# Changes in physical activity by context and residential greenness among recent retirees : Longitudinal GPS and accelerometer study

Pasanen, S.

2022-01

Pasanen , S , Halonen , J I , Gonzalez-Inca , C , Pentti , J , Vahtera , J , Kestens , Y , Thierry , B , Brondeel , R , Leskinen , T & Stenholm , S 2022 , ' Changes in physical activity by context and residential greenness among recent retirees : Longitudinal GPS and accelerometer study ' , Health & Place , vol. 73 , 102732 . https://doi.org/10.1016/j.healthplace.2021.102732

http://hdl.handle.net/10138/338746
https://doi.org/10.1016/j.healthplace.2021.102732

Health & Place 73 (2022) 102732

Contents lists available at ScienceDirect

Health and Place

journal homepage: www.elsevier.com/locate/healthplace

# Changes in physical activity by context and residential greenness among recent retirees: Longitudinal GPS and accelerometer study

S. Pasanen[a,b,*], J.I. Halonen[c], C. Gonzales-Inca[d], J. Pentti[a,b,e], J. Vahtera[a,b], Y. Kestens[f], B. Thierry[f], R. Brondeel[g], T. Leskinen[a,b], S. Stenholm[a,b]

[a] University of Turku and Turku University Hospital, Department of Public Health, Turku, Finland
[b] University of Turku and Turku University Hospital; Centre for Population Health Research, Turku, Finland
[c] Finnish Institute for Health and Welfare, Department of Health Security, Helsinki, Finland
[d] University of Turku, Department of Geography and Geology, Turku, Finland
[e] University of Helsinki, Clinicum, Faculty of Medicine, Helsinki, Finland
[f] Centre de Recherche en Santé Publique (CReSP), Montreal, Canada
[g] Ghent University, Department of Movement and Sports Sciences, Gent, Belgium

ARTICLE INFO

*Keywords:*
Physical activity
Older adults
Activity locations
Active travel
Residential greenness

ABSTRACT

This study examined the changes in accelerometer-measured physical activity by GPS-measured contexts among Finnish retirees (n = 45 (537 measurement days)) participating in a physical activity intervention. We also assessed whether residential greenness, measured with Normalized Difference Vegetation Index, moderated the changes. Moderate-to-vigorous physical activity (MVPA) increased at home by 7 min/day, ($P < 0.001$) and during active travel by 5 min/day ($P = 0.03$). The participants with the highest vs. lowest greenness had 25 min/day greater increase in MVPA over the follow-up (P for Time*Greenness interaction = 0.04). In conclusion, retirees participating in the intervention increased their MVPA both at home and in active travel, and more so if they lived in a greener area.

## 1. Introduction

Physical activity reduces the risk of various physical and mental diseases as well as mortality among older adults (Cunningham et al., 2020). In addition, a physically active lifestyle maintains physical and cognitive functioning as well as quality of life with advancing age (Cunningham et al., 2020). Physical activity occurs in various contexts (Jansen et al., 2016) and their characteristics may have an effect not only on physical activity itself (Van Holle et al., 2012), but also on how physical activity may change as a result of interventions promoting physical activity (Kerr et al., 2010) or when followed over time (Sugiyama et al., 2013).

Concerning the contexts of physical activity, studies from the Netherlands (Jansen et al., 2016) and the United States (Holliday et al., 2017) have observed, using accelerometer and Global Positioning System (GPS) devices, that activities at home location (Jansen et al., 2016) and on roads (Holliday et al., 2017; Jansen et al., 2016) are particularly important contributors to moderate-to-vigorous physical activity (MVPA) among middle aged (45–65 years) (Jansen et al., 2016) or older participants (subgroup of 60–85 years) (Holliday et al., 2017). Regarding the characteristics of the physical activity contexts, a study from Belgium (Dewulf et al., 2016) using accelerometer and GPS data combined with land use information, suggested that the time spent in green areas (vs. non-green areas) was associated with more physical activity among late middle-aged adults (58–65 years). Another study from the United States (James et al., 2017), based on accelerometer and GPS data linked with Normalized Difference Vegetation Index (NDVI), observed that a higher level of physical activity was related to higher greenness among women (22–82 years), and that the relationship was stronger among those who were white, had higher incomes, and were middle-aged.

While prior studies underline the importance of context for physical activity, longitudinal studies examining the changes in physical activity and across the contexts are lacking. To address this gap, this study uses accelerometer-measured physical activity data linked with GPS-measured contexts from a 1-year physical activity intervention, grounded on the use of a commercial activity tracker, aiming at increasing physical activity and reducing sedentary time among recent retirees.

---

[*] Corresponding author. Public Health, Kiinamyllynkatu 10, Medisiina A, FI, 20014, University of Turku, Finland.
*E-mail address:* sanna.pasanen@utu.fi (S. Pasanen).

https://doi.org/10.1016/j.healthplace.2021.102732
Received 3 June 2021; Received in revised form 7 October 2021; Accepted 3 December 2021

The aim of this study was to examine in which contexts, specifically regarding locations (home vs. non-home) and in travel mode (active vs. passive), changes in physical activity take place. In addition, we examined whether residential greenness modified the changes in physical activity.

## 2. Methods

### 2.1. Study population

In this study, a subsample of the intervention participants from the 'Enhancing physical activity and healthy aging among recent retirees – Randomized controlled in-home physical activity trial (REACT)' was used. The REACT study population was comprised of 231 former Finnish public sector workers, who retired between January 2016 and December 2018. The participants were randomized to intervention (n = 117) and control (n = 114) groups. The REACT study aimed to examine the effectiveness of a 1-year wearable technology-based intervention on physical activity among recent retirees. The present study uses data merely from the participants of the intervention group, because GPS measurements were conducted only in this group. Due to delay related to the delivery of the devices, only 61 of the intervention participants were included in the present study. The devices were given to the participants when the devices were available.

In the REACT study, participants in the intervention group were asked to wear a commercial activity tracker Polar Loop 2 (Polar, Finland) on their non-dominant wrist, during days and nights for one year, and to aim for their personal daily activity goal. Details of the intervention are described elsewhere (Leskinen T., Suorsa K., Tuominen M., Pulakka A., Pentti J., Löyttyniemi E., Heinonen I., Vahtera J., Stenholm, 2021). Briefly, during each day, the tracker provided an instant view on the screen of how much activity was still needed to reach the activity goal. Activities at higher intensities filled up the daily goal faster than activities at lower intensities. A higher goal was suggested by the researcher if the participant had frequently exceeded their goal. The control group received no intervention.

The REACT study has been conducted in accordance with the guidelines for good scientific practice set by the National Advisory Board on Research Ethics in Finland and the Declaration of Helsinki, and the study was approved by the Ethics Committee of the Hospital District of Southwest Finland (107/1801/2017). The study's ClinicalTrials.gov registration number is NCT03320746. Written informed consent was obtained from all REACT participants after they were informed about the study protocol and the voluntariness of the participation.

### 2.2. Accelerometer and GPS measurements

Waist-worn SenseDoc 2.0 device (Mobysens Technologies Inc, Canada) was used to collect accelerometer and GPS data. A study nurse instructed the use of the device during a clinical examination visit. Participants were asked to wear the device during waking hours for seven consecutive days, except when bathing or during water sports. The participants were also asked to keep a daily diary, where they provided information about their bedtimes. After the measurement week, the device and the diary were returned by mail.

The SenseDoc 2.0 device includes a high-sensitivity GPS receiver and a tri-axial accelerometer. More detailed description of the capabilities of this device has been reported earlier (Brondeel et al., 2019b). We initialized the devices to record GPS coordinates every second and accelerometer data at 80 Hz sampling rate. Raw accelerometer and GPS data were extracted from the SenseDoc 2.0 with SenseAnalytics (versions 1.9 and 1.10) before being aggregated into counts at 1-min epochs. We used the following software to process the raw accelerometer and GPS data: Python (version 3.6.6), R (version 3.5.3), ArcGIS (version 10.3.1) and Postgresql (version 11.1) with PostGIS extension.

At baseline, one participant confronted problems with the device, and thus did not provide any data. The follow-up data was missing from seven participants due to dropping out of the intervention (n = 4), problems with the device (n = 2) or problems in data processing (n = 1). We further excluded the participants who did not have at least two valid measurement days (≥600 min of wear time) in both baseline and follow-up (n = 8), because at least 600 min of wear-time per day is a commonly used threshold when measuring physical activity with accelerometers (Aadland and Ylvisåker, 2015).

We used an algorithm developed by BrØnd et al. (2017) to convert raw accelerometer data to ActiGraph equivalent counts (for details see the 'activityCounts' package in R (Brondeel et al., 2019a)). We aggregated the counts per second to counts per minute and applied commonly used thresholds for light physical activity (>100 and ≤ 2020 counts/-minute) and MVPA (>2020 counts/minute) (Troiano et al., 2008). Wear time was defined using Choi-algorithm, which flags as non-wear time any measure within a 90-min time window of consecutive zero counts, allowing 2-min interval of non-zero counts with the up or downstream in 30 min consecutive zero counts window (Choi et al., 2011, 2018)·

The final analytic sample consisted of 45 participants who provided 537 valid days in total. From all valid days, 8% were completed in spring, 7% in summer, 45% in autumn and 40% in winter.

### 2.3. Identification of locations and trips

We used an algorithm developed by Thierry et al. (Kestens et al., 2018; Thierry, 2018; Thierry et al., 2013) to identify the locations and trips from raw GPS data. The algorithm operates globally by computing a kernel density surface from the GPS points, then derives stop locations by identifying local maxima. Finally, the track is segmented into stop and trip bouts by allocating GPS points to either a local peak or a trip segment. For further details and validity statistics, see Thierry et al. (2013) and Kestens et al. (2018), which further documents convergent validity of GPS activity locations with self-reported VERITAS map-based questionnaire locations. The time spent in physical activity was aggregated for each location and trip on a day-to-day basis using the collected bedtime from the diaries. The GPS identified location nearest to and within 100 m of the residential address of the participant was defined as home location. All other identified locations were defined as non-home locations. Average speed for each trip (km/h) was calculated based on the length and duration of the trip. The variable indicating the mode of travel was created by dichotomizing the trips based on average speed as active (<20 km/h) vs. passive (≥20 km/h). Among older adults, cycling is expected to be included in the slower speed category (Aittasalo et al., 2019; Oja et al., 1998). There are good sidewalks almost everywhere in urban areas in Finland, and cycling and walking are among the most popular forms of exercise among adults (Heino, 2019). Thus, walkability and possibilities for active travel in the neighborhoods where the study participants live is likely to be very high. We used ArcGIS (version 10.3.1) and Postgresql (version 11.1) with PostGIS extension to identify the GPS based locations and trips.

### 2.4. Measurement of residential greenness

The level of residential greenness was obtained by calculating NDVI from Landsat 8 Operational Land Imager (OLI) satellite images (Rhew et al., 2011; Su et al., 2019), using images with a maximum of 30% of cloud cover during the maximum vegetation greenness period (June, July, and August). Thus, we combined images from three consequent years (2017–2019) to generate cloud-free composite maps of median NDVI values for the whole study region. Residential mean NDVI-values were calculated within a square buffer of 1250 m × 1250 m around the GPS based home location of the participant. The same NDVI value was used for both activity measurement points. The variable indicating residential greenness was categorized into three classes, using inter-quartile ranges Q1 and Q3 as cut-off points: low (NDVI <0.60), moderate (NDVI 0.60–0.70) and high (NDVI >0.70).

### 2.5. Covariates

The covariates included age, gender, occupational status, neighborhood socioeconomic disadvantage, Body Mass Index (BMI), and mobility limitations, because these factors have been associated with the level of physical activity (Althoff et al., 2017; Doherty et al., 2017; Halonen et al., 2020; Portegijs et al., 2017; Pulakka et al., 2020). We also adjusted all our analyses with device wear time and measurement season. We obtained the information about the date of birth, gender and occupational status from Register of pension insurance institute for the municipal sector in Finland. As an indicator of socioeconomic status, we used participants' last occupational status and neighborhood socioeconomic disadvantage score. Occupational status was categorized following the International Classification of Occupations (ISCO): ISCO classes 1–4 were categorized as non-manual (e.g. physicians, teachers, registered nurses and secretaries) and ISCO-classes 5–9 as manual occupations (e.g. practical nurses, cooks, maintenance workers and cleaners) (Statistics Finland, 2020). The neighborhood socioeconomic disadvantage score was obtained from Statistics Finland and it is based on the proportion of adults with low education, the unemployment rate, and the median household income in the 250 × 250 m map grid of the home address. Higher scores on the continuous standardized index denote greater disadvantage (Halonen et al., 2020). Body weight and height were measured during a clinic visit at baseline and were used to calculate BMI (weight in kg/height in meters squared). Mobility limitation was defined using the validated RAND-36 Health Survey (identical with the Short Form SF-36) (Aalto et al., 1995, 1999; Hays et al., 1993) as difficulties in walking 2 km and dichotomized into no limitations (no difficulties) and limitations (some and marked difficulties).

### 2.6. Statistical analysis

The characteristics of the participants are reported as mean values with standard deviation (SD) for continuous variables, and as frequencies and percentages for categorical variables. To examine the changes in physical activity by context and by level of residential greenness, we used linear regression analysis with generalized estimating equations (GEE) and exchangeable correlation structure. The GEE models take into account the intra-individual correlation between repeated measurements. The GEE method fits a marginal model to longitudinal data. The regression parameters in the marginal model are interpreted as population-averaged (Liang and Zeger, 1986). The models were adjusted first for age, gender, wear time and measurement season (Model 1), then adding occupational status and neighborhood socioeconomic disadvantage (Model 2), and finally BMI and mobility limitations (Model 3).

In order to further examine the association between residential greenness and changes in physical activity, we also tested how the results replicated using continuous residential greenness.

Because we required merely two valid days for each time point in our data selection, we conducted a sensitivity analyses to test if the effect size remains on the same level as in the main analyses, when changing the requirement of valid days to four (Supplemental Fig. 1 and Supplemental Table 1).

We used SAS statistical software, version 9.4 (SAS Institute, Inc. Cary, North Carolina) to perform our analysis.

## 3. Results

Baseline characteristics of the study population are shown in Table 1. The mean age of the participants was 64.8 (SD 1.2) and majority of them were women (87%). Participants provided valid measurement data for an average of 6.0 (SD 1.4) days at baseline, and 5.9 (SD 1.6) days at 1-year follow-up. The average wear time was 844 min per day at baseline and 836 min per day at 1-year follow-up.

**Table 1**
Characteristics of the study population at baseline (n = 45).

| Variable | |
|---|---|
| **Age mean (SD)** | 64.8 (1.2) |
| **Gender n (%)** | |
| Men | 6 (13.3) |
| Women | 39 (86.7) |
| **Body Mass Index (BMI) mean (SD)** | 28.2 (4.1) |
| **Occupational category n (%)** | |
| Non-manual | 30 (66.7) |
| Manual | 15 (33.3) |
| **Mobility limitation n (%)** | |
| No limitations | 40 (88.9) |
| Limitations | 5 (11.1) |
| **Greenness n (%)** | |
| Low | 11 (24.4) |
| Moderate | 22 (48.9) |
| High | 12 (26.7) |
| **Neighborhood disadvange mean (SD)** | 0.1 (1.0) |
| **Valid days (≥600 min wear time/day) mean (SD)** | |
| Baseline | 6.0 (1.4) |
| 1-year follow-up | 5.9 (1.6) |
| **Wear time (min/day) mean (SD)** | |
| Baseline | 844 (125) |
| 1-year follow-up | 836 (119) |

**Table 2**
Mean daily total physical activity (Total PA), light intensity physical activity (Light PA) and moderate-to-vigorous intensity physical activity (MVPA) (minutes) at baseline and at 1-year follow-up by context.

| | | Mean | 95% CL | | P |
|---|---|---|---|---|---|
| **All contexts** | | | | | |
| Total PA | Baseline | 297.8 | 276.4 | 319.3 | 0.74 |
| | 1-year | 295.7 | 275.7 | 315.8 | |
| Light PA | Baseline | 272.5 | 253.3 | 291.7 | 0.04 |
| | 1-year | 258.1 | 240.5 | 275.6 | |
| MVPA | Baseline | 25.3 | 18.2 | 32.4 | <0.001 |
| | 1-year | 37.9 | 29.2 | 46.5 | |
| **Home** | | | | | |
| Total PA | Baseline | 181.1 | 158.6 | 203.6 | 0.22 |
| | 1-year | 191.9 | 165.5 | 218.2 | |
| Light PA | Baseline | 174.2 | 152.6 | 195.7 | 0.62 |
| | 1-year | 178.2 | 153.5 | 202.9 | |
| MVPA | Baseline | 6.9 | 3.5 | 10.3 | <0.001 |
| | 1-year | 13.7 | 9.2 | 18.2 | |
| **Non-home** | | | | | |
| Total PA | Baseline | 86.6 | 72.6 | 100.6 | 0.09 |
| | 1-year | 73.5 | 55.3 | 91.7 | |
| Light PA | Baseline | 80.3 | 66.8 | 93.7 | 0.06 |
| | 1-year | 66.9 | 49.4 | 84.4 | |
| MVPA | Baseline | 6.3 | 3.9 | 8.6 | 0.73 |
| | 1-year | 6.6 | 4.0 | 9.2 | |
| **Active travel** | | | | | |
| Total PA | Baseline | 20.8 | 15.9 | 25.7 | 0.59 |
| | 1-year | 22.1 | 16.1 | 28.1 | |
| Light PA | Baseline | 9.5 | 6.9 | 12.1 | 0.01 |
| | 1-year | 5.7 | 3.7 | 7.6 | |
| MVPA | Baseline | 11.3 | 7.1 | 15.4 | 0.03 |
| | 1-year | 16.5 | 11.0 | 21.9 | |
| **Passive travel** | | | | | |
| Total PA | Baseline | 9.4 | 6.9 | 11.9 | 0.58 |
| | 1-year | 8.8 | 6.3 | 11.3 | |
| Light PA | Baseline | 8.6 | 6.2 | 10.9 | 0.24 |
| | 1-year | 7.7 | 5.4 | 9.9 | |
| MVPA | Baseline | 0.8 | 0.3 | 1.3 | 0.46 |
| | 1-year | 1.2 | 0.5 | 1.9 | |

Adjusted for age, gender, wear time and measurement season.

Table 2 presents average minutes of daily total physical activity, light intensity physical activity and MVPA at baseline and at 1-year follow-up for all contexts as well as by context. Over the 1-year follow-up, for all contexts, no change was observed in total physical activity, but light intensity physical activity declined from 272 to 258 min/day (P = 0.04) and MVPA increased from 25 to 38 min/day (P < 0.001). At home location, MVPA increased from 7 to 14 min/day ($P < 0.001$) with no change in daily total or light intensity physical activity. At non-home locations, light intensity physical activity decreased from 80 to 67 min/day ($P = 0.06$). During active travel, MVPA increased from 11 to 16 min/day ($P = 0.03$) while light intensity physical activity decreased from 10 to 6 min/day ($P = 0.01$). No changes in physical activity during passive travel was observed.

Fig. 1 illustrates the changes (adjusted for age, gender, wear time and measurement season) in mean daily total physical activity, light intensity physical activity and MVPA by participants' residential greenness. At baseline, the low greenness group had a lower level of daily total physical activity ($P = 0.0007$) and light intensity physical activity ($P = 0.0041$) compared to the high greenness group. After the 1-year follow-up, differences between the groups persisted, and the high greenness group increased their daily MVPA more than low and moderate greenness groups. The differences were maintained after accounting for other potential confounders (Table 3). Daily MVPA increased most in the high greenness group (mean change +28 min/day over the 1-year follow-up) compared to the moderate greenness group (mean change +14 min/day) and particularly to the low greenness group (mean change +4 min/day) (Model 3, P for interaction Time*Greenness = 0.04). The sensitivity analyses using a requirement of four valid days instead of two in both time points, replicated the results of the main analysis (Supplemental Fig. 1 and Supplemental Table 1), as did the results of the analysis using the continuous residential greenness as an exposure (Supplemental Table 2).

## 4. Discussion

This study examined the changes in accelerometer-measured physical activity by context (home vs. non-home and active vs. passive travel) and by residential greenness among recent retirees who participated in a 1-year physical activity intervention. Overall, the daily total physical activity remained constant, but we observed that light intensity physical activity had decreased and MVPA had increased over time. The increase in MVPA occurred at home and during active travel, while the decrease in light intensity physical activity was observed in active travel. Moreover, residential greenness moderated the changes in physical activity. The participants residing in the highest greenness areas had a higher level of physical activity at baseline, and their daily MVPA increased more over the 1-year follow-up, compared to those residing in the lowest greenness areas.

The observed increases in MVPA at home location and during active travel are in line with previous cross-sectional studies showing that both home location and active travel (Holliday et al., 2017; Jansen et al., 2016) are important contexts of physical activity among middle aged and older adults. A study from Canada (Winters et al., 2015), using travel diaries and accelerometers, reported that active travel can be a dominant mode of travel among older adults residing in highly walkable neighborhoods, as two thirds of the trips were made by active modes. We cannot be sure, why the increase in MVPA took place at home; however, the qualitative interviews conducted in our project may bring more information about this when these data are analysed. Regarding active travel, the light intensity physical activity decreased roughly the same amount of minutes as MVPA increased, which suggests that some of the active travel has been done at a higher intensity than at baseline. Such enhancement of the physical activity intensity is beneficial and in line with the 24-h movement guidelines, assembled by the Consensus Panel of the Canadian Society for Exercise Physiology, that emphasize reallocating time from sedentary time and light intensity physical activity to more strenuous activities (Ross and Tremblay, 2020).

Concerning the results by residential greenness, prior studies using device-based measures for physical activity have reported more physical activity related to higher level of greenness exposure among adults (Dewulf et al., 2016; James et al., 2017). We similarly observed higher total physical activity and light intensity physical activity among participants residing in the greenest areas compared to those residing in the least green areas. The increase in MVPA over the 1-year follow-up, seen in our results, was higher for the participants residing in the greenest areas. Thus, the effectiveness of the intervention may vary spatially. It may be that greenness provides an attractive living environment that promotes more physical activity, which can also moderate the impacts of a physical activity intervention. However, there is a lack of earlier device-based longitudinal studies investigating the relationship between residential greenness and physical activity change. Future studies should continue to investigate the effect of greenness on physical activity also beyond the spatially fixed buffers around merely residential locations, in which our research was limited to. An example of such methodology is the research of Tamura et al. (2019), where they used small buffers around GPS points. They also observed higher level of greenness being associated with higher level of physical activity; however, our results cannot be directly compared because their study population was younger than ours.

This study has various strengths. Physical activity is a rather constant behavior during adult life, but we were able to collect our data before and after a physical activity intervention, which enabled us to examine the contexts of physical activity in a setting that aimed to increase physical activity. Our data were collected using a device providing both the accelerometer and GPS capabilities, allowing simultaneous measurement of the intensity and the contexts of physical activity, and thus ensuring the synchronization of sensors. Furthermore, our measures for residential greenness were precise, because greenness was assessed using a satellite-based vegetation index NDVI.

There are also limitations that should be acknowledged. First, while our results suggest that residential greenness was related to higher increase in MVPA, we are not able to tell whether the activity tracker intervention had an impact on the observed change, because we had no GPS measurements from the control group due to a lack of devices. Second, in present study we analyse the impact of residential greenness (using 1250 m square buffer around the residential address) on physical

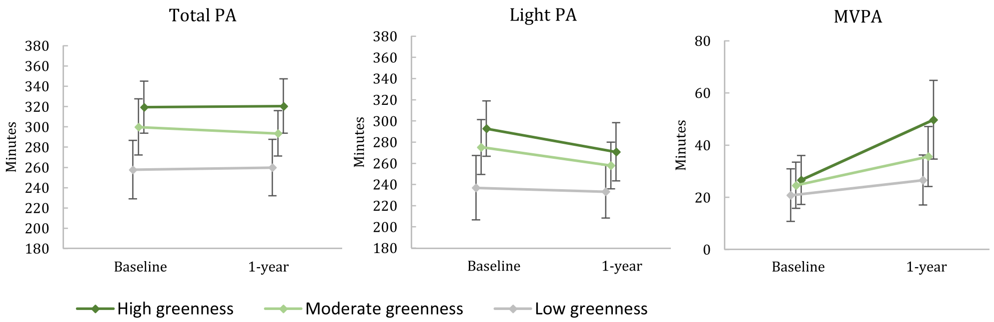

**Fig. 1.** Mean daily total physical activity (Total PA), light intensity physical activity (Light PA) and moderate-to-vigorous intensity physical activity (MVPA) (minutes) at baseline and at 1-year follow-up by residential greenness. Adjusted for age, gender, wear time and measurement season.

**Table 3**
Mean change over 1-year follow-up for daily total physical activity (Total PA), light intensity physical activity (Light PA) and moderate-to-vigorous intensity physical activity (MVPA) (minutes) by residential greenness.

| Intensity | Greenness | Baseline mean | Model 1 | | | | Model 2 | | | | Model 3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean change | 95% CL | | P* | Mean change | 95% CL | | P* | Mean change | 95% CL | | P* |
| Total PA | Low | 257.8 | 2.2 | −23.4 | 27.7 | 0.81 | 1.1 | −23.8 | 26.0 | 0.57 | 1.2 | −23.6 | 26.0 | 0.58 |
| | Moderate | 299.9 | −6.3 | −24.6 | 12.0 | | −10.5 | −30.4 | 9.4 | | −10.4 | −30.5 | 9.7 | |
| | High | 319.5 | 1.0 | −18.2 | 20.2 | | 5.0 | −15.5 | 25.5 | | 5.0 | −15.4 | 25.4 | |
| Light PA | Low | 236.9 | −3.6 | −32.3 | 25.2 | 0.59 | −2.4 | −30.2 | 25.5 | 0.43 | −2.2 | −29.9 | 25.5 | 0.43 |
| | Moderate | 275.4 | −17.3 | −36.6 | 1.9 | | −24.9 | −45.2 | −4.6 | | −24.7 | −45.1 | −4.3 | |
| | High | 292.8 | −22.0 | −42.8 | −1.2 | | −22.8 | −46.8 | 1.1 | | −22.8 | −46.7 | 1.1 | |
| MVPA | Low | 20.9 | 5.8 | −1.8 | 13.4 | 0.07 | 3.6 | −4.4 | 11.7 | 0.04 | 3.6 | −4.4 | 11.6 | 0.04 |
| | Moderate | 24.6 | 11.1 | 3.2 | 18.9 | | 14.5 | 7.4 | 21.6 | | 14.4 | 7.4 | 21.3 | |
| | High | 26.7 | 23.1 | 12.5 | 33.7 | | 28.0 | 13.9 | 42.1 | | 28.1 | 14.0 | 42.3 | |

Model 1. Adjusted for age, gender, wear time and measurement season.
Model 2. Adjusted for age, gender, wear time, measurement season, occupational status and neighborhood disadvantage.
Model 3. Adjusted for age, gender, wear time, measurement season, occupational status, neighborhood disadvantage, BMI and mobility limitations.
Mean change: 1-year after intervention vs. baseline.
*P for interaction Time*Greenness.

activity that occurs also outside of the exposure area. To push analysis of residential greenness away from issues of spatial misalignment of physical activity and greenness, future research should restrict the analyses to physical activity that occur within the studied buffer, when using spatially fixed buffers. This would help to ensure that the impact of residential greenness on physical activity has been examined within the actual exposure area measured. Third, our study population was rather small group of retirees in their 60's and majority of them were woman, which limits the generalizability of the findings. Also, due our small study population we required merely two valid measurement days (min 600 min wear time) instead of four or more, which is more commonly used in device-based studies. Fourth, our measurements were, for the most part, completed during autumn and winter, but the NDVI used in our study to measure residential greenness was based on the information from summertime. Thus, we may have assessed delayed effects of greenness on physical activity occurring other times of the year. However, greenness correlates with natural characteristics of the residential areas, such as open space and parks, which are present throughout the year. Fifth, we acknowledge the crudeness related to our way to dichotomize active and passive travel only by the speed of the trips, which can lead to misclassification of some the trips to wrong category. Finally, waist-worn accelerometers have an inadequate ability to detect certain activities, such as cycling, yoga, water sports and strength training (Schrack et al., 2016), which can lead to underestimation of the amount of physical activity. In addition, related to raw GPS-data, there is a possibility for missing GPS-points, as well as for false GPS-points (Thierry et al., 2013).

In conclusion, our results suggest that the increase observed in MVPA among recent retirees following a physical activity intervention occurs both at home and during active travel. Moreover, residential greenness was associated with both higher baseline level and increase in physical activity, meaning that those residing in the greenest areas were not only more active before the intervention, but also they increased their MVPA more over the follow-up than those residing in less green areas. This means that actions to increase greenness may contribute to higher level of physical activity among retirees, but also that the development and implementation of physical activity interventions should take residential contexts into consideration.

## Declaration of competing interest

Yan Kestens and Benoit Thierry are co-founders of Mobysens Inc., which developed and markets the SenseDoc device. Other authors have no competing interests.

## Acknowledgements

The work was supported by grants awarded by the Academy of Finland (Grant 321409 and 329240 to JV, 309526 to TL and 332030 to SS), the Juho Vainio Foundation (to TL), the Hospital District of Southwest Finland (to TL), and the Ministry of Education and Culture (Finland) (to SS). The authors would like to thank all the participants who took part in the REACT trial and the research staff members for their contribution in the data collection.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.healthplace.2021.102732.

## References

Aadland, E., Ylvisåker, E., 2015. Reliability of objectively measured sedentary time and physical activity in adults. PLoS One 10. https://doi.org/10.1371/journal.pone.0133296.

Aalto, A.-M., Aro, A.R., Teperi, J., 1999. RAND-36 Terveyteen Liittyvän Elämänlaadun Mittarina. In: Mittarin Luotettavuus Ja Suomalaiset Väestöarvot., Helsinki. Stakes, Tutkimuksia.

Aalto, A.-M., Aro, S., Aro, A.R., Mähönen, M., 1995. Rand 36-item Health Survey 1,0 : Suomenkielinen Versio Terveyteen Liittyvän Elämänlaadun Kyselystä : Kyselylomake Ja Käyttöohjeet, Stakes. Stakes.

Aittasalo, M., Tiilikainen, J., Tokola, K., Suni, J., Sievänen, H., Vähä-Ypyä, H., Vasankari, T., Seimelä, T., Metsäpuro, P., Foster, C., Titze, S., 2019. Socio-ecological natural experiment with randomized controlled trial to promote active commuting to work: process evaluation, behavioral impacts, and changes in the use and quality of walking and cycling paths. Int. J. Environ. Res. Publ. Health 16, 1661. https://doi.org/10.3390/ijerph16091661.

Althoff, T., Sosič, R., Hicks, J.L., King, A.C., Delp, S.L., Leskovec, J., 2017. Large-scale physical activity data reveal worldwide activity inequality. Nature 547, 336–339. https://doi.org/10.1038/nature23018.

BrØnd, J.C., Andersen, L.B., Arvidsson, D., 2017. Generating ActiGraph counts from raw acceleration recorded by an alternative monitor. Med. Sci. Sports Exerc. 49, 2351–2360. https://doi.org/10.1249/MSS.0000000000001344.

Brondeel, R., Anaraki, J.R., KhataeiPour, S., Fuller, D., 2019a. activityCounts: generate ActiLife counts. R package version 0.1.2. [WWW Document]. URL. https://cran.r-project.org/web/packages/activityCounts/index.html (accessed 3.12.21).

Brondeel, R., Wasfi, R., Perchoux, C., Chaix, B., Gerber, P., Gauvin, L., Richard, L., Gaudreau, P., Thierry, B., Chevrier, M., Hoj, S., Kestens, Y., 2019b. Is older adults' physical activity during transport compensated during other activities? Comparing 4 study cohorts using GPS and accelerometer data. J. Transp. Heal. 12, 229–236. https://doi.org/10.1016/J.JTH.2019.02.006.

Choi, L., Beck, C., Liu, Z., Matthews, C.E., Buchowski, M.S., 2018. Physical Activity: Process Accelerometer Data for Physical Activity Measurement. R Package Version 0.2-2.

Choi, L., Liu, Z., Matthews, C.E., Buchowski, M.S., 2011. Validation of accelerometer wear and nonwear time classification algorithm. Med. Sci. Sports Exerc. 43, 357–364. https://doi.org/10.1249/MSS.0b013e3181ed61a3.

Cunningham, C., O' Sullivan, R., Caserotti, P., Tully, M.A., 2020. Consequences of physical inactivity in older adults: a systematic review of reviews and meta-analyses. Scand. J. Med. Sci. Sports 30, 816–827. https://doi.org/10.1111/sms.13616.

Dewulf, B., Neutens, T., Van Dyck, D., de Bourdeaudhuij, I., Broekx, S., Beckx, C., Van de Weghe, N., 2016. Associations between time spent in green areas and physical activity among late middle-aged adults. Geospat. Health 11, 225–232. https://doi.org/10.4081/gh.2016.411.

Doherty, A., Jackson, D., Hammerla, N., Plötz, T., Olivier, P., Granat, M.H., White, T., van Hees, V.T., Trenell, M.I., Owen, C.G., Preece, S.J., Gillions, R., Sheard, S., Peakman, T., Brage, S., Wareham, N.J., 2017. Large scale population assessment of physical activity using wrist worn accelerometers: the UK biobank study. PLoS One 12, e0169649. https://doi.org/10.1371/journal.pone.0169649.

Halonen, J.I., Pulakka, A., Pentti, J., Kallio, M., Koskela, S., Kivimäki, M., Kawachi, I., Vahtera, J., Stenholm, S., 2020. Cross-sectional associations of neighbourhood socioeconomic disadvantage and greenness with accelerometer-measured leisure-time physical activity in a cohort of ageing workers. BMJ Open 10, 38673. https://doi.org/10.1136/bmjopen-2020-038673.

Hays, R.D., Sherbourne, C.D., Mazel, R.M., 1993. The rand 36-item health survey 1.0. Health Econ. 2, 217–227. https://doi.org/10.1002/hec.4730020305.

Heino, A., 2019. Aikuisväestön liikunta Suomessa-FinTerveys 2017-tutkimus. Terveyden ja hyvinvoinnin laitos. Tilastoraportti 48, 2019.

Holliday, K.M., Howard, A.G., Emch, M., Rodríguez, D.A., Rosamond, W.D., Evenson, K. R., 2017. Where are adults active? An examination of physical activity locations using GPS in five US cities. J. Urban Health 94, 459–469. https://doi.org/10.1007/s11524-017-0164-z.

James, P., Hart, J.E., Hipp, J.A., Mitchell, J.A., Kerr, J., Hurvitz, P.M., Glanz, K., Laden, F., 2017. GPS-based exposure to greenness and walkability and accelerometry-based physical activity. Cancer Epidemiol. Biomarkers Prev. 26, 525–532. https://doi.org/10.1158/1055-9965.EPI-16-0925.

Jansen, M., Ettema, D., Pierik, F., Dijst, M., Jansen, M., Ettema, D., Pierik, F., Dijst, M., 2016. Sports facilities, shopping centers or homes: what locations are important for adults' physical activity? A cross-sectional study. Int. J. Environ. Res. Publ. Health 13, 287. https://doi.org/10.3390/ijerph13030287.

Kerr, J., Norman, G.J., Adams, M.A., Ryan, S., Frank, L., Sallis, J.F., Calfas, K.J., Patrick, K., 2010. Do neighborhood environments moderate the effect of physical activity lifestyle interventions in adults? Health Place 16, 903–908. https://doi.org/10.1016/j.healthplace.2010.05.002.

Kestens, Y., Thierry, B., Shareck, M., Steinmetz-Wood, M., Chaix, B., 2018. Integrating activity spaces in health research: comparing the VERITAS activity space questionnaire with 7-day GPS tracking and prompted recall. Spat. Spatiotemporal. Epidemiol. 25, 1–9. https://doi.org/10.1016/j.sste.2017.12.003.

Leskinen, T., Suorsa, K., Tuominen, M., Pulakka, A., Pentti, J., Löyttyniemi, E., Heinonen, I., Vahtera, J., Stenholm, S., 2021. The effect of consumer-based activity tracker intervention on physical activity among recent retirees – an RCT study. Med. Sci. Sports Exerc.

Liang, K.Y., Zeger, S.L., 1986. Longitudinal Data Analysis Using Generalized Linear models, pp. 13–22.

Oja, P., Vuori, I., Paronen, O., 1998. Daily walking and cycling to work: their utility as health-enhancing physical activity. Patient Educ. Counsel. 33, S87–S94. https://doi.org/10.1016/S0738-3991(98)00013-5.

Portegijs, E., Keskinen, K., Tsai, L.-T., Rantanen, T., Rantakokko, M., 2017. Physical limitations, walkability, perceived environmental facilitators and physical activity of older adults in Finland. Int. J. Environ. Res. Publ. Health 14, 333. https://doi.org/10.3390/ijerph14030333.

Pulakka, A., Leskinen, T., Suorsa, K., Pentti, J., Halonen, J.I., Vahtera, J., Stenholm, S., 2020. Physical activity across retirement transition by occupation and mode of commute. Med. Sci. Sports Exerc. 1 https://doi.org/10.1249/mss.0000000000002326.

Rhew, I.C., Vander Stoep, A., Kearney, A., Smith, N.L., Dunbar, M.D., 2011. Validation of the normalized difference vegetation index as a measure of neighborhood greenness. Ann. Epidemiol. 21, 946–952. https://doi.org/10.1016/j.annepidem.2011.09.001.

Ross, R., Tremblay, M., 2020. Introduction to the Canadian 24-Hour Movement Guidelines for Adults aged 18-64 years and Adults aged 65 years or older: an integration of physical activity, sedentary behaviour, and sleep. Appl. Physiol. Nutr. Metabol. 45 https://doi.org/10.1139/apnm-2020-0843 v–xi.

Schrack, J.A., Cooper, R., Koster, A., Shiroma, E.J., Murabito, J.M., Rejeski, W.J., Ferrucci, L., Harris, T.B., 2016. Assessing daily physical activity in older adults: unraveling the complexity of monitors, measures, and methods. Journals Gerontol. - Ser. A Biol. Sci. Med. Sci. https://doi.org/10.1093/gerona/glw026.

Statistics Finland, 2020. Tilastokeskus - luokitukset - classification of occupations 2001 [WWW Document]. URL. http://www.stat.fi/meta/luokitukset/ammatti/001-2001/index_en.html (accessed 3.12.21).

Su, J.G., Dadvand, P., Nieuwenhuijsen, M.J., Bartoll, X., Jerrett, M., 2019. Associations of green space metrics with health and behavior outcomes at different buffer sizes and remote sensing sensor resolutions. Environ. Int. 126, 162–170. https://doi.org/10.1016/j.envint.2019.02.008.

Sugiyama, T., Giles-Corti, B., Summers, J., du Toit, L., Leslie, E., Owen, N., 2013. Initiating and maintaining recreational walking: a longitudinal study on the influence of neighborhood green space. Prev. Med. 57, 178–182. https://doi.org/10.1016/j.ypmed.2013.05.015.

Tamura, K., Wilson, J.S., Goldfeld, K., Puett, R.C., Klenosky, D.B., Harper, W.A., Troped, P.J., 2019. Accelerometer and GPS data to analyze built environments and physical activity. Res. Q. Exerc. Sport 90, 395–402. https://doi.org/10.1080/02701367.2019.1609649.

Thierry, B., 2018. Unpublished work: "Linking Finnish SenseDoc data to environmental indicators. Finland pilot project. Version 1.1.

Thierry, B., Chaix, B., Kestens, Y., 2013. Detecting activity locations from raw GPS data: a novel kernel-based algorithm. Int. J. Health Geogr. 12, 14. https://doi.org/10.1186/1476-072X-12-14.

Troiano, R.P., Berrigan, D., Dodd, K.W., Mâsse, L.C., Tilert, T., Mcdowell, M., 2008. Physical activity in the United States measured by accelerometer. Med. Sci. Sports Exerc. 40, 181–188. https://doi.org/10.1249/mss.0b013e31815a51b3.

Van Holle, V., Deforche, B., Van Cauwenberg, J., Goubert, L., Maes, L., Van de Weghe, N., De Bourdeaudhuij, I., 2012. Relationship between the physical environment and different domains of physical activity in European adults: a systematic review. BMC Publ. Health 12, 807. https://doi.org/10.1186/1471-2458-12-807.

Winters, M., Voss, C., Ashe, M.C., Gutteridge, K., McKay, H., Sims-Gould, J., 2015. Where do they go and how do they get there? Older adults' travel behaviour in a highly walkable environment. Soc. Sci. Med. 133, 304–312. https://doi.org/10.1016/J.SOCSCIMED.2014.07.006.