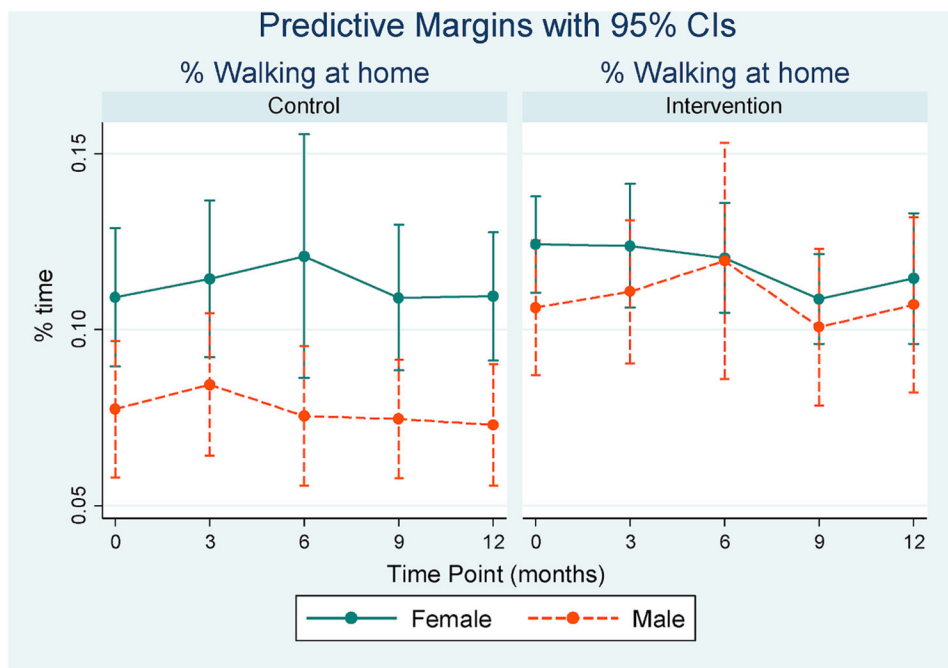
Predictive Margins with 95% CIs
% Walking on campus

Predictive Margins with 95% CIs
% Walking beyond neighborhood
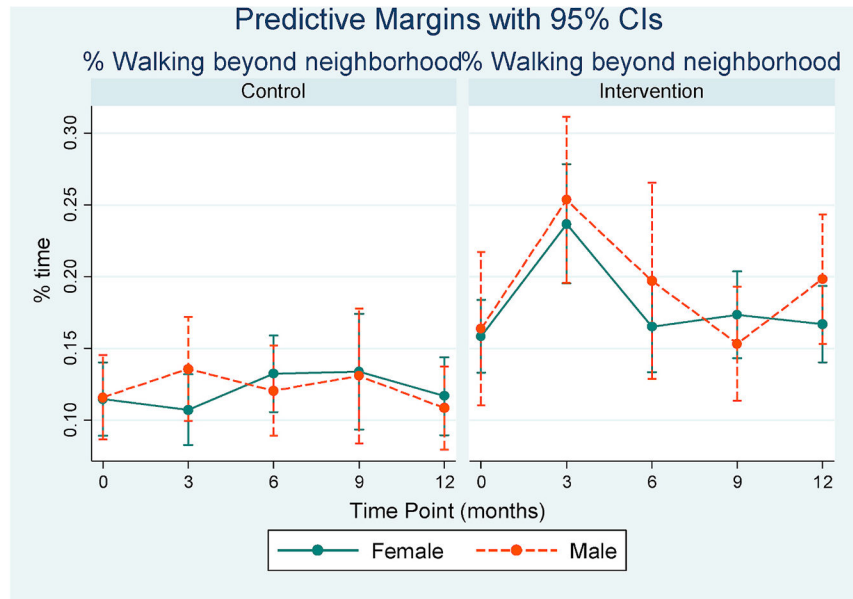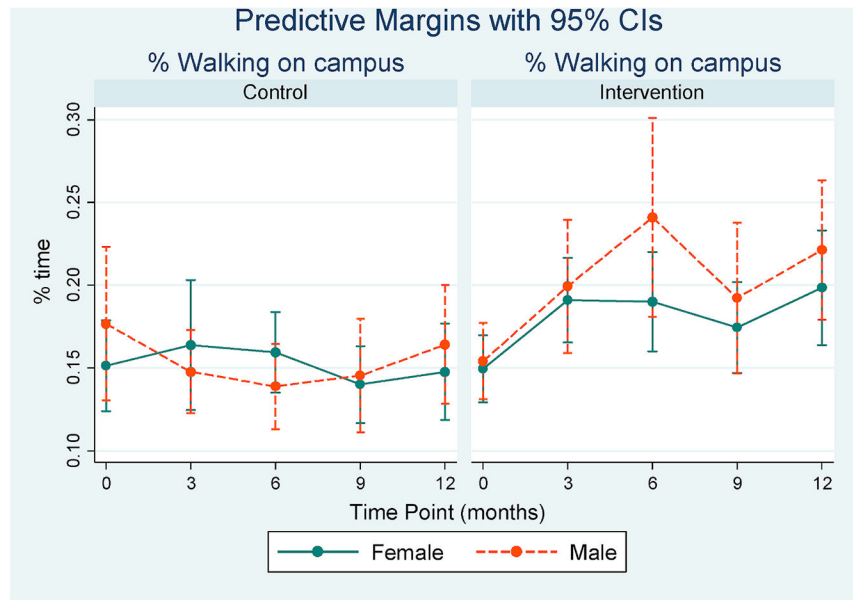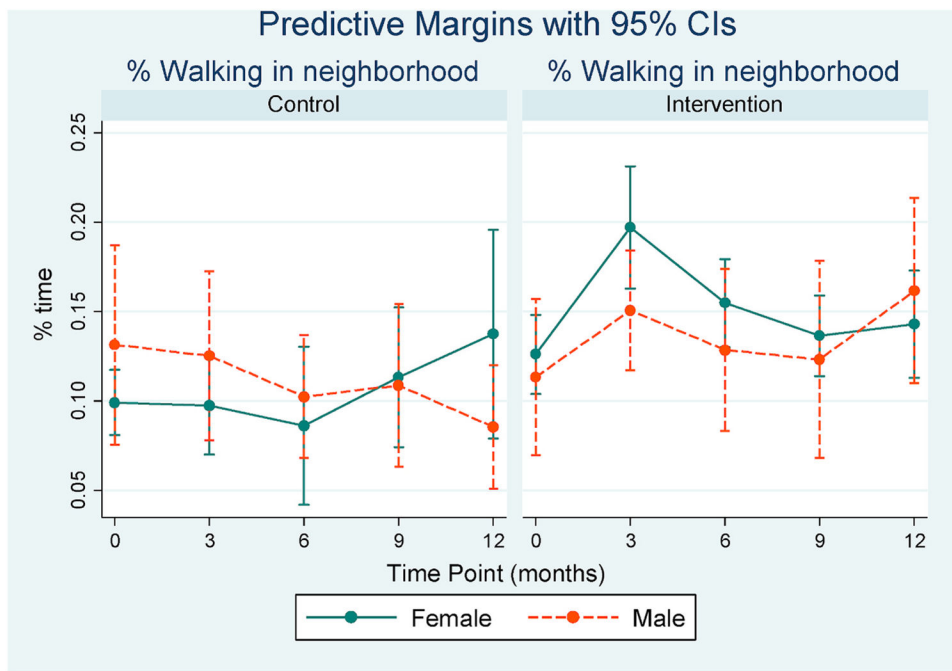
Appendix 8.

Marginal estimates and 95% confidence intervals for percentage of time spent walking in life-space domains for condition x time × gender interaction
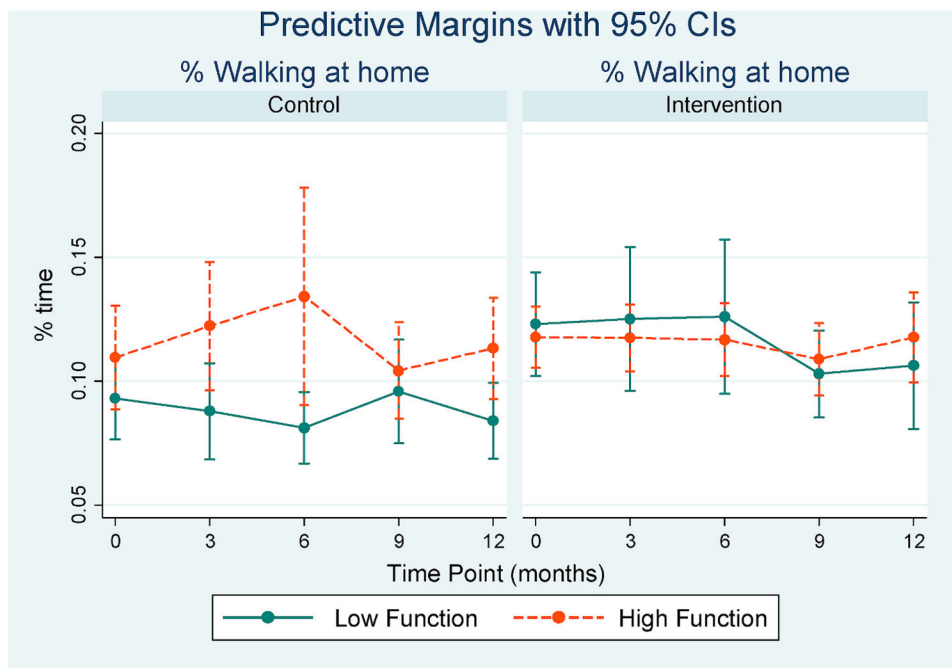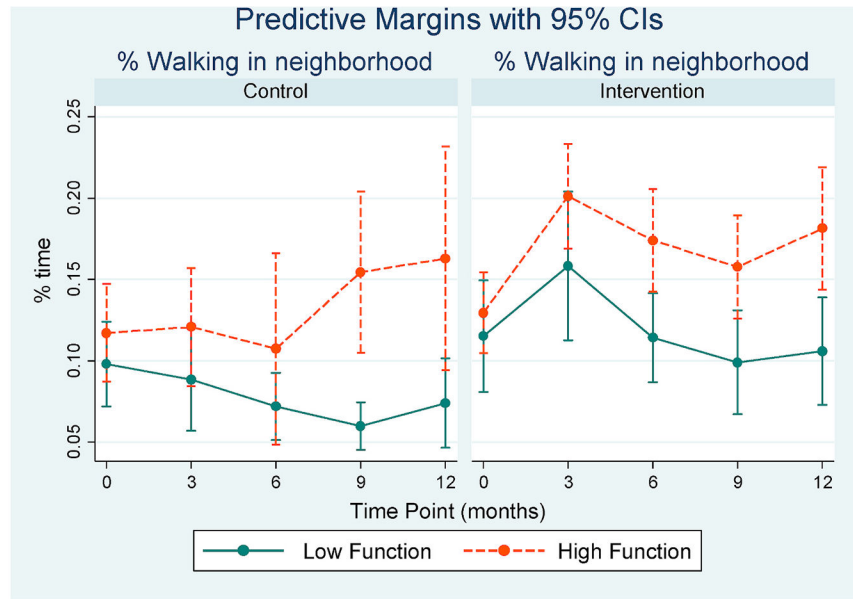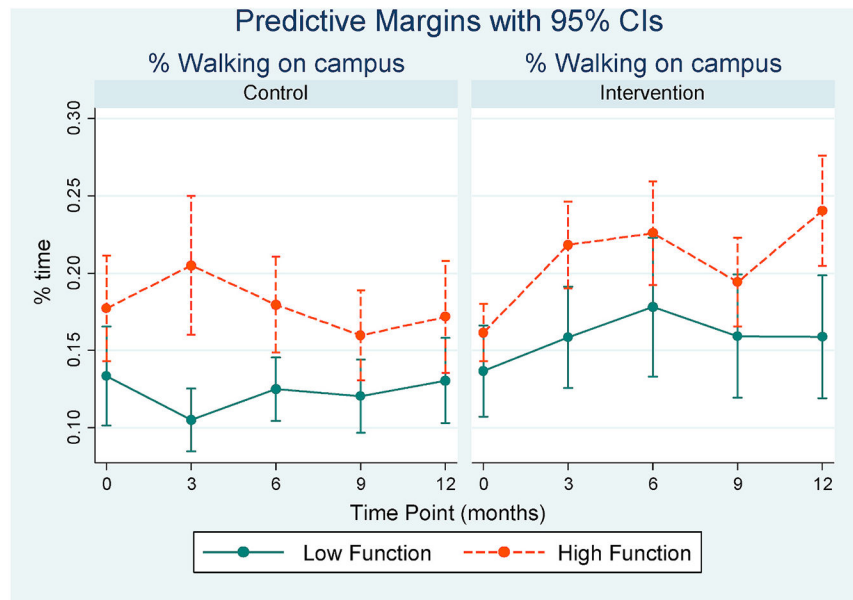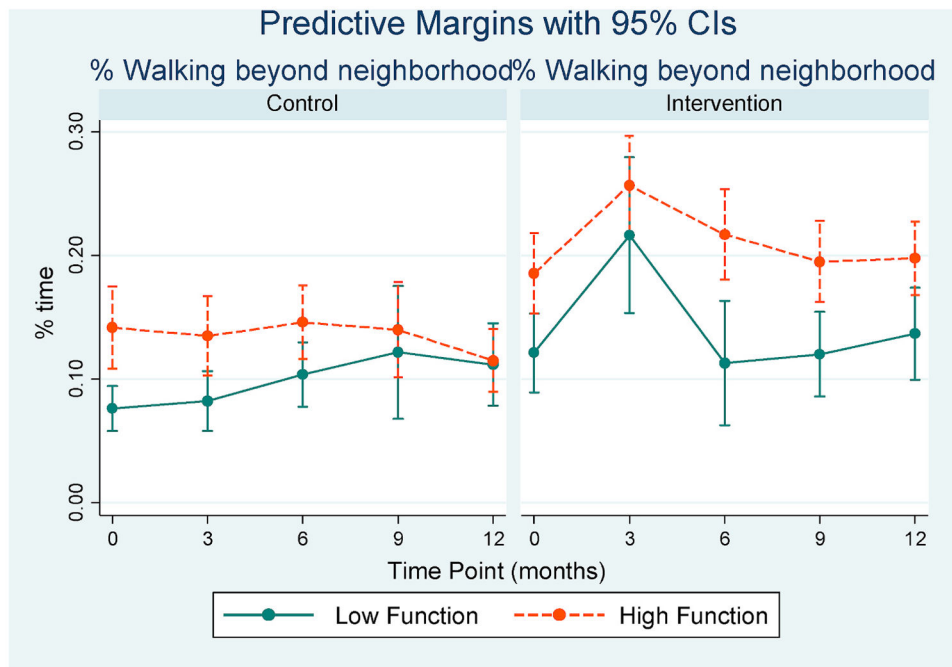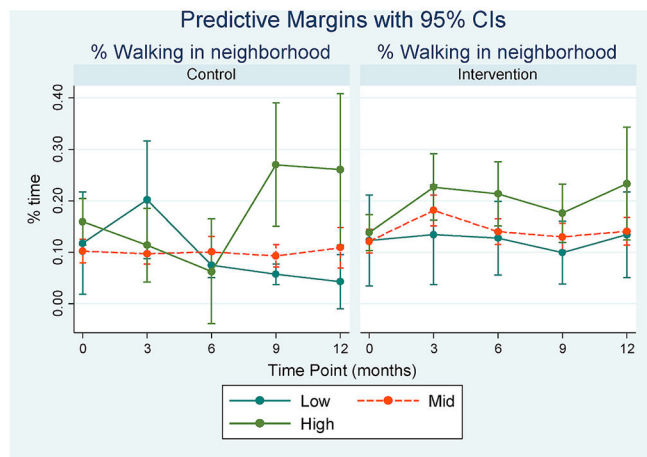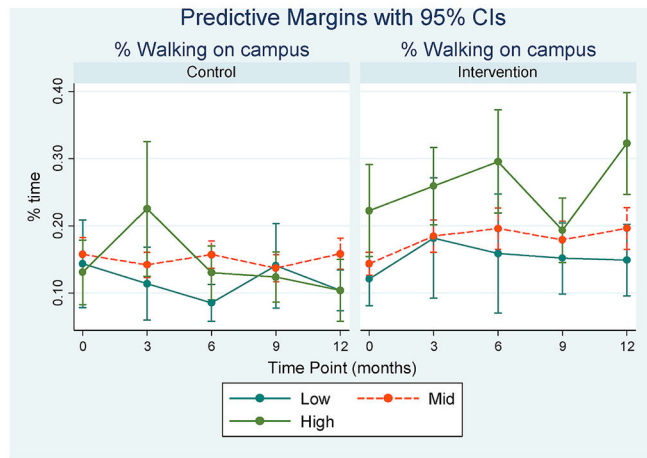
Predictive Margins with 95% CIs

% Walking on campus — Control / Intervention

Predictive Margins with 95% CIs

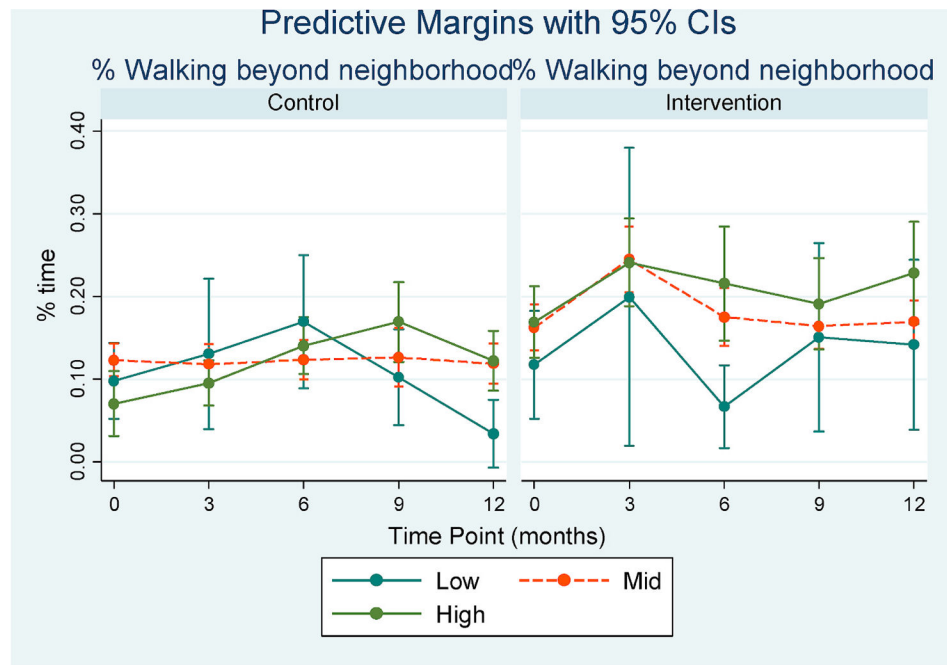% Walking in neighborhood — Control / Intervention

Appendix 9.

Marginal estimates and 95% confidence intervals for percentage of time spent walking in life-space domains for condition x time x physical function interaction

Predictive Margins with 95% CIs

% Walking on campus

Predictive Margins with 95% CIs

% Walking in neighborhood

Predictive Margins with 95% CIs
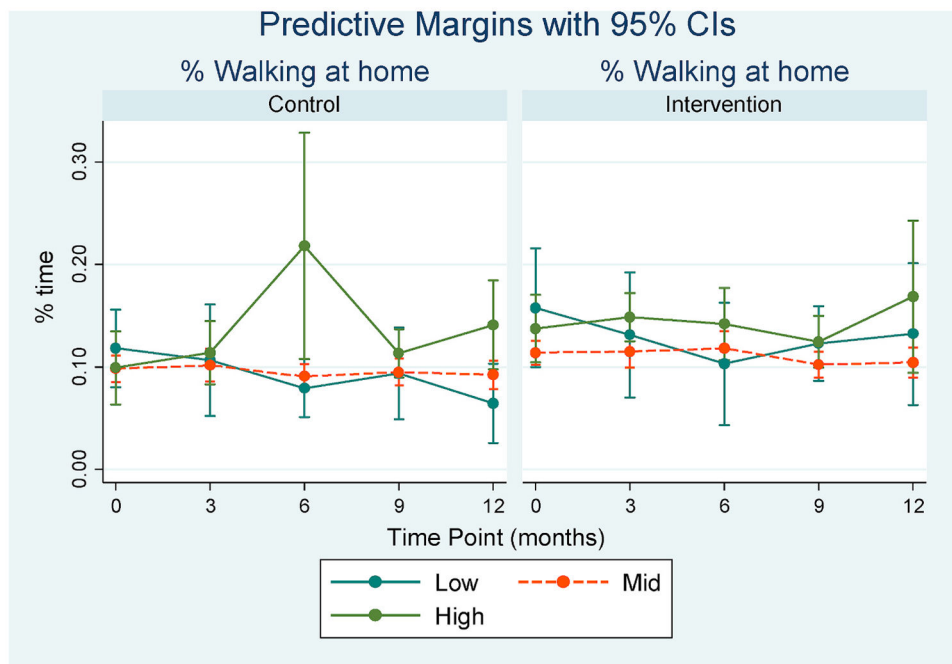
Appendix 10.

Marginal estimates and 95% confidence intervals for percentage of time spent walking in life-space domains for condition x time × cognition interaction

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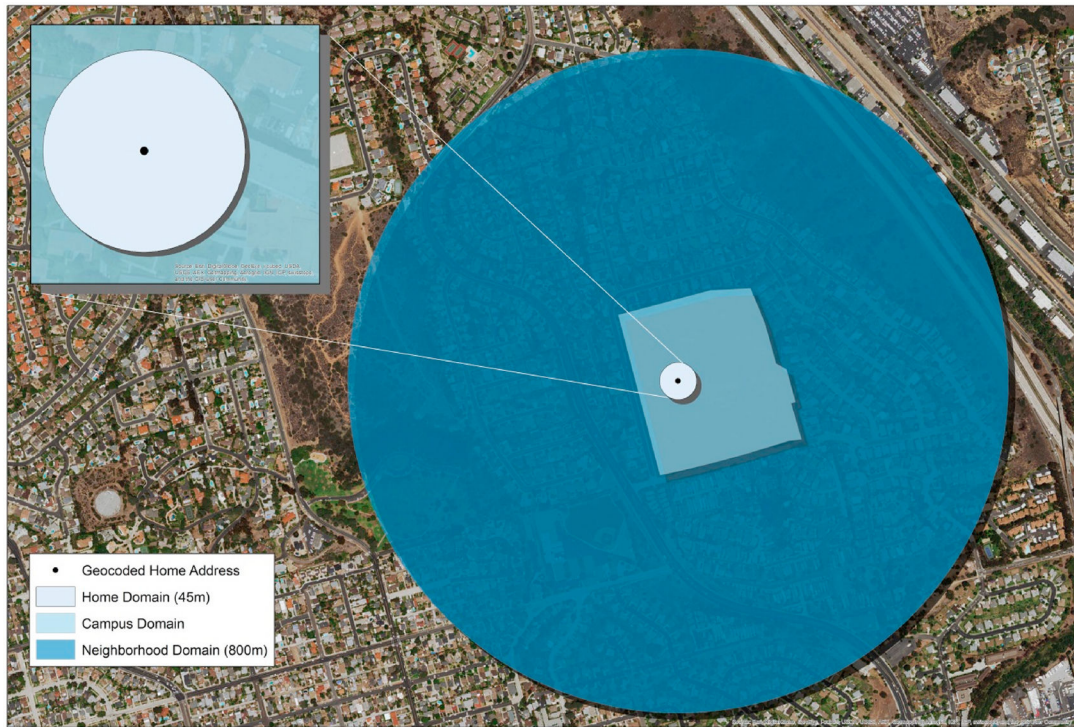
Fig. 1.
Example of mutually exclusive life-space domains: Home, Campus, Neighborhood, and Beyond Neighborhood.

Fig. 2.
Marginal estimates and 95% confidence intervals for time in non-home domains, total walk time and walk time in non-home domains (min/day).
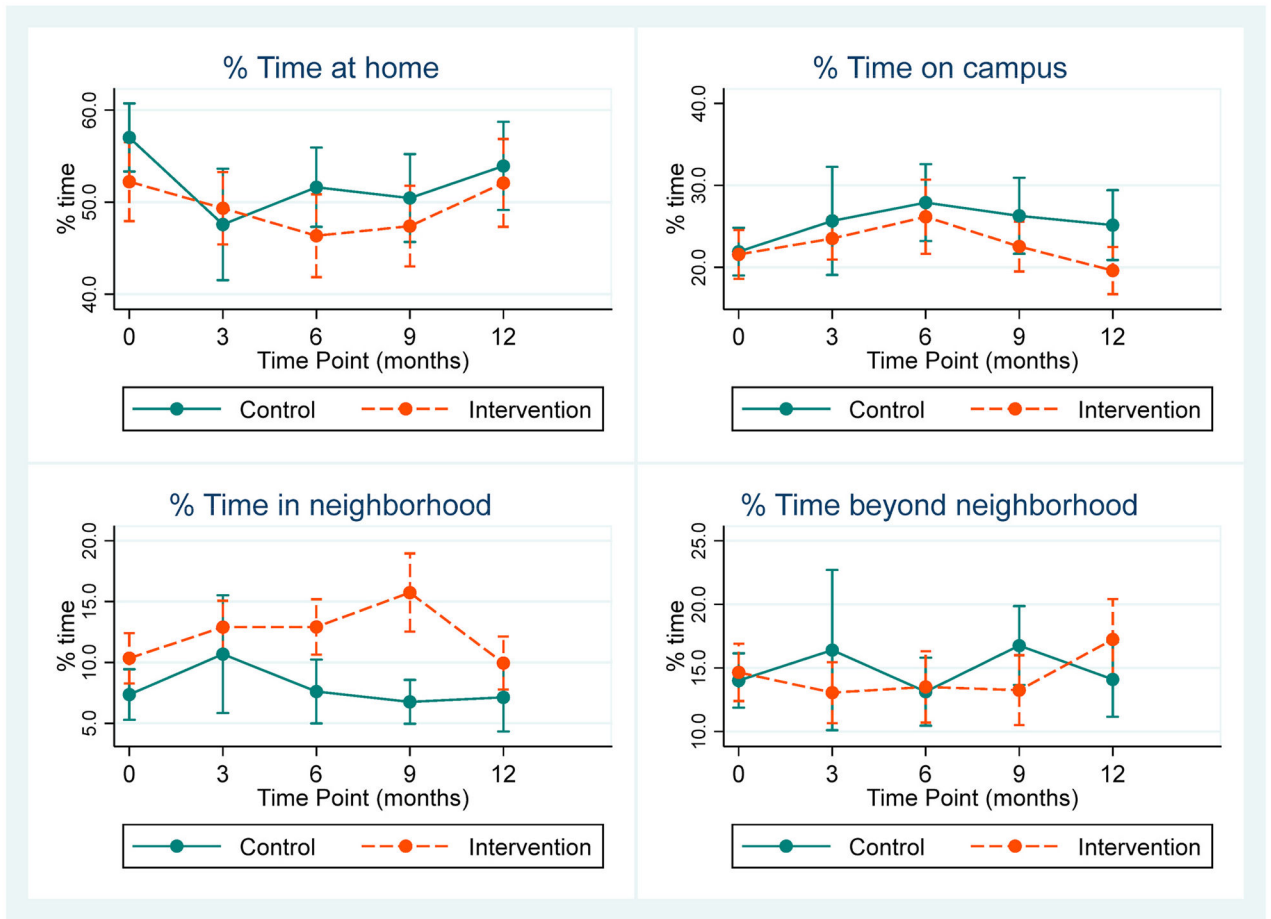
Fig. 3.
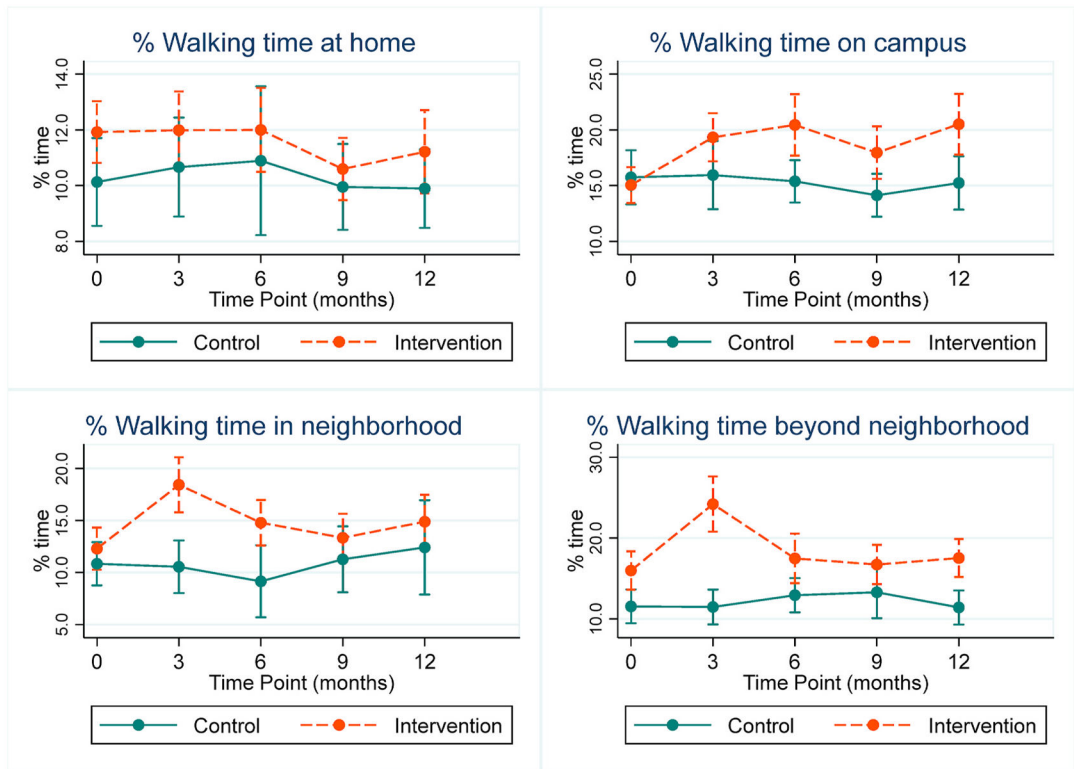Marginal estimates and 95% confidence intervals for percentage of time spent in life-space domains.

Fig. 4.
Marginal estimates and 95% confidence intervals for percentage of time spent walking in life-space domains.
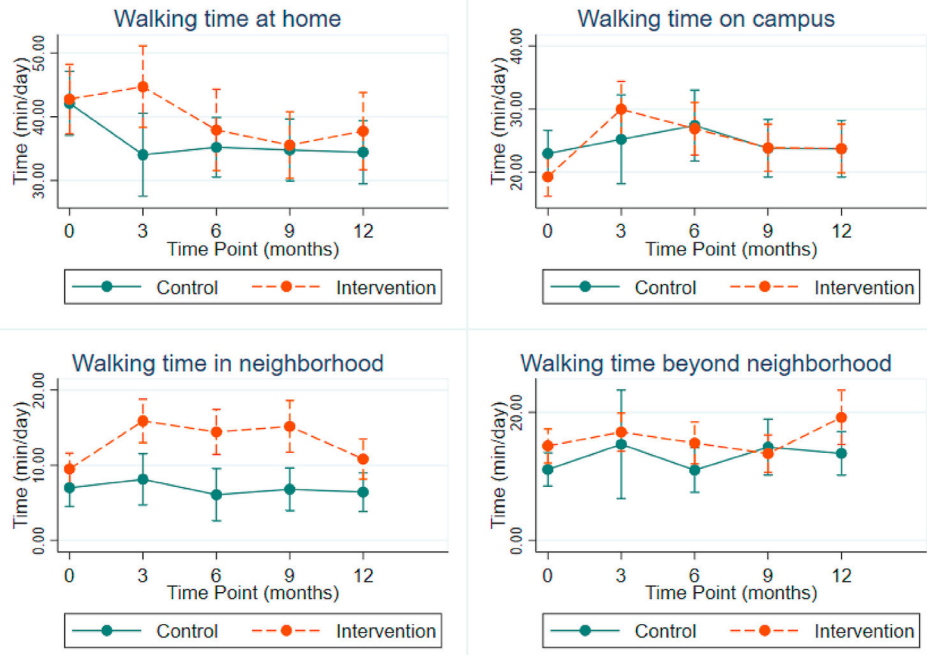
Fig. 5.
Marginal estimates and 95% confidence intervals for time spent walking in life-space domains (min/day).

Table 1.

MIPARC participant characteristics at baseline.

	Intervention	Control	p-value
N	150	155	
Age (years), mean (SD)	81.3 (5.8)	84.8 (6.5)	0.000
Female, n (%)	111 (74.0)	110 (71.0)	0.550
College education or above, n (%)	99 (66.0)	93 (60.0)	0.110
Married, n (%)	76 (50.7)	46 (29.7)	0.000
Total time in each domain, mean min/day (SD)			
Home	428.2 (254.9)	488.0 (231.4)	0.000
Campus	157.8 (169.8)	178.3 (168.7)	0.018
Neighborhood	85.6 (151.5)	65.1 (131.4)	0.005
Beyond neighborhood	113.0 (159.0)	87.4 (136.1)	0.001
Total walking time, mean min/day (SD)	83.8 (45.4)	72.7 (48.0)	0.000
Total walking time in each domain, mean min/day (SD)			
Home	40.6 (34.5)	38.2 (29.6)	0.150
Campus	17.9 (21.1)	19.9 (22.7)	0.072
Neighborhood	9.4 (18.3)	5.6 (13.4)	0.000
Beyond neighborhood	13.5 (25.6)	8.1 (16.3)	0.000
Daily device wear time, mean min/day (SD)	808.7 (78.3)	825.3 (75.9)	0.000
Physical function (SPPB), mean (SD)	9.4 (2.5)	8.2 (2.7)	0.000
Cognition composite z-score, mean (SD)	0.2 (0.8)	−0.1 (0.8)	0.000

*
p-values from *t*-test or chi square tests.