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CONTEXT-RELATED PHYSICAL ACTIVITY AND SEDENTARY BEHAVIOUR BEFORE AND AFTER RETIREMENT

GPS and accelerometer-based study

Sanna Pasanen



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ABSTRACT

In addition to individual and social factors, many environmental factors can modify physical activity. However, few studies have focused on older age groups. The aims of this dissertation were to examine the contexts in which physical activity and sedentary behaviour takes place before and after statutory retirement, and how natural vegetation, i.e., greenness, relates to physical activity. The study also examined changes in physical activity and sedentary behaviour during retirement, in relation to physical activity linked to pre-retirement work and commuting. The data was derived from the Finnish Retirement and Aging study (n=102–137) and from the Enhancing Physical Activity and Healthy Aging among Recent Retirees trial (n=45–53), and was collected using a device with GPS and accelerometer sensors.

On workdays, more time was spent, and more physical activity and sedentary time accumulated, in non-home locations than at home. Conversely, on days off, more sedentary time and physical activity accumulated at home. Greater exposure to green space during active travel (i.e., trips made in physically active ways) was associated with higher total and moderate-to-vigorous physical activity (MVPA) during active travel. However, these associations were observed on days off and on retirement days, but not on workdays. Greater residential greenness was positively associated with the level of retirees' physical activity. In addition, MVPA at home or during active travel increased to a greater extent during the physical activity intervention among retirees with the greatest exposure to residential greenness. Pre-retirement work-related and commuting physical activity predicted changes in physical activity and sedentary behaviour during retirement transition.

To conclude, this study shows that physical activity and sedentary behaviour are associated with different contexts. The results also highlight the need to distinguish between workdays and non-workdays when analysing the contexts of physical activity and sedentary behaviour among working-age populations. The study observed a positive association between greenness and physical activity, both overall and during active travel. Thus, accessible, good quality green spaces in residential areas and around pedestrian and bicycle lanes may promote physical activity among late middle-aged people.

KEYWORDS: Accelerometer, Active travel, Activity locations, Built environments, GPS, Greenness, Green spaces, Physical activity, Retirement

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TIIVISTELMÄ

Liikkumiseen, eli fyysiseen aktiivisuuteen, vaikuttavat yksilö- ja sosiaalisten tekijöiden lisäksi myös ympäristötekijät. Näitä tekijöitä on tutkittu verrattain vähän vanhemmissa ikäryhmissä. Tämän väitöskirjatutkimuksen tavoitteena oli tarkastella niitä ympäristöjä, missä liikkumista ja paikallaanoloa kertyy sekä ennen että jälkeen ikäperusteisen eläköitymisen. Lisäksi tutkittiin luontoympäristön, ts. vihreyden, yhteyttä liikkumiseen. Tutkimuksessa tarkasteltiin myös muutoksia liikkumisessa ja paikallaanolossa eläkesiirtymän aikana, riippuen työssä ja työmatkoilla ennen eläköitymistä kertyneestä fyysisestä aktiivisuudesta. Tutkimus perustuu Finnish Retirement and Aging study (n=102–137) ja Enhancing Physical Activity and Healthy Aging among Recent Retirees trial (n=45–53) tutkimuksiin. Aineistot kerättiin käyttäen GPS-sensorin ja liikemittarin yhdistävää laitetta.

Enemmän aikaa vietettiin ja siten enemmän fyysistä aktiivisuutta ja paikallaanoloaika kertyi työpäivinä kodin ulkopuolisissa paikoissa (vs. kotona) ja päinvastoin, vapaapäivinä enemmän kotona (vs. kodin ulkopuolella). Vihreys oli positiivisesti yhteydessä aktiivisiin tavoin kuljettujen matkojen aikana kertyneeseen fyysiseen kokonaisaktiivisuuteen sekä keskiraskaaseen tai raskaaseen fyysiseen aktiivisuuteen vapaa- ja eläkepäivinä, mutta ei työpäivinä. Asuinalueen suurempi vihreys oli yhteydessä eläkeläisten korkeampaan fyysisen aktiivisuuden tasoon sekä liikuntaintervention aikana lisääntyneeseen, kotona tai aktiivisen matkanteon aikana kertyneeseen, keskiraskaaseen tai raskaaseen fyysiseen aktiivisuuteen. Työhön ja työmatkoihin liittyvä fyysinen aktiivisuus ennen eläköitymistä ennusti muutoksia liikkumisessa ja paikallaanolossa eläkkeelle siirtymisen aikana.

Tämän tutkimuksen tulokset osoittavat, että eri ympäristöt ovat yhteydessä myöhäiskeskä-ikäisten liikkumiseen ja paikallaanoloon. Tulokset korostavat, että liikkumisen ja paikallaanolon ympäristöjä on tarpeen tarkastella erikseen työ- vapaa- ja eläkepäivinä. Tutkimuksessa havaittiin vihreyden positiivinen yhteys liikkumiseen yleisesti sekä erityisesti aktiivisiin tavoin kuljettujen matkojen aikana kertyneeseen liikkumiseen. Näin ollen, viheralueet asuinalueilla ja jalankulku- ja pyöräilyväylien varrella voivat tukea myöhäiskeskä-ikäisten liikkumista.

AVAINSANAT: Aktiivinen matkanteko, Eläköityminen, Fyysinen aktiivisuus, GPS, Liikemittari, Luontoympäristö, Rakennettu ympäristö, Viheralueet, Vihreys

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Abbreviations

BMI	Body Mass Index
CI	Confidence Interval
CORINE	Coordination of Information on the Environment
FIREA	Finnish Retirement and Aging study
GPS	Global Positioning System
HLPA	High-Light Physical Activity
ISCO	International Standard Classification of Occupations
LLPA	Low-Light Physical Activity
LMVPA	Light, Moderate and Vigorous Physical Activity
LPA	Light Physical Activity
MET	Metabolic Equivalent
MPA	Moderate Physical Activity
MVPA	Moderate-to-Vigorous Physical Activity
NDVI	Normalized Difference Vegetation Index
PA	Physical Activity
REACT	Enhancing Physical Activity and Healthy Aging among Recent Retirees trial
SD	Standard Deviation
SED	Sedentary Time
SES	Socioeconomic Status
VPA	Vigorous Physical Activity
WHO	World Health Organization

List of Original Publications

This dissertation is based on the following original publications, which are referred to in the text by their Roman numerals:

- I Pasanen S, Halonen JI, Pulakka A, Kestens Y, Thierry B, Brondeel R, Pentti J, Vahtera J, Leskinen T, Stenholm S. Contexts of sedentary time and physical activity among ageing workers and recent retirees: cross-sectional GPS and accelerometer study. *BMJ Open*. 2021 May 18;11(5):e042600.
- II Pasanen S, Halonen JI, Suorsa K, Leskinen T, Kestens Y, Thierry B, Pentti J, Vahtera J, Stenholm S. Does work-related and commuting physical activity predict changes in physical activity and sedentary behavior during the transition to retirement? GPS and accelerometer study. *Health & Place*. 2023. 81:103025.
- III Pasanen S, Halonen JI, Gonzales-Inca C, Pentti J, Vahtera J, Kestens Y, Thierry B, Brondeel R, Leskinen T, Stenholm S. Changes in physical activity by context and residential greenness among recent retirees: Longitudinal GPS and accelerometer study. *Health & Place*. 2022. 73:102732.
- IV Pasanen S, Halonen JI, Suorsa K, Leskinen T, Gonzales-Inca C, Kestens Y, Thierry B, Pentti J, Vahtera J, Stenholm S. Exposure to useable green space and physical activity during active travel: A longitudinal GPS and accelerometer study before and after retirement. *Health & Place*. 2024. 90: 103366.

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1 Introduction

One of the most important modifiable health behavioural factors is physical activity, as adequate physical activity reduces the risk of several chronic diseases and mortality, and helps people manage chronic illnesses and maintain physical and cognitive function when ageing (Bauman et al., 2016; Cunningham et al., 2020; DiPietro et al., 2019; Warburton and Bredin, 2017). Conversely, a high level of sedentary behaviour has been associated with a higher risk of several chronic diseases and increased mortality (De Rezende et al., 2014). Studies have reported a higher prevalence of insufficient physical activity among adults aged 60 and older (Bauman et al., 2016; Caspersen et al., 2000; Strain et al., 2024), and substantial increases have also been reported in sedentary behaviour after the age of 60 (Harvey et al., 2015). Less than half of Finnish middle-aged and late middle-aged adults engage in sufficient physical activity in accordance with the Finnish recommendations for health-enhancing physical activity (Finnish Institute for Health and Welfare, 2024).

Daily physical activity and sedentary behaviour occur in various contexts, and among adults are usually related to occupation, daily routines and preferred leisure activities (Samitz et al., 2011). Modifying different environments to encourage more physical activity can offer opportunities for promoting physical activity. Retirement, the common life transition in late middle age, can also lead to either positive or negative changes in physical activity behaviour (Gropper et al., 2020; Sprod et al., 2015; Vansweevelt et al., 2022), and in the contexts in which daily activities occur.

The home and the workplace are the contexts in which most physical activity, but also sedentary behaviour, accumulate (Holliday et al., 2017a; Jansen et al., 2016). It has been observed that more strenuous physical activity, such as moderate-to-vigorous physical activity (MVPA), often accumulates during trips and particularly during active travel, i.e., during trips made in physically active ways (Brondeel et al., 2019; Chaix et al., 2014; Costa et al., 2015; Holliday et al., 2017a; Jansen et al., 2016). Of all environmental characteristics, this dissertation focuses on exposure to natural vegetation, as green spaces and general greenness are reported to be associated with higher levels of physical activity (Chaix et al., 2016; Dewulf et al., 2016; James et al., 2017; Jansen et al., 2017, 2018; Marquet et al., 2022) and

participation in active travel (Chaix et al., 2016; Hirsch et al., 2016; Jansen et al., 2017; Marquet et al., 2022). Active travel and green spaces have also been the interest of policymakers, not only due to their health benefits, but also because they present co-benefits related to more sustainable communities (World Health Organization, 2018).

Prior studies examining physical activity and sedentary behaviour in different contexts or by greenness level, have been based on either self-reported measures, which are prone to biases, or on cross-sectional study design, which prevents the examination of behavioural changes over time. The limitations of self-reported measures can be overcome by measuring physical activity using accelerometry and Global Positioning System (GPS)-based devices. Using GPS in combination with accelerometer measurements increases the precision of both the measures of physical activity and sedentary behaviour and the examined exposure, for example, greenness, in comparison to self-reported measures (Schrack et al., 2016; Strath et al., 2013).

A few GPS and accelerometer-based studies of physical activity behaviour in different contexts have focused on weekdays and weekends (James et al., 2017; Ramulu et al., 2012). However, no studies have separately examined workdays, days off and retirement days, which better represent the activities of shift workers or people who have already retired. This dissertation separately examines the differences between physical activity and sedentary behaviour in different contexts on different days: on workdays and days off before retirement, and on days after retirement. This is because physical activity and sedentary behaviour in different contexts do not take place in the same way on all days or over time.

The aims of this dissertation were to examine the contexts in which physical activity and sedentary behaviour takes place before and after retirement, and how greenness is related to physical activity in different contexts. The study also examined how physical activity and sedentary behaviour change during the transition to statutory retirement, depending on physical activity at the pre-retirement workplace and while commuting. The study further analysed how the physical activity behaviour, among those participating in physical activity intervention, changed in the different contexts, and how greenness was related to the observed changes. A novel wearable device with GPS and movement sensors was used to measure physical activity and sedentary behaviour both before and after retirement, in different locations, and during travel.

2 Review of the Literature

2.1 Defining and assessing physical activity and sedentary behaviour

Physical activity is commonly defined as all bodily movements produced by skeletal muscles that result in energy expenditure (Caspersen et al., 1985; World Health Organization, 2020). In addition to amount, the intensity of physical activity is often considered in health-related discussions. The typically measured physical activity intensities are light physical activity (LPA) and MVPA. Physical activity can be further classified as either structured or incidental. Structured physical activity is planned, purposefully and repetitively practiced exercise with the objective of improving physical fitness, and incidental physical activity is unplanned and accumulates from daily activities at work, at home or during travel (Caspersen et al., 1985; Strath et al., 2013). Sedentary behaviour, in contrast, is considered as any waking time spent in a sitting, reclining or lying posture with an energy expenditure of no more than 1.5 metabolic equivalents (METs) (Tremblay et al., 2017).

The most common way of measuring physical activity or sedentary behaviour is self-reported methods, typically questionnaires. However, these methods are prone to recall, social desirability and measurement bias (Schrack et al., 2016; Strath et al., 2013). Self-reported diaries or logs may overcome some of these limitations, but diaries are rather burdensome for participants and challenging to analyse in large population-based studies. To improve the accuracy of measurements, and as a feasible method for both participants and researchers, wearable devices that contain an accelerometer are often used. Accelerometers enable more accurate information on the time, duration and intensity of activity than self-reported information. The devices can be worn in several places on the body, such as the waist, hip or thigh (Heesch et al., 2018; Sylvia et al., 2014). Moreover, combining a GPS sensor with an accelerometer enables a more objective examination of the context-related patterns of physical activity and sedentary behaviour, as GPS devices provide precise information on an individual's locations and travel between these locations, i.e., the contexts in which physical activity or sedentary behaviour occurs. Moreover, integrating combined GPS and accelerometer data with geographical data, such as information on green spaces or the general greenness of the locations or during trips,

enables objective analysis of how these environmental characteristics associate with physical activity behaviour.

2.2 Guidelines for physical activity and sedentary behaviour

The Finnish guidelines for adequate physical activity for adults aged 18–64 and over 65 years recommend moderately strenuous aerobic exercise for at least 2 hours 30 minutes per week or vigorous aerobic exercise for at least 1 hour 15 minutes per week, and muscle strengthening and balance activities for at least twice a week (UKK Institute, 2024). As a basis, doing light physical activities as often as possible and taking breaks from sedentary behaviours whenever possible is recommended. These recommendations are consistent with the international guidelines of the World Health Organization (WHO) (2020) for physical activity and sedentary behaviour. The Canadian 24-hour movement guidelines for adults (Ross et al., 2020) give more precise advice for limiting sedentary behaviour: they recommend restricting sedentary behaviour to eight hours or less, which includes no more than three hours of recreational screen time. Like the Finnish recommendations (UKK Institute, 2024), the Canadian 24-hour movement guidelines recommend breaking up long periods of sitting as often as possible. The 2022–2023 Healthy Finland Survey showed that 42% of men and 37% of women reached the recommended level of adequate physical activity in the 55–64-year age group. In the 65–74-year age group, the proportion was slightly higher, as 46% of men and 40% of women reached the recommended levels (Finnish Institute for Health and Welfare, 2024). According to the Measured physical activity, sedentary behavior and physical fitness of Finns 2018–2022 report, which used waist-worn accelerometers for data collection, the recommended amount of aerobic exercise was reached by 49% of men and 56% of women in the 50–59-year age group, and by 46% of men and 54% of women in the 60–69-year age group (Husu et al., 2022).

2.3 Changes in physical activity and sedentary behaviour during retirement

Physical activity decreases (Bauman et al., 2016; Caspersen et al., 2000) and sedentary behaviour increases (Harvey et al., 2015) as age increases. In addition, various life transitions, such as getting married, becoming a parent, or entering the labour market, are associated with changes in physical activity and sedentary behaviour (Gropper et al., 2020). One of the most common of these transitions is retirement. Prior studies that have used self-reported measures of physical activity have found that the transition to statutory retirement often increases leisure and

domestic physical activity, but reduces work- and travel-related physical activity and total physical activity. Low socioeconomic status (SES) has been associated with a decrease, and high SES with an increase in physical activity (Barnett et al., 2012; Gropper et al., 2020).

Pre-retirement work-related physical activity seems to play a considerable role in the changes in physical activity and sedentary behaviour during the transition to retirement. Several studies have shown that self-reported physical activity tends to decrease during the retirement transition among those with physically demanding pre-retirement work or manual occupations, whereas sedentary work or higher occupational position is associated with an increase in physical activity (Celidoni and Rebba, 2017; Chung et al., 2009; Stenholm et al., 2016).

The Finnish Retirement and Aging study (FIREA) was the first to publish the changes in physical activity and sedentary behaviour during the retirement transition based on accelerometer data. The study observed that, in line with prior self-reported results, the greatest decrease in total physical activity (Pulakka et al., 2020) and increase in total and prolonged sedentary time (Suorsa et al., 2022, 2021, 2019) occurred among women retiring from manual occupations. The FIREA study also suggested that retirement reduces the proportion of time spent on active behaviours, particularly MVPA, in relation to time spent on passive behaviours, i.e., sedentary time and sleep (Suorsa et al., 2022). Concerning active travel, among the FIREA participants, cycling to work was associated with better maintenance of physical activity level during the transition to retirement (Pulakka et al., 2020).

2.4 Examining the contexts of physical activity and sedentary behaviour using GPS and accelerometers

Methods that combine GPS and accelerometer sensors for collecting data are still considered novel, although they were piloted two decades ago (Rodríguez et al., 2005). Early GPS and accelerometer-based studies in particular, that have explored the association between environmental factors and physical activity behaviour among adults, have often only focused on the characteristics of residential neighbourhoods and how they modify physical activity behaviour (Rodríguez et al., 2005; Troped et al., 2010). Although near-home environments have shown to be important contexts for daily physical activity (Firth et al., 2022), particularly among older populations, (James et al., 2017), a significant portion of people's physical activity accumulates in areas other than around their homes (Chaix et al., 2012; Hillsdon et al., 2015; Troped et al., 2010). Methodological advancements, including the use of GPS for data collection, have enabled more dynamic measures to better identify the locations in which people have stayed during their daily activities and

the routes between these locations (Brondeel et al., 2019; Marquet et al., 2022; Perchoux et al., 2023). The following chapters present prior GPS and accelerometer-based studies and data collection methods, that can be used to study physical activity and sedentary behaviour in not only residential but also non-residential contexts. The literature review focuses on results from the Western world, so the results are comparable to those of this dissertation.

2.4.1 Physical activity and sedentary behaviour in different locations and during travel

Physical activity and sedentary behaviour take place in different locations and during travel. Table 1 summarizes the results of previous studies, all cross-sectional, of the accelerometer-measured physical activity and sedentary behaviour among adults in GPS-detected locations or during travel.

A study from the Netherlands (Jansen et al., 2016), which used a waist-worn accelerometer and a GPS device, showed that most of the adults' MVPA accumulated at home (10.4 min/per day) or at work (9.9 min/day). However, most of their waking hours were spent at home (311 min/day) and the workplace (298 min/day), and their results showed that the highest MVPA ratios in relation to total time spent in a location were obtained in sport facilities and during travel.

A French study, among middle-aged participants, which collected data using GPS and waist-worn accelerometers and a GPS-based mobility survey, showed that 38% of the steps taken and 33% of the MVPA over seven days were attributable to trips (Chaix et al., 2014). A study by Costa et al. (2015) among UK adults, which collected data using a travel diary and a device with GPS, accelerometer and heart rate sensors, observed that when commuting involved walking or cycling alone, a median of 89% or 100% of the time of the journey was MVPA, respectively. In the case of multimodal journeys (i.e., car and walk or car and cycling) a median of 21–23% of the journey was MVPA (Costa et al., 2015). Furthermore, Brondeel et al. (2019) reported that a large share of MVPA accumulated during travel among older adults. They used data from four cohorts from Canada, Luxembourg and France, collected using GPS and waist-worn accelerometers, and observed that the physical activity recorded during transport corresponded to 21% of daily total physical activity. As regards to the level of physical activity intensity; 23% of MVPA, 12% of high-light physical activity and 17% of low-light physical activity minutes was recorded during transportation.

A study among US adults by Ramulu et al. (2012), which used travel diaries and waist-worn accelerometer devices with GPS capabilities to collect data, examined the differences between walking within and walking outside a residential area, i.e., home region, on weekdays and weekend days. They observed that the majority of

steps (4255 steps/day) on weekdays were taken outside the home region, in comparison to 848 steps/day taken within the home region. No significant differences were observed between the number of steps taken within and outside home region at weekends. Another study among US adults by Holliday et al. (2017a), which used GPS and waist-worn accelerometers, investigated MVPA in different locations. They examined physical activity in bouts of ≥ 10 minutes and compared the results using different MVPA definitions: those of Matthews (≥ 760 counts per minute (cpm)) (Matthews, 2005) and the National Health and Nutrition Examination Survey (NHANES) (≥ 2020 cpm) (Troiano et al., 2008). The results differed in terms of used threshold, as they showed that the most common context for MVPA using Matthews' definition was the home (29% of bouts), but that the most common location using the NHANES definition was roads (28% of bouts). In their study, roads were particularly important for MVPA accumulation among the oldest age group of 60–85 years, regardless of the MVPA definition used (21% for Matthews' and 42% for NHANES definition).

Only a few studies have investigated adults' or older adults' sedentary behaviour on the basis of GPS and accelerometer-measured sedentary behaviour in different locations or during travel. A study by Perchoux et al. (2023), among late middle-aged and older adults from Luxembourg, which used GPS and waist-worn accelerometers, observed that sedentary time spent at the participants' residence accounted for 87% of location-based sedentary time (i.e., sedentary time divided between locations and trips) and 71% of total sedentary time. They also observed that sedentary time during motorized transportation represented 13% of total sedentary time. Brondeel et al. (2019) in turn reported that 14% of sedentary behaviour per day accumulated during transport.

To summarize, although much of physical activity seems to accumulate at home (Holliday et al., 2017a; Jansen et al., 2016), most sedentary time also accumulates there (Perchoux et al., 2023). Depending on occupation, much of person's physical activity or sedentary behaviour also accumulates at the workplace (Jansen et al., 2016). Prior studies have consistently shown that large amounts of MVPA (Brondeel et al., 2019; Costa et al., 2015; Holliday et al., 2017a; Jansen et al., 2016) or steps (Chaix et al., 2014) accumulate during trips, especially when the analyses examined active travel separately from motorized transport (Costa et al., 2015). One prior study observed a difference between steps taken within and outside residential areas on weekdays, but not on weekend days (Ramulu et al., 2012). Therefore, the type of day seems to be another factor that analyses should consider.

Table 1. GPS-based studies of accelerometer-measured physical activity or sedentary behaviour in different contexts.

AUTHORS, YEAR	PARTICIPANTS, POPULATION, N, GENDER, AGE, COUNTRY	DEVICE(S), WEAR LOCATION, LENGTH OF MEASUREMENT	MEASURED ACTIVITY BEHAVIOUR	CONTEXT	MAIN RESULTS
PERCHOUX ET AL. (2023)	Adults in Luxembourg, n=471, 49.4% female, Age: ≥65yrs	SenseDoc (GPS and accelerometer), Waist, 7 days	Total SED, residential SED, location-based SED, trip-based SED	Locations and trips, residence	SED spent at locations accounted for 83% of total SED. SED spent at residence accounted for 87% of location-based SED and 71% of total SED. Trip-based SED represented 13% of total SED.
FIRTH ET AL. (2022)	Adults in Canada, n=544, 51–71% female, Age: ≥18yrs	SenseDoc (GPS and accelerometer), Wear location not reported, 10 days	Total time spent in LPA, MPA, VPA and MVPA	Home and census-based neighbourhood	Majority of PA took place near or at home, and 45% of time spent in PA was in census-based neighbourhood.
BRONDEEL ET AL. (2019)	Older adults in Canada, Luxembourg, and France, n=636, 49% female, Age: ≥65yrs	SenseDoc (GPS and accelerometer), or QStarz BT (GPS)-Q1000XT with ActiGraph wGT3X+ (accelerometer), Waist, 7 days	Transport-related and daily, MVPA, HLPA, LLPA, SED	PA during trip, transport-related PA, non-transport PA	23% of MVPA, 12% of HLPA, 17% of LLPA, and 14% of SED per day accumulated during transport.
HOLLIDAY ET AL. (2017A)	Adults in the US, n=223, 57% female, Age: 18–85yrs	QStarz BT-1000X (GPS) with ActiGraph GT1M (accelerometer), Waist, 3 weeks	MVPA, VPA	Home, roads	Homes and roads encompassed >40% of bout-based PA minutes, regardless of intensity. Older adults often used roads for MVPA bouts.
JANSEN ET AL. (2016)	Adults in the Netherlands, n=308, 55% female, Age: 45–65yrs	QStarz BT-Q1000X (GPS) with ActiGraph GT3X (accelerometer), Waist, 7 days	MVPA	Home, shopping area, workplace, sports facilities other residential area	Most MVPA minutes accumulated at home and at the workplace. The highest MVPA ratios in relation to total time spent in a location were achieved in sports facilities and during transport.

COSTA ET AL. (2015)	Working adults in the UK, n=41, 56% female, Age 24–62yrs	QStarz BT-Q1000X (GPS) with Actiheart (accelerometer and heart rate monitor), Chest, 7 days	SED, LPA, MVPA and VPA in MET during commute to or from work	Commuting journeys by mode of transportation (self-reported; car, bus, car + walk, car + cycle, walk, cycle)	About 20% of the journeys durations, including any active travel (corresponding to 8 min) was spent in MVPA. Median PA intensity was 1.28 MET for car journeys; 1.67 MET for bus journeys; 4.61 MET for walking journeys; 6.44 MET for cycling journeys; 1.78 MET for journeys by car in combination with walking; and 2.21 MET for journeys by car in combination with cycling.
DEWULF ET AL. (2016)	Late middle-aged adults in Belgium, n=180, 48% female, Age: 59–65yrs	QStarz BT-Q1000XT (GPS) with ActiGraph GT3X (accelerometer), Waist, 7 days	SED, LPA, MVPA	Home	Spending more time at home was associated with more SED. Positive association was strongest among retired participants.
HILLSDON ET AL. (2015)	Adults in the UK, n=195, 58% female, Age: 18–91yrs	QStarz BT-1000X (GPS) with ActiGraph GT1M (accelerometer), Waist, 7 days	Outdoor LMVPA	Within home neighbourhood (800 m buffer) vs outside home neighbourhood	60% of outdoor LMVPA took place outside the home neighbourhood.
CHAIX ET AL. (2014)	Adults in France, n=227, 32% female, Median age: 58yrs	QStarz BT-Q1000XT (GPS) with ActiGraph GT3X (accelerometer), Waist, 7 days	Walking, MVPA, energy expenditure	Active travel: trip distance and travel mode (obtained from GPS-based mobility survey)	Participants spent a median of 1 h 58 min per day in transportation (8.2% of total time). 38% of steps taken, 31% of energy expended, and 33% of MVPA over 7 days were attributable to transportation. Walking, cycling and public transportation trips were associated with greater steps, MVPA, and energy expenditure than transport by personal motorized vehicle.
RAMULU ET AL. (2012)	Working adults in the US, n=26, 65% female, Age: 18–61yrs	pTrac Pro (tracking device using cellular network) with Actical (accelerometer), Waist, 6 days	MVPA, number of steps	Home region vs outside home region (536 m radius from home as a divider)	Most PA took place away from home on weekdays, but not on weekends. Most walking was performed away from home on weekdays in comparison to steps/day taken within the home region. No significant differences were seen in the number of steps taken within the home region vs away from home at weekends.

TROPED ET AL. (2010)	Adults in the US, n=148, 53% female, Age: 19-78yrs	GeoStats GeoLogger (GPS) with ActiGraph 7164 (accelerometer), Waist for accelerometer, shoulder for GPS, 4 days	MVPA	Home buffer 50 m, home buffer 1 km, work buffer 50 m, work buffer 1 km.	More MVPA occurred outside than within home and workplace buffers. Median distance from home to locations where MVPA minutes accumulated was 1855 m.
RODRÍGUEZ ET AL. (2005)	Adults in the US, n=35, 60% female, Age: 20-61yrs	Garmin Foretrex 201 (GPS) with ActiGraph 7164 (accelerometer), Waist for accelerometer, wrist or waist for GPS, 3 days	MVPA	Outdoor MVPA within home neighbourhood (1.54 km buffer) or outside home neighbourhood, parks	35% of MVPA occurred outdoors within the home neighbourhood and 32% outdoors outside the home neighbourhood. The presence of parks was associated with more MVPA within home neighbourhoods.

HLPA = High-light physical activity, LLPA = Low-light physical activity, LMVPA = Light, moderate and vigorous physical activity combined, LPA= Light physical activity, MET = Metabolic equivalent, MPA = Moderate physical activity, MVPA = Moderate-to-vigorous physical activity, SED = Sedentary time, VPA = Vigorous physical activity

2.4.2 Role of greenness in physical activity and active travel behaviour

Greenness has emerged as an environmental feature that could potentially facilitate physical activity (James et al., 2015), and physical activity researchers have been interested in the associations between greenness and physical activity long before GPS devices began to be more widely used for collecting data. However, the associations observed have been inconsistent (Klomp maker et al., 2018). In greenness-related physical activity studies, the amount of green space(s), such as parks and forests, is typically estimated using either different land cover or land use data (Zhou et al., 2022), or the satellite-based Normalized Difference Vegetation Index (NDVI), which measures the presence of general vegetation (Rhew et al., 2011). This chapter focuses on and Table 2 summarizes prior, all cross-sectional, greenness-related physical activity studies that have used GPS and accelerometers to collect data among adult populations.

A study among US women by James et al. (2017) reported a positive nonlinear relationships between NDVI-based greenness and physical activity. However, this observed relationship differed according to the levels of neighbourhood walkability: at low walkability levels, the relationship between greenness and physical activity was positive, but at higher walkability levels it plateaued slightly. The association was stronger on weekends than on weekdays, and among middle-aged than younger or older women (James et al., 2017). However, another NDVI-based study among US adults by Troped et al. (2010) found an inverse association between greenness and MVPA within a one-kilometre buffer around the home.

Another GPS-based study by Jansen et al. (2018) investigated the association between greenness and neighbourhood-based physical activity among middle-aged Dutch participants. It reported that green space was associated with less LPA within the neighbourhood area when it was measured using 800- and 1600-metre buffers around the home, but was positively associated with MVPA within the neighbourhood area when measured using a smaller, 400-metre buffer. Moreover, a US study among middle-aged adults (Boakye et al., 2021), which used GPS and waist-worn accelerometer devices to collect data, reported that a higher level of NDVI-based greenness during physical activities, as well as visiting parks, was positively associated with light-to-moderate vigorous physical activity (LMVPA) and MVPA.

A Belgian study among late middle-aged participants by Dewulf et al. (2016), who used GPS and waist-worn accelerometers, observed a positive association between spending time in green space and MVPA. Furthermore, a study among adults in the US by Holliday et al. (2017a), collected GPS and waist-worn accelerometer data, and reported that the use of parks contributed positively to

MVPA bouts (≥ 10 minutes), and that the use of parks for MVPA bouts increased with age.

Chaix et al. (2016) completed a trip-level analysis among French adults, using GPS receivers, waist-worn accelerometers and a GPS-based mobility survey, to explore the associations between greenness and mode of travel. They observed a positive association between green spaces at the beginning or end of a trip and walking for the entire trip (self-reported) or part of the trip (i.e., more than 200 steps taken each 10 minutes of the trip). Similarly, a US study by Marquet et al. (2022), based on GPS and waist-worn accelerometer measurements, observed that more greenness in the middle-aged women's activity spaces assessed along their daily path area was associated with a greater number of steps taken per week. Tamura et al. (2019) also conducted a study among US adults, in which they calculated exposure to greenness within small dynamically buffered areas (50-m circular buffer) around GPS points, and observed higher level of greenness to be associated with a higher level of accelerometer-measured MVPA and light-to-vigorous physical activity (LVPA). Another GPS and waist-worn accelerometer-based study by Jansen et al. (2017), among middle-aged Dutch adults, reported that larger sized natural environments (≥ 7 hectares) were associated with higher levels of MVPA and walking or jogging (speed of GPS data points < 12 km/h).

To summarize, previous GPS-based studies have shown consistent positive associations between greenness and physical activity (Chaix et al., 2016; James et al., 2017; Marquet et al., 2022), particularly between greenness and MVPA (Dewulf et al., 2016; Jansen et al., 2017, 2018). Prior results also suggest that the positive association between greenness and physical activity may be stronger on weekends than on weekdays, and among the middle-aged than younger or older people (James et al., 2017). The few prior GPS-based studies of the associations between greenness and accelerometer-measured active travel have reported a positive relation between greenness and steps taken, walking or jogging (Chaix et al., 2016; Hirsch et al., 2016; Jansen et al., 2017; Marquet et al., 2022).

Table 2. GPS-based studies of associations between greenness and accelerometer-measured physical activity.

AUTHORS, YEAR	PARTICIPANTS, POPULATION, N, GENDER, AGE, COUNTRY	DEVICE(S), WEAR LOCATION, LENGTH OF MEASUREMENT	MEASURED ACTIVITY BEHAVIOUR	CONTEXT	MAIN RESULTS
FIRTH ET AL. (2022)	Adults in Canada, n=544, 51–71% female, Age: ≥18 yrs	SenseDoc (GPS and accelerometer), Wear location not reported, 10 days	LPA, MPA, VPA and MVPA	Proximity to parks	Proximity to parks was positively associated with MVPA.
MARQUET ET AL. (2022)	Working female adults in the US, n=354, Age: 21–75 yrs	Qstarz BT1000X (GPS) with ActiGraph GT3X+ (accelerometer), Waist, 7 days	LPA, MVPA, steps	NDVI-based greenness of daily path area activity spaces, walkability	More greenness of activity space was associated with greater numbers of steps per week. Highest MVPA levels were observed among participants with both high walkability and more greenness in their activity spaces.
BOAKYE ET AL. (2021)	Adults in the US, n=288, 71.5% female, Mean age: 46 yrs	Qstarz BT-Q1000XT (GPS) with ActiGraph GT1M and GT3X (accelerometer), Waist, 14 days	LMVPA, MVPA	NDVI-based greenness and parks	More greenness and parks were positively associated with LMVPA and MVPA.
JANSEN ET AL. (2018)	Adults in the Netherlands, n=308, 54.9% female, Age: 45–65 yrs	QStarz BT-Q1000XT (GPS) with ActiGraph GT3X+ (accelerometer), Waist, 7 days	LPA, MVPA	Green space (land use data)	The proportion of green space was positively associated with LPA within 800-m and 160-m buffers and with MVPA within a 400-m buffer.

HOLLIDAY ET AL. (2017A)	Adults in the US, n=223, 57% female, Age: 18–85 yrs	QStarz BT-1000X (GPS) with ActiGraph GT1M (accelerometer), Waist, 3 weeks	MVPA, VPA	Parks	Parks were used for 13% of MVPA bout minutes but only 4% of VPA bout minutes. Parks were used for 9% of MVPA bout minutes by 18–35-year-olds, 15% by 36–59-year-olds and 19% by 60–85-year-olds.
JAMES ET AL. (2017)	Female adults in the US, n=360, Age 22–82 yrs	Qstarz BT1000X (GPS) with ActiGraph GT3Xp, Waist, 7 days	PA	NDVI-based greenness	Positive relationship was observed between greenness and PA, which was stronger on weekends than weekdays, and among middle-aged than younger or older participants.
JANSEN ET AL. (2017)	Adults in the Netherlands, n=279, 54% female, Age: 46–65 yrs	QStarz BT-Q1000X (GPS) ActiGraph GT3X (accelerometer), Waist, 7 days	LPA, MVPA	Parks, recreational areas, agricultural greens, forests and moorlands	Modality (i.e., spatially concentrated PA, walking, jogging and cycling) and intensity of PA varied significantly between natural environment types. Compared to parks, less walking but more spatially concentrated PA was observed in recreational areas and green spaces. Larger sized natural environments (≥ 7 hectares) were associated with higher levels of MVPA, walking, jogging and cycling.
JANSEN ET AL. (2016)	Adults in the Netherlands, n=308, 55% female, Age: 45–65 yrs	QStarz BT-Q1000X (GPS) with ActiGraph GT3X (accelerometer), Waist, 7 days	MVPA	Small green areas, larger green areas (land use data)	Having a garden at home or elsewhere was positively associated with MVPA in small green areas.
CHAIX ET AL. (2016)	Adults in France, n=227, 32% female, Age: ≥ 35 yrs	QStarz BT-Q1000XT (GPS) with ActiGraph GT3X (accelerometer), Waist, 7 days	Steps, survey-based walking	Green spaces (land use data)	Odds of walking increased in line with the density of green space at the beginning and end of trips.

<p>DEWULF ET AL. (2016)</p>	<p>Late middle-aged adults in Belgium, n=180, 48% female, Age: 59–65 yrs</p>	<p>QStarz BT-Q1000XT (GPS) with ActiGraph GT3X (accelerometer), Waist, 7 days</p>	<p>LPA, MVPA</p>	<p>Green vs non-green areas (land use data)</p>	<p>Participants were more physically active when they spent more time in green areas than in non-green areas. Time spent in non-green areas was related to more MVPA among males and less MVPA among females. Positive associations between time spent in green areas and MVPA were the strongest among highly educated people and those living in green neighbourhoods.</p>
<p>TROPEL ET AL. (2010)</p>	<p>Adults in the US, n=148, 53% female, Age: 19–78yrs</p>	<p>GeoStats GeoLogger (GPS) with ActiGraph 7164 (accelerometer), Waist for accelerometer, shoulder for GPS, 4 days</p>	<p>MVPA</p>	<p>NDVI-based greenness</p>	<p>NDVI was negatively associated with MVPA within a 1-km buffer.</p>

LMVPA = Light-to-moderate-vigorous physical activity, LPA = Light physical activity, MPA = Moderate physical activity, MVPA = Moderate-to-vigorous physical activity, NDVI = Normalized difference vegetation index, PA= Physical activity, VPA = Vigorous physical activity

2.5 Gaps in previous research

Despite the opportunities provided by combining GPS data with accelerometer-measured physical activity information, relatively few studies have used these methods together, particularly when examining late middle-aged and older populations (Yi et al., 2019). This dissertation adds to this field with its analyses of the contexts in which late middle-aged people are physically active and at which intensity.

Prior evidence of the associations between pre-retirement occupation and changes in physical activity and sedentary behaviour during retirement is consistent (Barnett et al., 2014; Pulakka et al., 2020; Suorsa et al., 2022, 2021, 2019). However, in all these prior studies, physical activity related to work has been estimated using self-reported or register-based information on job titles, which are imprecise measures of the actual physical activity that occurs at work. Similarly, active commuting to pre-retirement workplace has been associated with changes in accelerometer-measured physical activity (Pulakka et al., 2020), however, commuting activity has been identified using self-reported information, which is prone to biases (Schrack et al., 2016; Strath et al., 2013). To take a step further, this dissertation investigates the associations between work-related and commuting physical activity and changes in physical activity and sedentary behaviour based on GPS and accelerometer data.

Furthermore, some prior GPS-based studies have compared the results regarding physical activity environments between weekdays and weekends (James et al., 2017; Ramulu et al., 2012), but have not explored these differences between workdays and days off. In addition to providing evidence about the differences between weekdays and weekends, this dissertation also compares actual workdays and days off, as this division captures more details about people's work schedules.

Regarding the associations between greenness and physical activity or physical activity that accumulates during active travel, previous GPS and accelerometer-based evidence among adults has come from cross-sectional studies. This dissertation provides new insights into the associations between residential greenness and physical activity using longitudinal data that combines GPS and accelerometer measurements from an intervention study grounded on the use of activity trackers. The dissertation also addresses the role of greenness in physical activity behaviour by studying the associations between exposure to greenness during active travel trips and physical activity accumulated during the same trips, and examines the associations separately for workdays, days off and retirement days. This has not been done before.

3 Aims

The overall aim of this dissertation was to examine the associations between environmental contexts, physical activity and sedentary behaviour among late middle-aged people.

The specific research aims were:

1. To examine and compare the amount of physical activity and sedentary behaviour in different contexts on workdays and days off among those still working, and on weekdays and weekends among retirees (Study I).
2. To examine how pre-retirement physical activity at the workplace and while commuting are associated with changes in physical activity and sedentary behaviour during the transition to retirement (Study II).
3. To examine changes in physical activity by context during a physical activity intervention, and to determine whether residential greenness modifies the observed changes (Study III).
4. To examine how exposure to useable green space during active travel associates with physical activity accumulated during active travel, and how these relations differ on workdays, days off and retirement days (Study IV).

4 Materials and Methods

This dissertation is based on two studies administered by the Unit of Public Health of the University of Turku in Finland: 1) the FIREA study and 2) the Enhancing Physical Activity and Healthy Aging among Recent Retirees (REACT) trial. Table 3 briefly describes the main characteristics of the populations and the methods used in Studies I–IV.

Table 3. Study populations and methods of original Studies I–IV.

	STUDY I		STUDY II	STUDY III	STUDY IV
POPULATION	FIREA	REACT	FIREA	REACT	FIREA
MEAN AGE (YEARS) (SD)	62.4 (1.0)	64.8 (1.1)	62.9 (1.1)	64.8 (1.2)	63.3 (1.0)
SAMPLE SIZE	137	53	118	45	102
STUDY DESIGN	Cross-sectional		Longitudinal	Longitudinal	Longitudinal
MAIN ANALYTICAL METHOD	Linear regression analysis with Generalized Estimating Equations (GEE)				
MAIN EXPOSURE	Different physical activity contexts (home, non-home locations, active travel, non-active travel)	Work- and commuting-related physical activity	Residential greenness and physical activity context (home, non-home locations, active travel, non-active travel)	Exposure to useable green space during active travel	
MAIN OUTCOME	Sedentary time, LPA and MVPA.	Changes in sedentary time, LPA and MVPA during retirement transition.	Changes in total physical activity, LPA and MVPA during intervention.	Total physical activity, LPA and MVPA during active travel on workdays, days off and retirement days.	

LPA = Light physical activity, MVPA = Moderate-to-vigorous physical activity

4.1 Study populations

4.1.1 The FIREA study

FIREA is an ongoing longitudinal cohort study examining changes in the health and health behaviour of retiring Finnish public sector employees (Stenholm et al., 2023). First phase of FIREA focused on the years around statutory retirement and was conducted between 2013 and 2022. The FIREA study consists of the FIREA survey cohort, the FIREA activity sub-study and the FIREA clinical sub-study. Studies I–II and Study IV of this dissertation used data from the FIREA clinical sub-study, which was conducted between 2015 and 2022.

The eligible sample of the FIREA cohort study included public sector employees whose personal retirement date was between 2014 and 2019, and who worked in 2012 in any town in Southwest Finland, or in any of the a priori selected ten towns or five hospital districts around Finland (n=10629). They were first sent a questionnaire 18 months before their estimated retirement date. Questionnaires were then sent to them once a year, with the aim of gathering information from at least two time points before and two time points after the transition to statutory retirement. In total, 6783 participants responded to the survey at least once. Details of the FIREA study are provided in the FIREA cohort profile article (Stenholm et al., 2023).

From 2015, the Finnish-speaking FIREA survey cohort participants who lived in Southwest Finland, were still working, and whose estimated retirement date was in 2017–2019, were invited to participate in the FIREA clinical sub-study (n=773). Of these, 290 gave their written informed consent and participated in the FIREA clinical sub-study. Data were annually collected from the FIREA clinical sub-study participants via surveys and a clinical follow-up visit, which included taking blood and hair samples, measuring anthropometry, cardiovascular function, physical fitness, physical and cognitive function, and physical activity. The annual data collection continued until the person retired. The mean number of annual measurements in the FIREA clinical sub-study was 3.0 (range 1–5, Standard Deviation (SD) 0.6). In March 2016, measurements to define the context of physical activity, using a SenseDoc 2.0 device that combines GPS and an accelerometer, were added to the FIREA clinical sub-study protocol. Data were collected throughout the year, but each person's measurements were always aimed to take during the same season.

4.1.2 The REACT trial

The REACT-trial was a randomized controlled trial (RCT) (NCT03320746) that aimed to examine the effects of a 12-month consumer-based activity tracker

intervention on the accelerometer-measured physical activity and sedentary behaviour of recent retirees (Leskinen et al., 2021). The REACT study population consisted of retired Finnish public sector employees who lived in Southwest Finland in 2017 and whose estimated statutory retirement dates were between January 2016 and April 2019 (n=1475). The participants were first contacted by a letter to their home address between January and March 2018. The letter contained a link to a web-based survey that collected information on their actual time of retirement and current state of health. Of those contacted (n=272), 252 who met the inclusion criteria were invited to participate in the study. Of these, 21 were unable to participate, and thus the REACT study population consisted of 231 participants.

The participants were randomized into intervention (n=117) and control groups (n=114). The intervention participants were asked to wear a commercial wrist-worn activity tracker (Polar Loop 2; Polar, Kempele, Finland) for one year and to try to reach their personal daily activity goal, for example, daily steps, and to upload their activity data onto a web-based programme every week. Polar Loop 2 contains a built-in accelerometer for tracking physical activity, and various kinds of activities contribute to the achievement of the daily activity goal, though higher intensity activities fulfil the daily goal faster than lower intensity activities. The researcher suggested a higher goal if the participant frequently exceeded it. The control group did not wear the activity tracker and were requested not to wear any other activity tracker during the follow-up year. After the follow-up year, the intervention group were allowed to keep the activity trackers, and trackers were also given to the control group. Details of the REACT intervention are provided in an article by Leskinen et al. (2021). The present study used a subsample of the intervention group participants, because only the intervention group participants provided GPS and accelerometer measurements using the SenseDoc 2.0-device. The measurements were taken at baseline and after one year. Due to a delay related to the delivery of the devices from the manufacturer, only 61 of the intervention group participants were measured. The devices were offered to the participants when they were available. Data was collected between 2018 and 2020.

4.2 Defining retirement

In Finland, each age group has its own retirement age, which is based on the calculated life expectancy of each age cohort. An individual may retire upon reaching statutory retirement age, but they may also continue working after the minimum retirement age to accumulate a higher pension. The lowest retirement ages are between 63 and 65 years. Partial retirement, such as partial early old-age pension or partial disability pension, is also possible (Keva, 2024a). In both FIREA and REACT, the estimated retirement dates were obtained from Keva (2024b), which is

the insurance institution that administers municipal sector pensions. Estimated retirement dates were used to identify the study populations and plan the timing of data collection; later the participants self-reported their actual retirement date, and this information was used to separate pre- and post-retirement measurements.

4.3 Research ethics

Both FIREA and REACT were conducted in accordance with the guidelines for good scientific practice set by the Finnish Research Ethics Advisory Board and the Declaration of Helsinki. Both studies were approved by the Ethics Committee of the Hospital District of Southwest Finland: FIREA: 84/1801/2014 and REACT 107/1801/2017. The ClinicalTrials.gov registration number of the REACT trial is NCT03320746. A study information sheet was provided and written informed consent was obtained from all participants in both studies.

4.4 Selecting analytical samples

Figure 1 shows a flowchart of the analytical sample selection for Studies I and III, and Figure 2 shows the same for Studies II and IV. In all the original studies, the participants who had at least 600 min/day of device-wear time were included. Cross-sectional Study I included ageing workers and recent retirees who provided at least two valid measurement days of data in total; however, one day had to be a workday and the other a day off while still working. Retirees were required to have a minimum of one weekday and one weekend day (n=137 for workers and n=53 for retirees). Longitudinal Studies II and IV required a minimum of two valid measurement days before and two after retirement. Before retirement, one day had to be a workday and the other a day off. In addition, Study II participants had to have an identified workplace and had to commute (n=118), and Study IV participants had to have active travel and information on useable green space linked to activity data (n=102). Longitudinal Study III was based on the intervention study, and required two valid measurement days at both the baseline and follow-up measurement points (n=45)

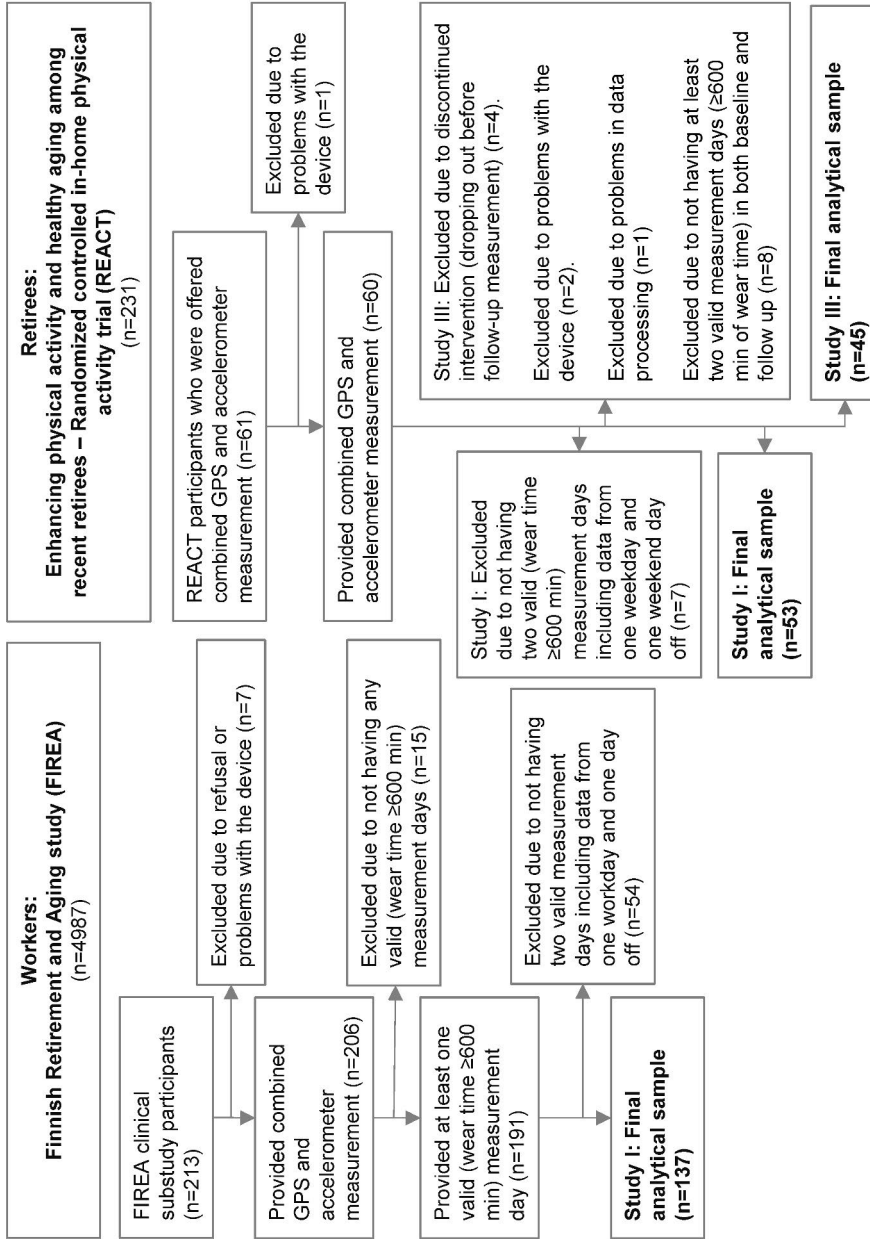


Figure 1. Flow chart of selection of analytical sample in Study I and Study III.

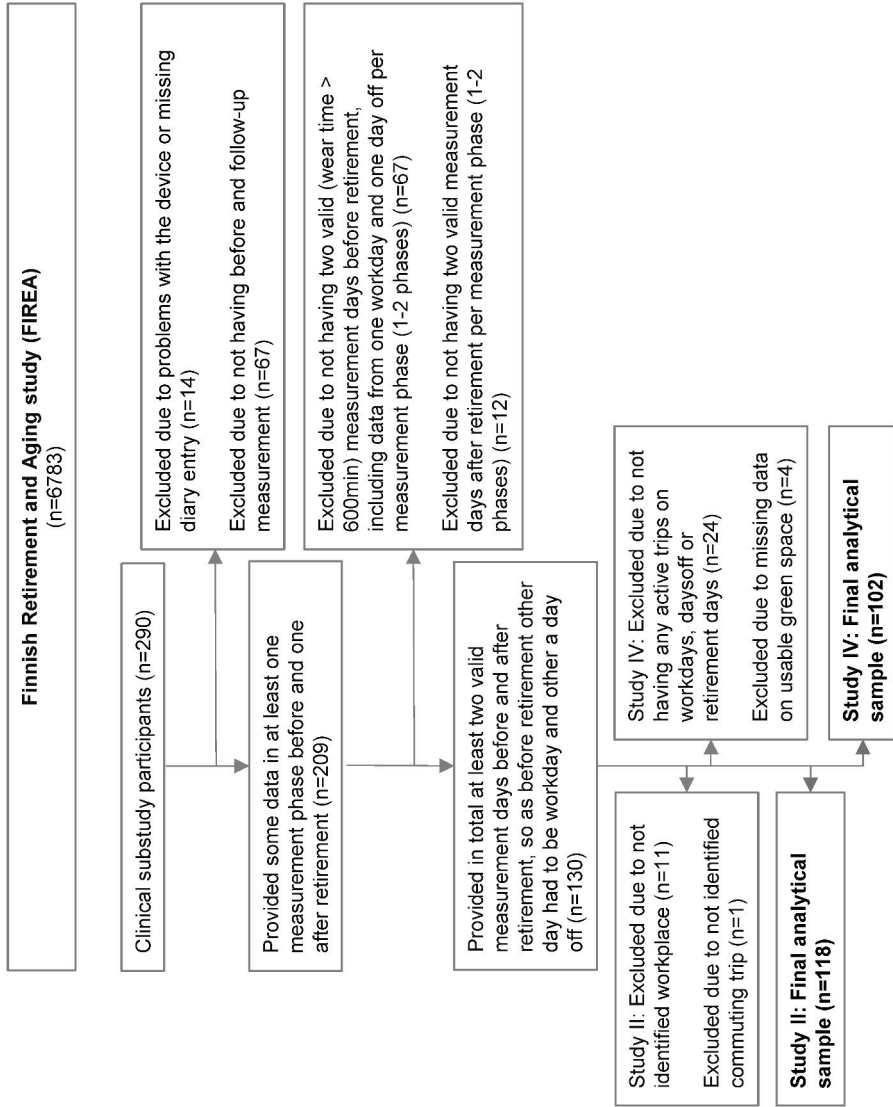


Figure 2. Flow chart of selection of analytical samples in Study II and IV.

4.5 Collecting and processing GPS and accelerometer data

A waist-worn SenseDoc 2.0 device (Mobysens Technologies Inc, Canada), which includes a GPS sensor and a tri-axial accelerometer, was used to collect data on the intensity and context of physical activity and sedentary behaviour (Figure 3). Both the FIREA and REACT participants received the device and instructions on its use from the study nurse during the clinical examination visit. The device was initialized



Figure 3. SenseDoc 2.0 device (image by author).

to record GPS coordinates once per second and to collect the accelerometer data at a sampling rate of 80 Hz. The device was attached with an elastic, adjustable belt. The participants were asked to wear the device during their waking hours, but to remove it when bathing or doing water sports.

The FIREA participants were asked to wear the device continuously so that the measurement covered at least two workdays and two days off when still working, and a minimum of four days when measurements were conducted after retirement. The REACT participants were asked to wear the device for seven consecutive days. The participants were also asked to keep a diary on their measurement days, their workdays, and days off when still working, as well as their bedtimes. Days were separated from the GPS and accelerometer data on the basis of self-reported bedtimes. The device and the diary were returned by mail after the measurement phase. Only the data for the days marked in the diary as measurement days were used. The measurements were taken during all four seasons of the year, but the annual measurements of each participant were always aimed to take during the same season.

Table 4 summarizes the data collection and processing methods, the phases of which are explained in more detail in the following paragraphs. More details on the features of the SenseDoc 2.0 device are available in Brondeel et al. (2019).

Table 4. Collecting and processing combined GPS and accelerometer data.**DATA COLLECTION AND PROCESSING METHODS IN BRIEF (STUDIES I-IV)**

COLLECTION GPS AND ACCELEROMETER DATA	Device: SenseDoc 2.0 Manufacturer: Mobysens Technologies Inc, Canada Wear location: Right hip Sampling rate: 1-s / 80 Hz
ALGORITHM USED IN GPS DATA PROCESSING	The kernel-based algorithm of Thierry et al. (2013) was used, which operates globally by computing a kernel density surface from the GPS points, then deriving stop locations by identifying local maxima. The track is segmented into stop (<5-min visits are dropped) and trip bouts by allocating GPS points to either a local peak (stay in the location) or a trip segment.
ALGORITHM AND THRESHOLDS USED IN ACCELEROMETER DATA PROCESSING	An algorithm developed by Brønd et al. (2017) was used to convert the raw accelerometer data into ActiGraph equivalent counts. Counts per second were aggregated to counts per minute, and thresholds were applied for sedentary time (≤ 100 counts/min), LPA (>100 and ≤ 2020 counts/min) and MVPA (>2020 counts/min).
EPOCH LENGTH	1-min
DEVICE-WEAR TIME DETECTION	Device-wear time was assessed from the accelerometer signal, using Choi's method, which flags as non-wear time any measure within a 90-min time window of consecutive zero counts, allowing 2-min intervals of non-zero counts within the up or downstream in the 30-min consecutive zero counts window (Choi et al., 2021, 2011).
SOFTWARE USED IN DATA DOWNLOAD AND PROCESSING	SenseAnalytics (versions 1.9 and 1.10) ArcGIS (version 10.3.1) Python (version 3.6.6) R (version 3.5.3) PostgreSQL (version 11.1) with PostGIS extension

4.5.1 Detecting physical activity in different locations and during trips

The algorithm of Thierry et al. (2013) was used to identify the different intensities of physical activity in different locations and during the trips between these locations. The algorithm operates globally by computing a kernel density surface from the GPS points, then derives stop locations by identifying local maxima. The track is segmented into stops (<5-min visits are dropped) and trip bouts by allocating GPS points to either a local peak (stay in the location) or a trip segment. For further details and validity statistics, see Thierry et al. (2013) and Kestens et al. (2018). SenseAnalytics (versions 1.9 and 1.10) was used to connect to SenseDoc devices to download the raw binary data from the device into CSV files readable by the remaining of the processing pipeline. ArcGIS (version 10.3.1) was used to segment the GPS track into visited locations and trips using the algorithm (Thierry et al., 2013), which runs as a Python (version 3.6.6) script.

4.5.2 Estimating physical activity and sedentary behaviour

An algorithm developed by Brønd et al. (2017) was used to convert the raw accelerometer data into ActiGraph equivalent counts using the R program (version 3.5.3) (GitHub, 2022). PostgreSQL (version 11.1) with PostGIS extension were used to merge the GPS and accelerometer datastreams and produce the aggregated metrics. Counts per second were aggregated to counts per minute, and commonly used thresholds were applied for sedentary time (≤ 100 counts/min) (Ekelund et al., 2020; Matthews et al., 2016), LPA (>100 and ≤ 2020 counts/min) (Loprinzi and Brosky Jr, 2014; Wolff-Hughes et al., 2015) and MVPA (>2020 counts/min) (Troiano et al., 2008). Minutes of sedentary time, LPA and MVPA were processed for the locations and trips where they were accumulated.

For the analyses, minutes of sedentary time, LPA and MVPA were calculated as averages for all the valid measurement days. In Study II, which aimed to present a typical working week, sedentary time, LPA and MVPA before retirement were calculated as a weighted average ($(5 \times PA_{\text{work day}} + 2 \times PA_{\text{day off}})/7$).

The small discrepancy between the threshold for MVPA used in Studies I–IV (>2020 counts/min) and the original Troiano paper, using a threshold of ≥ 2020 counts/min (Troiano et al., 2008), should be noted. This mistake in the used algorithm was only noticed at a late stage of the dissertation work. Nevertheless, it presumably hardly affected the results, as the difference was only one count per minute.

4.6 Defining different contexts

After the data had been processed into locations or trips, the GPS-detected locations were divided into home and non-home locations, and the trips were divided into active and non-active travel. A workplace and active or non-active trips between work and home were further recognized. Figure 4 illustrates the different GPS-recognized contexts and the original studies in which they were analysed.

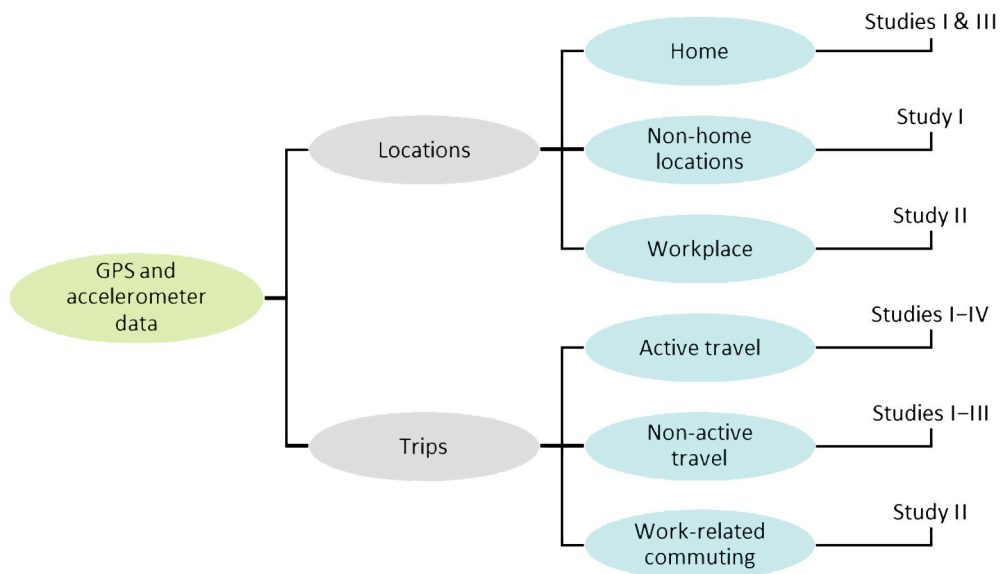


Figure 4. GPS-recognized contexts and the studies in which they were used.

Home was the algorithm-identified location that was the nearest to and within 100 metres of the participant’s registered home address. Registered home addresses were obtained from the Finnish Population Information System (Digital and population data services agency, 2024). For those who had no registered home address or for whom the distance between home address and the nearest identified location was more than 100 metres, home was determined as the location at which the participant spent most of their time. **Non-home locations** consisted of all other algorithm-identified locations. **Workplace** was assumed to be a non-home location within 100 km from home, at which the participant had the longest device-wear time on workdays. The 100-km range was chosen to exclude the days on which a person had business trips, etc. Wear time at the workplace had to be at least four hours, either continuously or accumulated from shorter phases at the workplace. **Active travel** was estimated on the basis of the average speed of algorithm-identified trips, so that trips with an average speed of <20 km/h were assumed to be active travel and trips of ≥ 20 km/h **non-active travel**. The average speed for each trip (km/h) was calculated on the basis of its length and duration. To identify **work-related commuting**, the time of day when the participant was at the workplace for the first time on a workday was detected, and the previous departure from home was identified. Then all trips between these times were collected. The return journey from work was identified using the same protocol, but in the opposite direction.

The threshold speed selected for dichotomizing active and non-active travel was based on previous information on the walking and cycling speeds of the adult

population (walking from 5.8 to 6.2 km/h and cycling from 14 to 20 km/h) (Aittasalo et al., 2019; Oja et al., 1998). The different thresholds between 16 and 24 km/h used to dichotomize the trips were tested and reported in Study I. Changing the threshold within this range did not notably change the results. In Study II, the validity of the chosen threshold speed of 20 km/h was examined by comparing the GPS-based classification of active vs non-active travel and self-reported mode of commuting (walk, bicycle vs. bus, car). This analysis examined 603 commuting trips for which self-reported travel mode information was available from the diaries. The agreement percentage was 90% and kappa coefficient was 0.78 (95% Confidence Interval (CI) 0.73–0.83). A further examination of the threshold for separating active and non-active travel in original Study IV showed that most total physical activity minutes accumulated at travel speeds of <20 km/h.

In Study II, work-related physical activity was measured as the average of total physical activity, including LPA and MVPA, accumulated during time spent at the workplace. Participants were categorized as ‘non-active workers’ or ‘active workers’ on the basis of their median (123 min/day) of total physical activity at the workplace. To define active or non-active commuting, each trip detected between the home and the workplace was categorized as an active or non-active trip on the basis of a threshold speed of 20 km/h. Participants with a higher number of active than non-active trips were categorized as active commuters, and those with as many or a higher number of non-active trips than active trips were categorized as non-active commuters. For the analyses, four activity groups were formed on the basis of work-related and commuting physical activity: ‘Non-active workers and commuters’, ‘Non-active workers but active commuters’, ‘Active workers but non-active commuters’, and ‘Active workers and commuters’.

4.7 Defining exposure to residential greenness or useable green space

Two different indicators were used to measure exposure to greenness: residential greenness (Study III) and useable green space (Study IV).

Residential greenness (Study III): 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). Images from three consequent years (2017–2019) were combined to generate cloud-free composite maps of the median NDVI values for the whole study region. Residential mean NDVI values were calculated within a square buffer of 1250 x 1250 metres around the GPS-detected home location of the participant. The same NDVI data were used for both activity measurement points: at baseline and at follow up.

Useable green space (Study IV): Useable green space represents areas in which people can engage in physical activity, e.g., green urban areas, forests, and vegetated sports and leisure facilities. Areas such as urban fabric, industrial or commercial units, plantations, pastures and marine areas were excluded from the definition of useable green space. The data to define useable green space were provided by the Finnish Environment Institute (Syke) (2018), utilizing the 2018 CORINE Land Cover data with a 20 m x 20 m grid size. The land use information was linked to GPS-based travel data using ArcGIS (version 10.3.1) and PostgreSQL (version 11.1) with a PostGIS extension. The exact classes of the CORINE Land Cover data used to define useable green space are presented in Appendix 1.

4.8 Assessing participant characteristics and covariates

The covariates used in all the original studies were age, gender, occupational status, Body Mass Index (BMI), and mobility limitations, because these factors have been associated with physical activity levels (Althoff et al., 2017; Doherty et al., 2017; Halonen et al., 2020; Portegijs et al., 2017; Pulakka et al., 2020). The measurement season was also used as a covariate in all the studies because weather conditions may influence physical activity (Prins and van Lenthe, 2015). Neighbourhood socioeconomic disadvantage was used as a covariate in Studies I–III and provided additional information on the participants' SES, which is a well-known determinant of physical activity (Troost et al., 2002). The analyses in Studies I–III also took device-wear time into account. Table 5 presents details on the formation of the covariates. In addition, self-reported leisure-time physical activity was used to examine possible selection bias in Studies II and IV. For this, the respondents were asked to estimate their weekly hours of leisure-time physical activity (including commuting) that they had spent walking, walking briskly, jogging or running, or equivalent activities, within the previous year (Kujala et al., 1998). The time spent on activities at each intensity level was multiplied by the average energy expenditure of each activity and expressed in MET values (Ainsworth et al., 2011).

Table 5. Description of covariates used in analyses in Studies I–IV.

VARIABLE	STUDIES	DEFINITION
AGE	I–IV	Information obtained from Keva register (2024b).
GENDER	I–IV	Information obtained from Keva register (2024b).
OCCUPATIONAL STATUS	I–IV	The occupational codes, based on the International Standard Classification of Occupations (ISCO), were obtained from the Keva register (2024b) and categorized as non-manual (ISCO classes 1–4, e.g., managers and professionals, associate professionals and office workers) and manual (ISCO classes 5–9, e.g., service and manual workers). Occupational status was used as an indicator of socioeconomic status.
BODY MASS INDEX (BMI)	I–IV	BMI was calculated as weight in kg divided by height in metres squared using the body weight and height, measured during the clinical visit.
MOBILITY LIMITATIONS	I–IV	Difficulties walking 2-km; no limitations (no difficulties) and limitations (some and marked difficulties) based on the validated RAND-36 Health Survey, identical with the Short Form SF-36 (Aalto et al., 1999, 1995; Hays et al., 1993).
NEIGHBOURHOOD DISADVANTAGE	I–III	A score was calculated on the basis of the data obtained from Statistics Finland (2024), which consisted of the proportion of adults with a low education, the unemployment rate, and the median household income in the 250 x 250-m map grid of the home address. Higher scores in the continuous standardized index denote greater disadvantage (Halonen et al., 2020).
MEASUREMENT SEASON	I–IV	Time of year when GPS and accelerometer measurements were taken from participants who met the selection criteria: spring, summer, autumn or winter.
DEVICE-WEAR TIME	I–III	Device-wear time was determined using Choi's method (Choi et al., 2021, 2011), which flags as non-wear time a measure with 90-min of consecutive zero activity counts, allowing for 2-min of non-zero counts.

4.9 Statistical methods

In all the original studies, the characteristics of the participants were described as mean values with SD for the continuous variables, and as frequencies and percentages for the categorical variables. In the longitudinal studies, the characteristics were obtained from the last pre-retirement measurement (Studies II and IV) or from the baseline measurement (Study III). To compare the groups, Analysis of Variance was used for the mean values, the Median test for the median values, and the Chi-squared test for percentages.

Linear regression analysis with Generalized Estimating Equations (GEE) and an exchangeable correlation structure was used to examine between-group differences or changes over time in sedentary behaviour (Studies I–II), LPA (Studies I–IV), MVPA (Studies I–IV), and total physical activity (Study III), as well as LPA, MVPA and total physical activity accumulated during active travel (Study IV). The GEE method considers the intra-individual correlation between repeated measurements. It fits a marginal model for longitudinal data, and the regression parameters in the marginal model are interpreted as population-averaged (Liang and Zeger, 1986). To compare changes across the groups, the GEE models included the interaction terms ‘activity group*time’ in Study II, ‘greenness*time’ in Study III and ‘useable green space*day type’ in Study IV. The results were presented as mean values with 95% CI in Studies I, II and IV. In Study IV, the percentage of daily active travel time in useable green space as an exposure variable was standardized, and the results indicate an effect of one additional SD in exposure on physical activity during active travel, and are shown as a beta coefficients with 95% CI.

In Studies I–IV, the models were adjusted for age, gender, occupational status, BMI, mobility limitations and measurement season. In Studies I–III, they were also adjusted for neighbourhood disadvantage and device-wear time. In Studies II and IV, as supplementary analyses, possible selection bias was examined by comparing the characteristics of the analytical sample to those of all the participants in the FIREA clinical sub-study as an eligible sample, and to the FIREA survey cohort. All statistical analyses were performed using SAS statistical software, version 9.4 (SAS Institute, Inc. Cary, North Carolina).

5 Results

5.1 Characteristics of study populations (Studies I–IV)

Table 6 presents the characteristics of the study populations. The mean ages of the participants ranged from 62.4 to 64.8 years. All the studies had more women (range 82%–91%) than men and more participants in non-manual than manual occupations (range 67%–70%). Only 4%–11% of the participants reported mobility limitations, and the range of the mean BMI was 25.4–28.3 kg/m².

Table 6. Characteristics of study participants. The values in the longitudinal studies (Studies II–IV) are from the last measurement before retirement in Study II and IV, and from the baseline measurement in Study III.

CHARACTERISTICS	STUDY I		STUDY II	STUDY III	STUDY IV
	FIREA (n=137)	REACT (n=53)	FIREA (n=118)	REACT (n=45)	FIREA (n=102)
Age mean (SD)	62.4 (1.0)	64.8 (1.1)	62.9 (1.1)	64.8 (1.2)	63.3 (1.0)
Women n (%)	119 (86.9)	48 (90.6)	97 (82.2)	39 (86.7)	84 (82.4)
Non-manual occupational status n (%)	92 (67.2)	37 (69.8)	82 (69.5)	30 (66.7)	69 (67.7)
BMI (kg/m²) mean (SD)	26.0 (4.5)	28.3 (4.6)	25.5 (4.6)	28.2 (4.1)	25.4 (4.2)
No mobility limitations n (%)	125 (91.2)	48 (90.6)	109 (92.4)	40 (88.9)	98 (96.1)
Measurement season n (%)					
Spring	52 (38.0)	12 (22.6)	42 (35.6)	7 (15.6)	35 (34.3)
Summer	20 (14.6)	0 (0.0)	19 (16.1)	0 (0.0)	23 (22.6)
Autumn	31 (22.6)	25 (47.2)	28 (23.7)	25 (55.6)	21 (20.6)
Winter	34 (24.8)	16 (30.2)	29 (24.6)	13 (28.9)	23 (22.6)
Neighbourhood disadvantage mean (SD)	-0.1 (0.7)	0.1 (1.0)	-0.1 (0.6)	0.1 (1.0)	
Valid data (≥600 min wear time/day) mean days (SD)					
Workdays Weekdays	2.1 (0.9)	4.3 (1.0)			
Days off Weekend days	1.9 (0.7)	1.8 (0.5)			
Before retirement			5.0 (2.2)		
After retirement			4.8 (2.2)		
Baseline				6.0 (1.4)	
1-year follow up				5.9 (1.6)	
Workdays					2.3 (1.3)
Days off					2.3 (1.4)
Retirement days					3.3 (1.8)

The possible selection bias was examined in Studies II and IV by comparing the characteristics of the analytical samples to those of all the FIREA clinical sub-study participants as an eligible sample, and to the FIREA survey cohort (Supplemental Table 2 in original Study II and Supplemental Table 6 in original Study IV). There were no major differences between the analytical and the eligible samples. However, in the FIREA survey cohort, less participants were in non-manual occupations (63%) and their self-reported leisure-time physical activity was lower (24 MET hours/week) than that in the analytical samples of Studies II and IV (Study IV 68%, Study II 69%, 30 MET hours/week in both Studies). Nevertheless, no marked differences were observed in comparison to the FIREA clinical sub-study population (69%, 29 MET hours/week).

5.2 Levels of physical activity and sedentary time (Studies I–IV)

Before retirement, the level of participants' daily mean sedentary time ranged from 521 min/day to 545 min/day (Studies I–II). Pre-retirement LPA ranged from 254 min/day to 280 min/day and MVPA from 28 to 39 min/day (Studies I, II and IV). After retirement, the level of sedentary time ranged from an average of 510 min/day to 522 min/day (Studies I–II). The post-retirement level of LPA ranged from 267 min/day to 289 min/day, and MVPA from 25 to 36 min/day (Studies I–IV).

Figure 5 presents the mean values of sedentary time, LPA and MVPA on workdays and days off among the participants still working and on weekdays and weekend days among the retirees (Study I). Sedentary time and LPA were similar on workdays and days off among the workers, but they accrued on average of six minutes more MVPA per day on days off (34 min/day, 95% CI 29–39 min/day) than on workdays (28 min/day, 95% CI 24–32 min/day). The retirees' levels of sedentary time, LPA and MVPA did not differ between weekdays and weekend days.

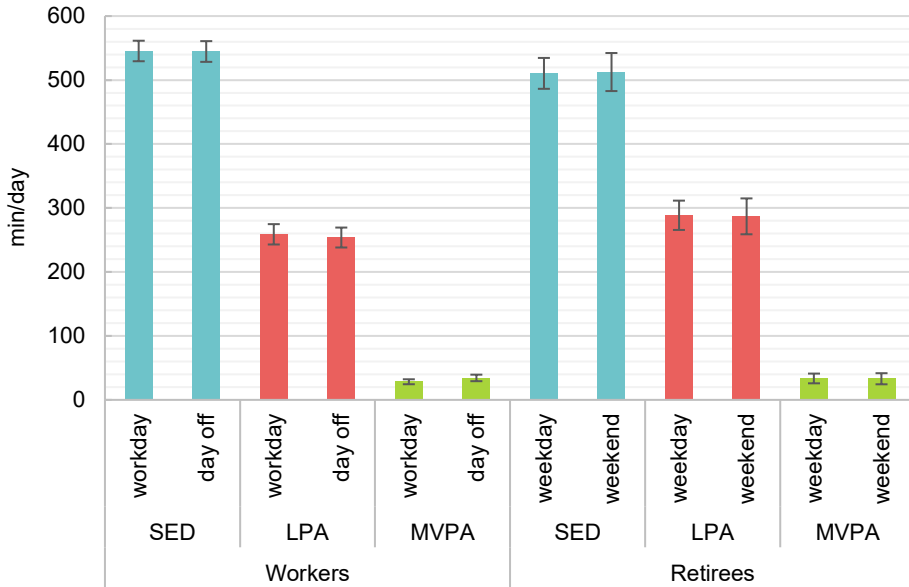


Figure 5. Mean values for sedentary time (SED), light physical activity (LPA) and moderate-to-vigorous physical activity (MVPA) on workdays and days off among workers, and weekdays and weekend days among retirees. Adjusted for age, gender, occupational status, device-wear time, mobility limitations, BMI and neighbourhood disadvantage.

More total physical activity (including both LPA and MVPA) was observed during active travel on days off (34 min/day, 95% CI 28–39 min/day) and retirement days (37 min/day, 95% CI 32–42 min/day) than on workdays (23 min/day, 95% CI 19–27 min/day) (Figure 6) (Study IV). When LPA and MVPA were analysed separately, no differences in LPA during active travel between workdays and days off were observed, but the analyses showed 11 min/day more MVPA during active travel on days off and after retirement than on workdays (Figure 6).

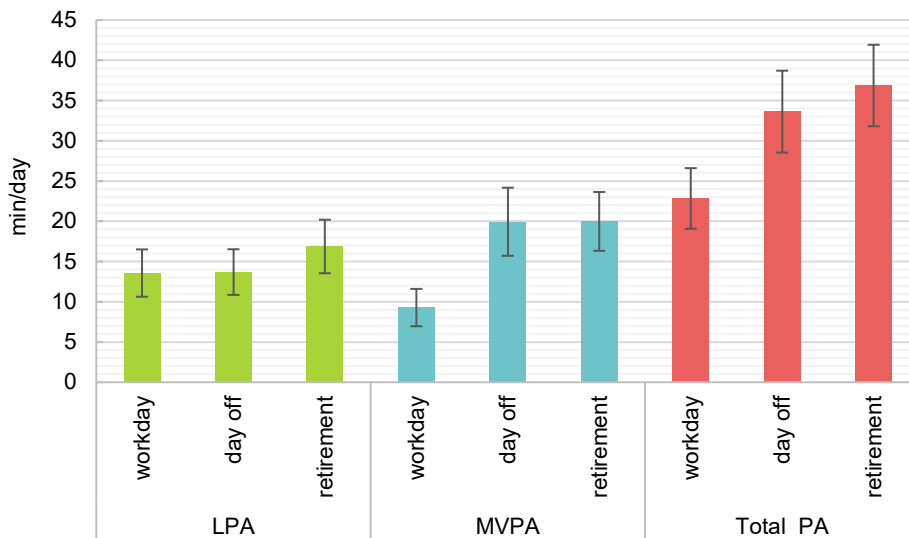


Figure 6. Mean level of light physical activity (LPA), moderate-to-vigorous physical activity (MVPA) and total physical activity (Total PA) during active travel between workdays, days off and retirement days. Adjusted for age, gender, occupational status, mobility limitations and BMI.

5.3 Changes in physical activity and sedentary behaviour during retirement transition by work- and commuting-related physical activity (Study II)

Table 7 presents the changes in sedentary time, LPA and MVPA during the retirement transition in four activity groups, categorized by the participants' work- and commuting-related physical activity: 'Non-active workers and commuters', 'Non-active workers but active commuters', 'Active workers but non-active commuters' and 'Active workers and commuters'. Overall, no changes in sedentary time or LPA were observed during the retirement transition. However, the changes in sedentary time and LPA varied by activity group (P for interaction 'activity group*time' 0.0002 and <.0001, respectively). Among the 'Non-active workers and commuters', sedentary time decreased by 38 min/day (95% CI -69 - -7 min/day), and LPA increased by 35 min/day (95% CI 8-63) min/day). The changes were similar among the 'Non-active workers but active commuters', but not statistically significant. Among the 'Active workers but non-active commuters', sedentary time increased by 49 min/day (95% CI 24-74 min/day) and LPA decreased by 53 min/day (95% CI -77--30 min/day), but among the 'Active workers and active commuters', the rather low level of sedentary time and high level of LPA continued after retirement (only minor changes observed). MVPA increased on average by 4 min/day (95% CI 0-9

min/day) overall during retirement, from 29 min/day to 33 min/day. However, no differences were observed across the activity groups (P for interaction 'activity group*time' = 0.91).

Table 7. Mean change in sedentary time (SED), light physical activity (LPA) and moderate-to-vigorous physical activity (MVPA), overall and by work (W)- and commuting (C)-related physical activity.

	GROUP	BEFORE RETIREMENT MEAN	95% CI	MEAN CHANGE	95% CI	INTERACTION P*
SED (MIN)	Overall	521.0	509.6–532.4	1.2	-18.3–20.8	
	W↓C↓	555.8	535.0–576.6	-38.3	-69.1--7.4	0.0002
	W↓C↑	547.8	518.2–577.3	-29.7	-60.6–1.2	
	W↑C↓	496.7	480.2–513.2	49.0	23.6–74.5	
	W↑C↑	474.6	448.5–500.6	9.3	-28.1–46.8	
LPA (MIN)	Overall	272.1	261.2–282.9	- 5.4	-23.1–12.3	
	W↓C↓	240.0	221.1–258.8	35.3	7.7–63.0	<.0001
	W↓C↑	249.4	220.2–278.5	24.0	-2.4–50.5	
	W↑C↓	295.8	279.0–312.6	-53.2	-76.9--29.6	
	W↑C↑	310.1	285.8–334.4	-16.1	-48.4–16.2	
MVPA (MIN)	Overall	28.5	25.5–31.5	4.5	0.5–8.6	
	W↓C↓	25.6	19.9–31.3	3.6	-3.4–10.5	0.91
	W↓C↑	24.6	18.4–30.7	6.3	-2.4–14.9	
	W↑C↓	29.1	24.3–33.9	4.6	-1.0–10.1	
	W↑C↑	36.9	28.3–45.5	7.3	-2.5–17.2	

W↓C↓ = Non-active workers and commuters

W↓C↑ = Non-active workers but active commuters

W↑C↓ = Active workers but non-active commuters

W↑C↑ = Active workers and commuters

Adjusted for age, gender, BMI, mobility limitations, occupational status, device-wear time, neighbourhood disadvantage and measurement season.

Mean change: after vs before retirement

*P for interaction 'activity group*time'

Modified, with permission, from Table 2 of original Study II.

5.4 Physical activity and sedentary behaviour in different contexts (Study I)

This study analysed physical activity and sedentary behaviour in four contexts: at home, in non-home locations and during active or non-active travel. Device-wear time was also analysed in the same contexts. Most of the wear time of the participants who were still working, i.e., ‘workers’, accumulated in non-home locations on workdays and at home during days off (Figure 7). Most of the retirees’ device-wear time accumulated at home on both weekdays and weekend days. Device-wear time during travel did not vary by type of day among either the workers or the retirees (Figure 7).

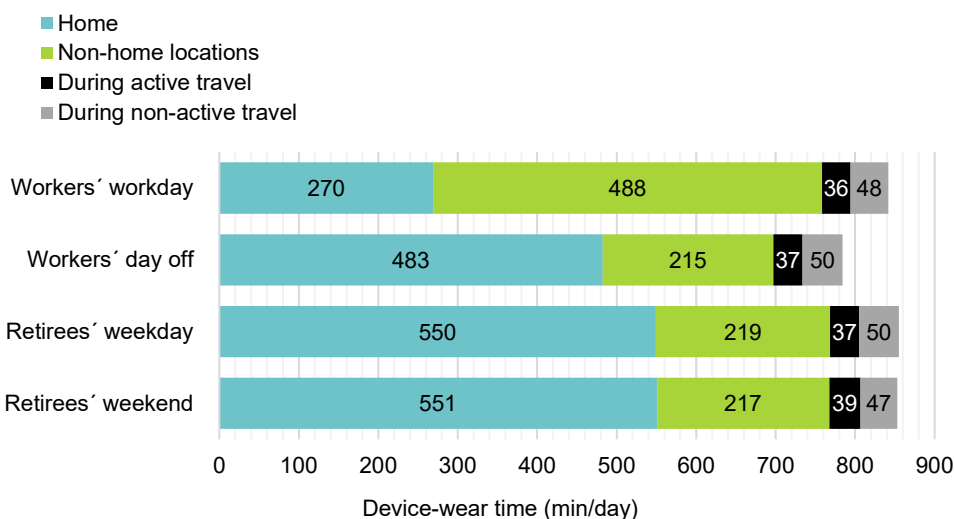


Figure 7. Unadjusted distribution of daily device-wear time across different contexts: home, non-home locations and during travel among workers and retirees. Modified, with permission, from Figure 1 of original Study I.

Table 8 shows physical activity and sedentary time by different contexts and compares workers’ workdays and days off, and retirees’ weekdays and weekend days. Workers accumulated markedly more of their sedentary time (330 min/day vs. 167 min/day), LPA (162 min/day vs. 85 min/day) and MVPA (12 min/day vs 8 min/day) in non-home locations on workdays than on days off. Conversely, more of the workers’ sedentary time (321 min/day vs 163 min/day), LPA (148 min/day vs 74 min/day) and MVPA (11 min/day vs 6 min/day) accumulated at home on days off than on workdays. Workers accumulated more MVPA during active travel on days off (14 min/day) than on workdays (9 min/day). Retirees’ levels of physical activity and sedentary time in different contexts did not differ between weekdays and weekend days.

Table 8. Mean values of sedentary time (SED), light physical activity (LPA) and moderate-to-vigorous physical activity (MVPA) on workdays and days off among workers, and on weekdays and weekend days among retirees in different contexts.

	HOME		NON-HOME LOCATIONS		ACTIVE TRAVEL		NON-ACTIVE TRAVEL		
	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	
SED (MIN)									
WORKERS	workday	163.4	141.7–185.2	329.6	307.4–351.9	17.9	13.3–22.5	34.5	27.2–41.9
	day off	321.0	283.7–358.3	167.1	135.1–199.1	14.4	9.6–19.3	42.8	31.0–54.5
RETIRES	weekday	362.2	321.9–402.4	95.6	62.8–128.3	11.8	5.1–18.5	41.4	27.4–55.3
	weekend	361.2	303.6–418.8	102.2	55.0–149.4	13.1	3.6–22.5	36.4	23.0–49.8
LPA (MIN)									
WORKERS	workday	73.8	61.8–85.9	162.2	147.1–177.4	15.1	11.8–18.4	7.4	5.6–9.1
	day off	147.8	129.0–166.5	84.9	69.3–100.5	12.3	8.7–15.9	8.3	6.2–10.3
RETIRES	weekday	194.7	168.9–220.6	73.9	52.4–95.4	12.7	5.6–19.7	7.4	4.7–10.0
	weekend	186.7	153.8–219.6	84.5	51.7–117.3	10.7	5.2–16.1	5.4	3.0–7.8
MVPA (MIN)									
WORKERS	workday	5.7	3.6–7.9	11.9	10.0–13.8	8.8	6.0–11.6	1.8	1.3–2.4
	day off	11.0	8.1–14.0	8.2	5.8–10.7	13.7	10.4–17.1	1.3	0.6–1.9
RETIRES	weekday	7.5	3.0–12.0	10.4	6.7–14.0	13.8	8.0–19.7	1.5	0.8–2.2
	weekend	9.2	3.3–15.2	7.9	4.4–11.3	14.1	7.4–20.8	1.4	0.1–2.8

Adjusted for age, gender, occupational category, mobility limitations, BMI, device-wear time, neighbourhood disadvantage and measurement season. Modified, with permission, from Table 2 of original Study I.

5.5 Intervention-induced changes in physical activity behaviour (Study III)

5.5.1 Changes by context

Among the retirees participating in the physical activity intervention, based on the use of an activity tracker, no overall change in total physical activity was observed over the one-year follow up. However, LPA declined by 14 min/day from 272 min/day (95% CI 253–292 min/day) to 258 min/day (95% CI 241–276 min/day); and MVPA increased by 13 min/day, from 25 min/day (95% CI 18–32 min/day) to 38 min/day (95% CI 29–47 min/day) (Table 2 in original Study III).

Table 9 presents the mean levels of physical activity by context at baseline and after one-year follow up. At home, MVPA increased from 7 min/day to 14 min/day, with no change in total physical activity or LPA. In non-home locations, LPA decreased by 13 min/day, from 80 min/day to 67 min/day. During active travel, MVPA increased by 5 min/day, from 11 min/day to 16 min/day, whereas LPA decreased by 4 min/day from 10 min/day to 6 min/day. No changes were observed in physical activity of any intensity during non-active travel.

Table 9. Mean daily total physical activity (Total PA), light physical activity (LPA) and moderate-to-vigorous physical activity (MVPA) at baseline and at 1-year follow up, by context.

		HOME		NON-HOME LOCATIONS		ACTIVE TRAVEL		NON-ACTIVE TRAVEL	
		Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
LPA (MIN)	Baseline	174.2	152.6–195.7	80.3	66.8–93.7	9.5	6.9–12.1	8.6	6.2–10.9
	1-year	178.2	153.5–202.9	66.9	49.4–84.4	5.7	3.7–7.6	7.7	5.4–9.9
MVPA (MIN)	Baseline	6.9	3.5–10.3	6.3	3.9–8.6	11.3	7.1–15.4	0.8	0.3–1.3
	1-year	13.7	9.2–18.2	6.6	4.0–9.2	16.5	11.0–21.9	1.2	0.5–1.9
TOTAL PA (MIN)	Baseline	181.1	158.6–203.6	86.6	72.6–100.6	20.8	15.9–25.7	9.4	6.9–11.9
	1-year	191.9	165.5–218.2	73.5	55.3–91.7	22.1	16.1–28.1	8.8	6.3–11.3

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

Modified, with permission, from Table 2 of original Study III.

5.5.2 Changes by residential greenness

Figure 8 illustrates the mean levels of LPA, MVPA and total physical activity, by participants' residential greenness at baseline and at one-year follow up. At baseline, the low greenness group had lower total physical activity (267 min/day, 95% CI 237–297 min/day) than the high greenness group (326 min/day, 95% CI 280–373 min/day). Similarly, the low greenness group had less LPA (243 min/day, 95% CI 212–274 min/day) than the high greenness group (299 min/day, 95% CI 253–344 min/day). Over the one-year follow up, the differences in total physical activity and LPA between the low and high greenness groups persisted. Instead, MVPA increased more in the high greenness group (28 min/day, 95% CI 14–42 min/day) than in the moderate greenness group (14 min/day, 95% CI 7–21 min/day), and particularly more than in the low greenness group (4 min/day, 95% CI -4–12 min/day) (P for interaction 'time*greenness' = 0.04).

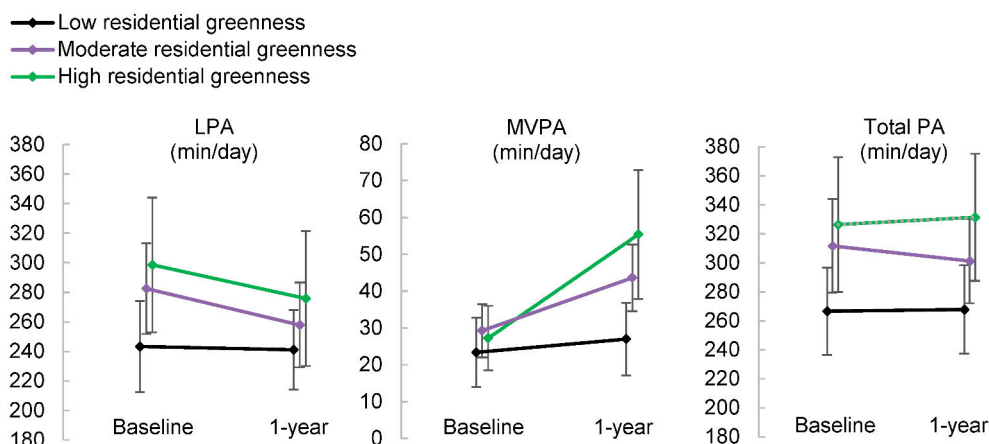


Figure 8. Mean daily light physical activity (LPA) and moderate-to-vigorous physical activity (MVPA) and total physical activity (Total PA) at baseline and at 1-year follow up by residential greenness (measured using NDVI). Adjusted for age, gender, device-wear time, measurement season, occupational status, neighbourhood disadvantage, BMI and mobility limitations. Modified, with permission, from Figure 1 of original Study III.

5.6 Exposure to useable green space and physical activity during active travel (Study IV)

Assessment of how useable green spaces along active travel trips were associated with physical activity accumulated during active travel (Study IV) showed that a greater proportion of the participants' active travel generally took place in useable green space on days off (29%, 95% CI 25–34%) and after retirement (28%, 95% CI 24–32%) than on workdays (19%, 95% CI 16–22%) (Table 2 of original Study IV).

Figure 9 shows that one SD addition to useable green space exposure during active travel was associated with 11 min/day (95% CI 7–15 min/day) of additional total physical activity during active travel on days off and 12 min/day (95% CI 9–16 min/day) on retirement days. No association was observed between exposure to useable green space and total physical activity during active travel on workdays. The P-value for the interaction between ‘useable green space*day type’, indicating the difference between the days, was 0.003. No associations were observed between the exposure to useable green space and LPA during active travel on any type of day. However, one SD addition to useable green space exposure was associated with 8 min/day (95% CI 4–11 min/day) of additional MVPA during active travel on days off, and 9 min/day (95% CI 6–13 min/day) on retirement days (P for interaction 0.008) (Table 3, Supplemental Table 2 and Supplemental Figure 3 of original Study IV).

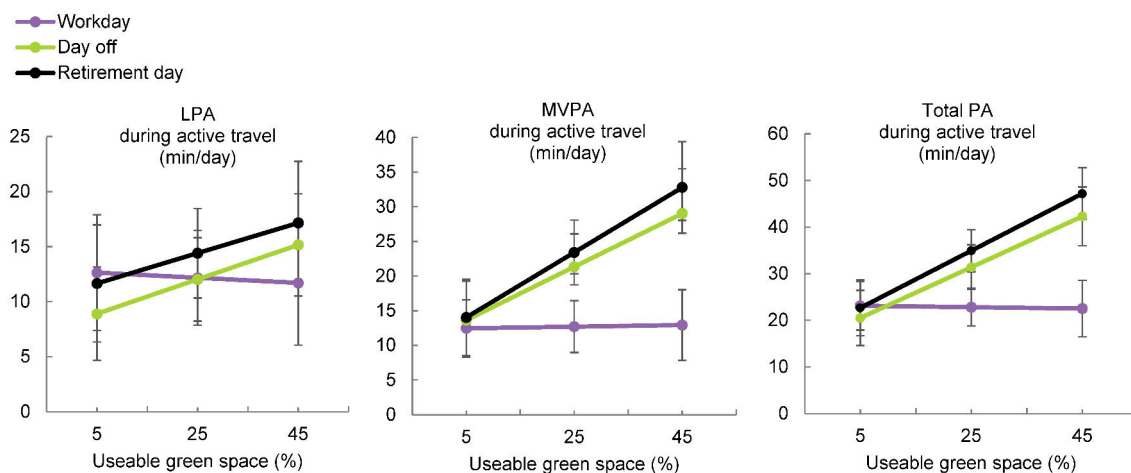


Figure 9. Association between exposure to useable green space (mean 25%, SD=20%) and light physical activity (LPA), moderate-to-vigorous physical activity (MVPA) and total physical activity (Total PA) during active travel on workdays, days off and retirement days. Adjusted for age, gender, occupational status, BMI, mobility limitations and measurement season. Modified, with permission, from Figure 1 and Supplemental Figure 3 of original Study IV.

6 Discussion

This study used repeatedly collected, combined GPS and accelerometer measurements to examine physical activity and sedentary behaviour in different contexts before and after retirement. People transitioning to retirement are an important population group to study, as physical activity and sedentary behaviour may change either positively or negatively when a person retires, and different environments may play a role in this. Physical activity and sedentary behaviour were examined separately for different days and in different contexts, including the locations in which the participants stayed during the day and their travel between the locations. Furthermore, the associations between greenness and physical activity were examined by analysing how residential greenness was related to physical activity overall and in different contexts, and how exposure to useable green space during active travel was associated with the physical activity accumulated during active travel.

6.1 Contexts of physical activity and sedentary behaviour on different types of days (Studies I and IV)

The results of Studies I and IV showed that whether it was a workday or a day off clearly related to physical activity and sedentary behaviour in different contexts before retirement. When still working, the participants accumulated more sedentary time, LPA and MVPA in non-home locations than at home on workdays, and conversely more sedentary time and physical activity at home than in non-home locations on their days off (Study I). More total physical activity and MVPA accumulated during active travel on days off and on retirement days than on workdays (Studies I and IV). Study I also showed that retirees' physical activity and sedentary behaviour in different contexts appeared similar on weekdays and weekends. As no differences were observed, the later articles of this dissertation did not separate retirees' weekdays from weekend days. Moreover, Studies I and IV showed that retirees' physical activity and sedentary behaviour in different contexts on any day was rather similar to their physical activity and sedentary behaviour on

days off before retirement. Thus, the findings suggest that leisure-time physical activity habits tend to remain the same before and after retirement.

As far as is known, no previous GPS and accelerometer-based studies have examined physical activity or sedentary behaviour separately on workdays and days off in different contexts. Overall, based on accelerometer measurements (Pulakka et al., 2019) or heart rate variability measures (beat-to-beat R-R interval recording) (Mutikainen et al., 2014), without separating different locations or during travel, adults seem to accumulate more MVPA on days off than on workdays. Consistently, in Study I, more MVPA accumulated overall on days off than on workdays among those still working. Prior GPS and accelerometer-based studies have observed that when separated by context, a large proportion of physical activity among adults (Firth et al., 2022; Holliday et al., 2017a; Jansen et al., 2016), and also sedentary behaviour among older adults (Perchoux et al., 2023), accumulates at home. However, the workplace has shown to be an almost equally important location in terms of the accumulation of physical activity (Jansen et al., 2016) among people still of working age. Thus, the workplace probably dominates the results of Study I for non-home locations. One GPS and accelerometer-based study among US adults (Ramulu et al., 2012) noted that physical activity at home vs. away from home differed between weekdays and weekends, as most physical activity took place away from home on weekdays, but not on weekends. This is in line with the findings of this study regarding workers' workdays and days off. However, these findings are not directly comparable, as dividing time merely into weekdays and weekends may not accurately explain people's work schedules.

Maintaining sufficient accumulation of MVPA at later ages is important, as MVPA has shown to provide many health benefits (Menai et al., 2017) and is thus also included in the global recommendations for health-enhancing physical activity among both adults and older adults (World Health Organization, 2020). Therefore, an important finding of Studies I and IV was that a large share of daily MVPA accumulated during active travel among both the participants still working and those already retired. The results of Study IV also indicated that more MVPA accrued during active travel on days off and on retirement days than on workdays. These results are consistent with those earlier studies that have reported high amounts of MVPA accumulating during trips in general (Jansen et al., 2016), and during active travel in particular (Brondeel et al., 2019; Chaix et al., 2014; Costa et al., 2015).

To summarize, the results highlight the need to distinguish between work- and non-workdays when analysing the contexts of physical activity and sedentary behaviour among working age populations, because the type of day clearly relates to the outcomes of the analyses. The findings emphasize the importance of taking into account both non-home and home environments when promoting daily physical activity among late middle-aged adults. The results also suggest that encouraging

active travel offers potential ground for interventions to increase more strenuous physical activity among late middle-aged adults, and consequently to promote better health. Moreover, it appears that retirement does not mean giving up active travel, which is often considered to primarily relate to commuting and to end after retirement. Thus, targeting the promotion of active travel at people who have already retired can also be beneficial.

6.2 Changes in physical activity and sedentary behaviour when retiring, by work-related and commuting physical activity (Study II)

Study II showed that both work-related and commuting physical activity predicted changes in physical activity and sedentary behaviour during the transition to retirement. Among the ‘Non-active workers and commuters’, sedentary time decreased and LPA increased during the transition. A similar trend was also observed among the ‘Non-active workers but active commuters’. Among the ‘Active workers but non-active commuters’ the results were the opposite, as their sedentary time increased and their LPA decreased during the retirement transition, whereas the ‘Active workers and commuters’ maintained their rather low level of sedentary time and high level of physical activity.

The studies prior to this dissertation have been limited by the use of self-reported or occupational title-based information on the physical demands of work. Occupational titles are imprecise measures of actual physical activity at the workplace, as shown by the results of Study II, in which the group of active workers classified by GPS and accelerometer data included workers with both manual and non-manual occupational titles (Table 1 of original Study II). In line with the results of Study II, accelerometer-measured daily physical activity and sedentary time have also previously been observed to vary by pre-retirement occupation (Van Domelen et al., 2011). The results of Study II are also consistent with prior studies that have found that LPA decreases (Pulakka et al., 2020) and sedentary time increases (Suorsa et al., 2022, 2021, 2019) among manual workers during the retirement transition. However, long-term studies based on self-reported physical activity suggest that an increase in physical activity after retirement may be temporary (Holstila et al., 2017; Stenholm et al., 2016). As the data of Study II did not extend to post-retirement years, long-term changes were not assessed. Self-reported active commuting, on the other hand, has been associated with higher accelerometer-measured physical activity both before and after retirement, and better maintenance of physical activity during the transition to retirement (Pulakka et al., 2020). However, estimations of physical activity or sedentary behaviour using self-reported information is prone to recall and measurement biases (Schrack et al., 2016; Strath et al., 2013).

For those doing physically active work before retirement, occupational activity accounts for a large part of daily LPA (Prince et al., 2019b) and it may be demanding to maintain the same, often high level (Holtermann et al., 2018) of LPA after retirement. In contrast, non-active workers often have an occupation that requires them to be sedentary, and have lower levels of LPA and higher levels of sedentary behaviour on workdays than manual workers (Pulakka et al., 2018; Yu et al., 2022). Thus, when they retire, it seems easier for non-active workers to increase their level of physical activity and decrease sedentary behaviour than for active workers.

The results of Study II suggest that those with active pre-retirement work but with non-active commuting may be a risk group for declining levels of physical activity upon retirement. However, it is not certain whether the decrease of occupational physical activity is a negative issue, as prior studies have noted that occupational physical activity may not provide the same health benefits as leisure-time physical activity, or can even be harmful to health (Coenen et al., 2018; Holtermann et al., 2018, 2012; Li et al., 2013). Thus, future studies with longer follow up times are needed to better understand the role of occupational physical activity and its absence after retirement in health and functional development with advancing age.

In Study II, ‘Active workers and commuters’ showed no clear changes during the retirement transition in their rather low level of sedentary time and high level of physical activity. This is supported by previous accelerometer-based findings that participants who self-reported walking or cycling to work were more physically active before retirement than car drivers, and also maintained their total physical activity level during retirement (Pulakka et al., 2020). These results suggest that pre-retirement active commuting is part of an active lifestyle, which may attenuate the otherwise observed increase in sedentary behaviour and decrease in LPA among those who retire from physically active work.

To conclude, the results show that people retiring from physically active work might be at risk of insufficient physical activity after retirement, if the observed trend of declining physical activity persists. Supporting active commuting could be one way to both increase daily physical activity and strengthen long-term engagement in active modes of travel, as this may attenuate the otherwise observed decrease in physical activity and increase in sedentary behaviour when retiring.

6.3 Associations between greenness and physical activity in different contexts (Studies III–IV)

The associations between greenness and physical activity were examined by measuring exposure to greenness using NDVI-based residential greenness (Study III) and useable green space, based on CORINE Land Cover data (Study IV). The

results of Study III suggest that greater residential greenness is positively associated with daily LPA and total physical activity, overall in all contexts. By context, Study III showed that MVPA that accumulated at home or during active travel increased more among the retiree participants of the physical activity intervention when they lived in areas with more residential greenness than in areas with less residential greenness. In Study IV, greater exposure to useable green space during trips was associated with higher total physical activity and MVPA that accumulated during active travel. However, this association was only observed on days off and on retirement days, and not on workdays.

Previous studies of the associations between greenness and physical activity without GPS-based measures have reported inconsistent associations (Klompmaaker et al., 2018). It seems that the results may depend on how exposure to greenness is defined (Klompmaaker et al., 2018), or whether the green spaces are actually used (Prince et al., 2019a). Perhaps because GPS devices enable actual exposure to be captured more accurately, GPS-based studies with accelerometer-measured physical activity information have mostly reported positive associations between greenness and physical activity (Chaix et al., 2016; Dewulf et al., 2016; James et al., 2017; Jansen et al., 2017, 2018; Marquet et al., 2022).

Thus, the results of Study III, showing a positive association between residential greenness and the overall level of physical activity, are consistent with the results of prior GPS and accelerometer-based studies (Dewulf et al., 2016; James et al., 2017; Jansen et al., 2018). The results of Studies III and IV, suggesting more active travel in relation to higher exposure to greenness, were consistent with results of prior studies that have observed an association between higher greenness and more survey-based walking or higher accelerometer-based step count (Chaix et al., 2016; Marquet et al., 2022). The results also support those previous results based on self-reported physical activity and NDVI-based greenness among middle-aged adults in the UK (Sarkar, 2017), which showed an association between more greenness around participants' homes and higher odds of engaging in active travel for non-work trips and walking for physical activity for more than 30 min per day.

Similarly to the findings of this dissertation, showing a positive association between greenness and physical activity particularly on days off and in retirement, a study among adults in the US, has shown that the association between greenness and physical activity varied between weekdays and weekends and that the positive association was stronger on weekends (James et al., 2017). In Study IV, the positive association between exposure to useable green space and total physical activity during active travel appeared to be more related to MVPA, as no association between exposure to useable green space and LPA during active travel was observed. Prior studies have also observed a positive relation between active travel and MVPA

(Chaix et al., 2014; Costa et al., 2015) or greenness and MVPA (Boakye et al., 2021; Dewulf et al., 2016).

As the association between exposure to useable green space and total physical activity and MVPA during active travel was only observed on days off and on retirement days (Study IV), it seems that personal choices play a crucial role in the observed associations. These results may thus have been affected by selective daily mobility bias (Chaix et al., 2013; Firth et al., 2022), which is common when using GPS measures to examine environmental effects. This means that the participants with higher exposure to useable green space during active travel may have selected the type of environment, for example, parks, for their intended exercise, such as walking. Therefore, although there was a positive association between exposure to useable green space and total physical activity and MVPA during active travel, we cannot conclude that higher exposure to useable green space induces more physical activity.

In Study III, the high greenness group participants' LPA decreased by approximately the same number of minutes as MVPA increased, which suggests that some of the active travel was done at a higher intensity during the follow-up measurement than at baseline. Thus, to reach their daily goal, the participants might have changed cycling or public transport to walking, for instance. It should be noted here however, that the participants wore commercial activity trackers, as an intervention, on their wrists and reached their personal daily physical activity goal more easily by walking, during which the hand moves more than during cycling, when the hand is stationary.

To conclude, the results indicate that greenness might facilitate leisure-time MVPA, particularly among late middle-aged adults, and especially the accumulation of MVPA during active travel. Thus, constructing and maintaining green spaces in residential neighbourhoods and around pedestrian and bicycle lanes might increase physical activity, particularly participation in active travel.

6.4 Methodological aspects

A major strength of this dissertation is that all the Studies, I–IV, were based on GPS and accelerometer measurements, which measure physical activity and sedentary behaviour in different contexts and during active travel very precisely. Studies II–IV applied a longitudinal study design, which enabled examining the changes in physical activity and sedentary behaviour during the transition to statutory retirement (Studies II and IV) or over time among people participating in a physical activity intervention (Study III). The study populations of this dissertation were relatively healthy and homogeneous in terms of age, so the changes examined in the longitudinal models of Studies II–IV are unlikely to be explained by changes in

health status. The measures of residential greenness and useable green space during active travel were also objective, as greenness was assessed using a satellite-based vegetation index – the NDVI (Study III) and CORINE Land Cover classes (Study IV).

The main weakness of the original studies, as well as many of the prior GPS-based studies, is their relatively small dataset. Most prior GPS-based studies have had a small number of participants, as is seen in the study of Yi et al. (2019), which reported the median sample size as having been 148 participants. This is perhaps because collecting GPS data can be burdensome for both the study participants and the researchers, and collecting combined GPS and accelerometer data even more so. GPS devices can be rather large for participants to wear and thus they may not wear them all day or at other requested times, which can easily lead to participants being excluded from the analyses due to insufficient wear time. A common requirement for a valid measurement day is 10 hours or more of wake wear time (Aadland and Ylvisåker, 2015a; Schrack et al., 2016). Issues such as the limited battery life of the devices (if the participant forgets to recharge it) or losing the GPS signal are common and can easily lead to insufficient wear time (Krenn et al., 2011; Shareck et al., 2013; Thierry et al., 2013).

In this dissertation, insufficient wear time was partly the reason for the variation in the number of available and valid measurement days in Studies I–IV. Another reason for the variation is that in the FIREA study, the participants were asked to wear the SenseDoc device for at least two workdays and two days off when still working, and for at least four days in total during the post-retirement measurement period, which resulted in relatively small numbers of measurement days from the beginning. The REACT participants, in turn, wore the SenseDoc device for seven consecutive days, and thus provided more days.

Following the small amount of valid measurement days, but to limit the number of excluded participants, the required number of measurement days in the original studies were rather low. In Study I, two valid measurement days were required for both groups, workers and retirees, in Studies II and IV two valid days before and after retirement, and in Study III two days for both baseline and follow-up measurements. Four or more measurement days per measurement period are commonly thought to reflect an individual's usual physical activity levels (Aadland and Ylvisåker, 2015b; Schrack et al., 2016), and 12 to 14 measurement days are recommended for reliable GPS measurement of activity spaces (Holliday et al., 2017b; Zenk et al., 2018). Thus, the results should be interpreted with caution, as the data may not represent typical daily physical activity or sedentary behaviour.

The common limitations of waist-worn accelerometers, such as their inability to detect certain types of physical activity, particularly cycling (Schrack et al., 2016), exists in the original studies. A study of Tarp et al. (2015) showed that waist-worn

accelerometers do not effectively capture MVPA from cycling, however, the population in that study was children. Thus, the results of this dissertation concerning MVPA during active travel in particular are likely to mostly apply to walking. No prior studies have examined middle-aged or older adults' accumulation of accelerometer-measured MVPA during cycling.

Prior attempts have been made to estimate travel mode using combined GPS and accelerometer data (Carlson et al., 2015; HABITUS-SDU, 2024), but they have encountered many challenges, particularly with waist-worn accelerometers. In the original studies, dichotomization into active vs non-active travel based on only the speed of trips means that some trips may have been miscategorized, although several additional analyses were conducted to find the best possible threshold, as described in the Method section. The small size of the dataset prevented the separate examination of travel modes, such as walking and cycling trips. It also prevented examination of sub-groups, for example, the impact of the measurement season on the results.

The greenness-related analyses of Studies III–IV also had some limitations. The main weakness of Study III is spatial misclassification (Chaix, 2018; Duncan et al., 2017), as exposure to residential greenness was only measured within a square buffer of 1250-m x 1250-m around the GPS-based home location of the participant, but physical activity also accumulated elsewhere. Thus, as the exposure was only measured around the participants' homes, it does not reflect the true exposure during activities outside the buffer area (Chaix, 2018). This may be particularly problematic when investigating adults' physical activity behaviour, as previous GPS and accelerometer-based studies have shown that a large proportion of adults' physical activity occurs beyond the area typically considered their residential neighbourhood (Hillsdon et al., 2015; Rodríguez et al., 2005; Troped et al., 2010). A better way to explore the associations between residential greenness and physical activity would be to also limit the measure of physical activity to that accumulated within the exposure area, such as within the neighbourhood, as in the study by Jansen et al. (2018).

Although the results of Study III suggest that residential greenness was related to a greater increase in MVPA among the participants of the physical activity intervention, it is not possible to conclude whether the intervention had an impact on the observed change, because, due to a lack of devices, no GPS and accelerometer measurements were taken of the control group. Moreover, the measurements in Study III were often completed during the autumn and winter, but the NDVI used to measure residential greenness was based on information from summertime. Thus, the study partly assessed the delayed effects of greenness on physical activity occurring at other times of the year. However, greenness can be considered to

indicate the general natural characteristics of residential areas, such as open space and parks, which can often be used throughout the year.

In Study IV, although both the exposure to useable green space and the minutes of physical activity of different intensities were estimated for each trip, exposure to useable green space and different physical activity intensity levels may not have fully coincided. Both estimates were measured for each entire trip but were not necessarily accumulated at exactly the same time. Nevertheless, this dissertation went a step further than using fixed buffers, for example residential buffers, which has been encouraged (Laatikainen et al., 2018), and investigated exposure to greenness during active travel trips.

Concerning the generalizability of the results, the majority of the study population were women, and due to the small sample size, gender-specific analysis was not feasible. Thus, the generalizability of the results to men is limited. Moreover, because the study populations consisted of only late middle-aged participants, they may not be generalizable to other age groups. The results of this dissertation may also not be generalizable to those who are physically less active, as selection bias analysis showed more self-reported physical activity among the eligible sample and the final analytical sample than in the larger FIREA survey cohort (Studies II and IV). As regards the characteristics of the examined contexts, there is no reason to assume that the study populations of this dissertation, residing in Southwest Finland, would not represent people from other urban areas of Finland, as good pedestrian and bicycle lanes and accessible public green spaces are usually found almost everywhere in Finland. However, globally, the results are not applicable to regions where such facilities do not exist.

6.5 Significance of the findings

This dissertation enhances the understanding of accelerometer-measured physical activity and sedentary behaviour in different GPS-detected contexts, among people in their 60s, around the time of retirement and during the retirement transition. It reveals positive associations between greenness and physical activity behaviour, particularly between greenness and active travel behaviour. The dissertation also provided methodological experience of rather recently developed devices that combine GPS and accelerometer sensors, which are hugely improving the precision of measuring different behaviours in different environments.

6.5.1 Suggestions for future research

Concerning physical activity and sedentary behaviour in different locations, the home-related results regarding days off and retirement days were clearly affected by

the fact that people generally spend the majority of their time on these days at home, and thus a great proportion of physical activity accumulates at home. Future studies should more carefully take the time relation into account in their analyses when examining which environments have the most potential to encourage increasing physical activity. Further studies could also separate different modes of commuting during trips in combined GPS and accelerometer data, and see how environmental characteristics relate to different modes of travel. They could consider combining a thigh-worn accelerometer with a GPS sensor to accurately recognize physical activity accumulated while cycling. Thigh-worn devices enable better identification of types of physical activity than waist-worn accelerometers due to the thigh angle and acceleration (Skotte et al., 2014; Stemland et al., 2015). As regards to changes during the retirement transition, this dissertation was only able to study immediate changes, thus studies with longer follow up times after retirement are warranted to determine whether the observed changes are persistent.

The positive association between exposure to useable green space and total physical activity and MVPA during active travel was seen in Study IV on days off and after retirement, but not on workdays, and thus, future studies are needed to determine which environmental factors support active travel specifically on workdays. In addition to greenness, the environmental attributes positively associated with accelerometer-measured physical activity in previous GPS-based studies have included street connectivity, land use mix, proximity to amenities, population density, walkability, safety from traffic or crime, and weather conditions (Boakye et al., 2021; Evenson et al., 2013; Firth et al., 2022; Hwang et al., 2016; Jansen et al., 2017, 2018, 2016; Marquet et al., 2022; Perez et al., 2016; Rodríguez et al., 2005; Stewart et al., 2016; Tamura et al., 2019; Troped et al., 2010).

As in this dissertation, previous studies have mostly investigated environmental factors associated with physical activity and much less research has focused on the environmental effects of sedentary behaviour (Prince et al., 2019a). Furthermore, as travel behaviour is easier to think of as being more sensitive to the characteristics of the environment, than physical activity that occurs at home, for example, further considerations are needed to determine why the greenness-related increase in MVPA also took place at home (Study III). Perhaps distinguishing between physical activity indoors and outdoors might provide new insights into this issue: residential areas with more greenness may have more houses with their own yards or gardens, which require physically demanding care.

6.5.2 Practical implications

Interventions aiming to encourage active travel both before and after retirement seem a feasible way to increase more strenuous physical activity among late middle-aged

people. Good quality, public green spaces in residential areas and around walking and bicycle lanes may increase daily physical activity and participation in active travel on days off and after retirement.

Promoting active commuting on workdays before retirement might be an efficient way to increase daily physical activity in all occupational groups, but may also be a good way to support the formation of physically active travel habits that may attenuate the otherwise observed decreases in levels of physical activity of active workers upon retirement. Encouraging active commuting requires a good network of safe, pleasant and year-round well-maintained pedestrian and bicycle lanes. Employers could also support active travel with, for example, benefits for leasing or purchasing bikes, or by providing secure bike storage, showers and changing rooms at workplaces. Future interventions could pay special attention to those retiring from physically demanding work, so that the observed decrease in the levels of physical activity among active workers upon retirement could be reduced.

Green spaces seem to attract late middle-aged people as an environment for physical activities, which is worth taking advantage of in physical activity promotion. For seniors, green spaces and routes for active travel within greenness need to be close to home and well-maintained all year round. Special attention should be paid to the quality of green spaces, for example, they should have resting places such as benches. Guided exercise or walking groups for older people in green spaces might also be a way of encouraging physical activities, at the same time offering opportunities for social connections that may benefit wellbeing.

7 Conclusions

The present dissertation was designed to examine where and on which days physical activity and sedentary behaviour occur before and after retirement, and how natural vegetation, i.e., greenness, relates to these behaviours. It also assessed how physical activity and sedentary behaviour change during the transition to statutory retirement or during a physical activity intervention after retirement, both overall and in different contexts. The data were collected using combined GPS and accelerometer measurements, and an algorithm was applied to define the locations in which the participants stayed and the trips they took between the locations. Different greenness indicators were used to define residential greenness and exposure to useable green spaces during active travel.

The main conclusions of this dissertation are:

1. A relatively large share of the participants' MVPA accumulated during active travel, both before and after retirement. An increase in MVPA accumulated during active travel was observed among the retirees who participated in the physical activity intervention, which was greater when the participants resided in a neighbourhood with a high level of greenness. Furthermore, exposure to useable green spaces during active travel was positively associated with total physical activity and MVPA accumulated during active travel on non-workdays. This suggests that active travel has high potential for encouraging physical activity among people in their 60s, and particularly more strenuous physical activity such as MVPA. Having enough accessible, good quality green spaces in residential areas, as well as around pedestrian and bicycle lanes, may support active travel among late middle-aged people.
2. Physical activity accumulates in all daily contexts, home and non-home environments, as well as during travel, and future aims to increase daily physical activity should consider all these contexts. However, among people still of working age, the type of day, i.e., workdays or days off, influenced physical activity and sedentary behaviour in different contexts. The environmental characteristics of the contexts may be differently related to

physical activity on different days, as the positive association of exposure to useable green space on physical activity during active travel was only observed on days off and retirement days. Thus, the type of day needs to be taken into account in future studies and interventions, particularly when targeting working-aged people. In contrast, among retirees, physical activity and sedentary behaviour in different contexts appeared to be similar on weekdays and weekends, and the behaviours seemed to be similar to days off before retirement.

3. Pre-retirement work- and commuting-related physical activity played a considerable role in the changes in physical activity and sedentary behaviour during the transition to retirement. Less work-related physical activity was associated with a decrease in sedentary behaviour and an increase in LPA during the transition to retirement. Conversely, more work-related physical activity was associated with an increase in sedentary behaviour and a decrease in LPA, except among active workers who were also active commuters. Those who retire from physically active occupations may be at particular risk of decreased physical activity and increased sedentary behaviour after retirement. It seems that promoting active commuting before retirement might be an efficient way of supporting the maintenance of a higher level of physical activity and a lower level of sedentary behaviour in retirement.

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Appendices

Appendix 1. Corine Land Cover classes used to define useable green space (Category 1).

CATEGORY 0		CATEGORY 1		CATEGORY 2	
111	Continuous urban fabric	141	Green urban areas	411	Inland marshes (in water)
112	Discontinuous urban fabric	142	Sport and leisure facilities (vegetated areas)	421	Salt marshes (in the water)
121	Industrial or commercial units	242	Complex cultivation	511	Water bodies
122	Road and rail networks and associated land	243	Land principally occupied by agriculture, with significant areas of natural vegetation	523	Sea and ocean
123	Port areas	244	Agro-forestry areas		
124	Airports	311	Broad-leaved forest		
131	Mineral extraction sites	312	Coniferous forests		
132	Dump sites	313	Mixed forest		
133	Construction sites	321	Natural grassland		
142	Sport and leisure facilities: Leisure apartments	322	Moors and heathland		
142	Sport and leisure facilities: Racecourses for horses	324	Transitional woodland/shrub		
211	Non-irrigated arable land	331	Beaches, dunes, and sand plains		
222	Fruit trees and berry plantations	332	Bare rock		
231	Pastures	333	Sparsely vegetated areas		
412	Peatbogs (exploited)	411	Inland marshes (on land)		
		412	Peatbogs (natural)		
		421	Salt marshes (on land)		

Detailed descriptions of the land in each category can be found in Copernicus Land Monitoring Service (2024). Modified, with permission, from Supplemental Table 1 of original Study IV.



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