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## Neighborhood environment and physical activity

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2013

[Link to publication](#)

*Citation for published version (APA):*

Eriksson, U. (2013). *Neighborhood environment and physical activity*. [Doctoral Thesis (compilation)]. Family medicine, cardiovascular epidemiology and lifestyle.

*Total number of authors:*

1

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# Neighborhood environment and physical activity



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by

Ulf Eriksson

AKADEMISK AVHANDLING

som för avläggande av filosofie doktorsexamen

vid Medicinska fakulteten, Lunds universitet,

kommer att offentligas försvaras i Medicinens aula, Inga Marie Nilssons

gata 46, Malmö, fredagen den 11 januari 2013, kl. 13.00.

Fakultetsopponent: Professor Peter Schantz

Mittuniversitetet, Östersund

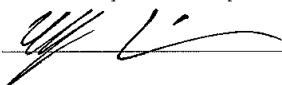
Gymnastik- och idrottshögskolan, Stockholm

Organization LUND UNIVERSITY		Document name DOCTORAL DISSERTATION	
Faculty of Medicine		Date of issue 11 January 2013	
Department of Clinical Sciences, Malmö		Sponsoring organization	
Author(s) Ulf Eriksson			
Title and subtitle Neighborhood environment and physical activity			
<p>Abstract</p> <p><b>Introduction:</b> Insufficient levels of physical activity are one of the top contributors to global mortality, and it is an important public health priority to increase the proportion of physically active people in the population. The interest in environmental determinants of physical activity has been rapidly increasing over the past few years. However, a majority of the previous literature concerns studies from North America and Australia, and it has often been based on self-reported neighborhood environments and/or on self-reported physical activity. The aim of this thesis was to investigate, for the first time in a Swedish context, the associations between objectively assessed neighborhood characteristics and objectively assessed and self-reported physical activity. <b>Methods:</b> This thesis is based on data from the Swedish Neighborhood and Physical Activity (SNAP) study. Neighborhood characteristics were objectively assessed using Geographic Information Systems (GIS). A walkability index consisting of residential density, street connectivity, and land use mix was constructed to define 32 highly and less walkable neighborhoods in the city of Stockholm where data were collected. Physical activity was assessed by accelerometers and by the International Physical Activity Questionnaire (IPAQ). <b>Results:</b> The walkability index was associated with higher levels of moderate to vigorous physical activity and walking for transportation and for leisure. The influence of neighborhood walkability was most pronounced during periods of the day when many people are likely to be exposed to their neighborhood environment. When analyzed separately, residential density and land use mix, but not street connectivity, were positively associated with physical activity. Significant proportions of these associations were mediated by vehicle ownership. A positive association was also found between the availability of exercise facilities and time spent in moderate to vigorous physical activity and meeting the physical activity recommendations. None of the associations found in this thesis were modified by individual factors, i.e. people living in dense mixed-use neighborhoods may benefit from these environments regardless of age, gender, income and vehicle ownership status. <b>Conclusions:</b> These results add to a growing body of evidence suggesting that policy makers and city planners have the potential, by designing environments that promote physical activity, to increase the levels of physical activity in the population and thereby improve public health.</p>			
Key words: Neighborhood, physical activity, GIS, walking, public health, physical activity pattern, environment, accelerometer, residential density, land use, walkability			
Classification system and/or index terms (if any):			
Supplementary bibliographical information:		Language English	
ISSN and key title: 1652-8220 Faculty of Medicine Doctoral Dissertation Series 2013:1		ISBN 978-91-87189-69-2	
Recipient's notes	Number of pages 143	Price	
	Security classification		

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# Neighborhood environment and physical activity



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Faculty of Medicine, Department of Clinical Sciences, Malmö

ISBN 978-91-87189-69-2

ISSN 1652-8220

Printed in Sweden by Media-Tryck, Lund University

Lund 2013

*We are the spaces we create.*

# **ABSTRACT**

## **Introduction**

Insufficient levels of physical activity are one of the top contributors to global mortality, and it is an important public health priority to increase the proportion of physically active people in the population. The interest in environmental determinants of physical activity has been rapidly increasing over the past few years. However, a majority of the previous literature concerns studies from North America and Australia, and it has often been based on self-reported neighborhood environments and/or on self-reported physical activity. The aim of this thesis was to investigate, for the first time in a Swedish context, the associations between objectively assessed neighborhood characteristics and objectively assessed and self-reported physical activity.

## **Methods**

This thesis is based on data from the Swedish Neighborhood and Physical Activity (SNAP) study. Neighborhood characteristics were objectively assessed using Geographic Information Systems (GIS). A walkability index consisting of residential density, street connectivity, and land use mix was constructed to define 32 highly and less walkable neighborhoods in the city of Stockholm where data were collected. Physical activity was assessed by accelerometers and by the International Physical Activity Questionnaire (IPAQ).

## **Results**

The walkability index was associated with higher levels of moderate to vigorous physical activity and walking for transportation and for leisure. The influence of neighborhood walkability was most pronounced during periods of the day when many people are likely to be exposed to their neighborhood environment. When analyzed separately, residential density and land use mix, but not street connectivity, were positively associated with physical activity. Significant proportions of these associations were mediated by vehicle ownership. A positive association was also found between the availability of exercise facilities and time spent in moderate to vigorous physical activity and meeting the physical activity recommendations. None of the associations found in this thesis were modified by individual factors, i.e. people living in dense mixed-use neighborhoods may benefit from these environments regardless of age, gender, income and vehicle ownership status.

## **Conclusions**

These results add to a growing body of evidence suggesting that policy makers and city planners have the potential, by designing environments that promote physical activity, to increase the levels of physical activity in the population and thereby improve public health.

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- Study 1**      **Neighborhood walkability, physical activity, and walking behavior: The Swedish Neighborhood and Physical Activity (SNAP) study**  
Kristina Sundquist, Ulf Eriksson, Naomi Kawakami, Lars Skog, Henrik Ohlsson, Daniel Arvidsson  
Social Science & Medicine, 2011, 72:1266–1273.
- Study 2**      **Neighborhood walkability, income and hour by hour physical activity patterns**  
Daniel Arvidsson\*, Ulf Eriksson\*, Sara Larsson Lönn, Kristina Sundquist  
\*These authors contributed equally  
Medicine & Science in Sports & Exercise (Accepted for publication 15 October 2012)
- Study 3**      **Walkability parameters, active transportation and objective physical activity: moderating and mediating effects of motor vehicle ownership in a cross-sectional study**  
Ulf Eriksson, Daniel Arvidsson, Klaus Gebel, Henrik Ohlsson, Kristina Sundquist  
International Journal of Behavioral Nutrition and Physical Activity, 2012, 9:123.
- Study 4**      **Availability of exercise facilities and physical activity in 2,037 adults: cross-sectional results from the Swedish neighborhood and physical activity (SNAP) study**  
Ulf Eriksson, Daniel Arvidsson, Kristina Sundquist  
BMC Public Health, 2012, 12:607.

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# Preface

Although physical activity is known to influence human health, large proportions of populations worldwide do not meet the recommended levels of physical activity. According to the World Health Organization, insufficient levels of physical activity are the fourth largest contributor to global mortality. It is therefore a highly important public health priority to increase the proportion of physically active people. Interventions at the individual level, however, have rarely been successful in the long term. The purpose of this thesis is to provide evidence on the associations between neighborhood environment characteristics and physical activity in a Swedish context. The first chapters in this thesis define physical activity, describe the evolution of physical activity guidelines and present the levels of physical activity in Sweden. This is followed by a presentation of the social-ecological model which describes the multi-component influence of individual factors, the social environment, the physical environment and policy factors on physical activity behavior. Methodological issues in assessments of physical activity and neighborhood environment are discussed and the previous literature on neighborhood environment and physical activity is presented. Also, the research gaps in the previous literature are pointed out. This is followed by a detailed description of the aims, methods and results of the studies included in this thesis. These results are discussed in relation to previous research and the implications and conclusions of this thesis are presented.

# Introduction

## Physical activity – definitions of dimensions

Physical activity is a complex behavior and can be described in various ways. The overall definition of physical activity is: any bodily movement produced by skeletal muscles that results in increased energy expenditure. Exercise is a subcategory of physical activity that is planned, structured and performed with the purpose of enhancing or maintaining one or more components of physical fitness [1]. Physical activity can be described by means of intensity, duration, frequency, volume, and type and in which domain or context it is performed. The *intensity* is the energy expended when performing a specific physical activity and can be described in absolute values (e.g. ml O<sub>2</sub>/minute or kcal/minute) or in relation to, for example, an individual's body weight (ml O<sub>2</sub>/minute/kg) or maximal aerobic capacity (e.g. %VO<sub>2max</sub>). It can also be expressed as a multiple of the energy consumption in a resting state and is then referred to as metabolic energy turnover (MET). For example, a physical activity that expends 60% more energy than the resting metabolic rate has an MET of 1.6. A comprehensive compendium of MET values for different physical activities was released in 1993 and has been updated twice since then [2-4]. Physical activity intensities can be classified into sedentary (1.0–1.5 MET), light (1.6–2.9 MET), moderate (3–5.9 MET) and vigorous (≥6 MET) [2, 5–6]. The *duration* simply refers to the time an activity is performed at a single event, a bout of physical activity. The *frequency* describes how often an activity is performed during a specified time period (e.g. per day or per week). The *volume* of a physical activity is the product of its intensity, frequency and duration and is often described as energy expenditure. The overall volume of physical activity can also be calculated by summing the volume of all activities performed during a certain period of time, such as a week. The *type* of activity is simply the kind of activity that is being performed, such as walking, playing tennis or vacuuming. The *domain* or *context* describes the circumstances of the physical activity. For example, the activity can be transport-related, work-related, household-related or performed for recreational purposes during leisure time. It can also be coupled with geographic information about where it is performed, e.g. in a park, within the neighborhood or at an exercise facility.



## Physical activity guidelines – from ancient times to now

Early thoughts about the health effects of physical activity are found in notes from ancient times. The first descriptions of organized exercise for purposes of health promotion are from the ancient China around 2500 BC. The Chinese physician and surgeon Hua T'o encouraged physical activities inspired by animal movement, mainly the movements of the tiger [7]. Also, Hippocrates and Galen from ancient Greece understood the importance of physical activity and fitness and advised moderate amounts of physical activity to maintain good physical and mental health [7-8]. In the 1950s, the field of physical activity epidemiology was initiated by Morris and colleagues with studies on occupational physical activity and coronary heart disease. They found that coronary heart disease among heavy workers was "less common, less severe, and occurring later than among light workers" [9-10]. Numerous studies have been performed since then, and there is now a large body of evidence on the preventive effects of physical activity on premature death, cardiovascular disease, type 2 diabetes, osteoporosis, breast cancer, colon cancer and depression [11-12]. Researchers have been investigating the dose-response relationship between physical activity and health and have established different recommendations in the past few decades, based on the available evidence at the time. The first public health recommendation on physical activity was published in 1995 by the Center for Disease Control (CDC) and the American College of Sports Medicine (ACSM) [13]. It recommended adults to accumulate at least 30 minutes of moderate physical activity on most, preferably all, days on the week. The recommended 30 minutes could be accumulated in shorter bouts of activity throughout the day. As new evidence emerged, the recommendation from 1995 was updated by the ACSM and the American Heart Association (AHA) in 2007 [5]. The updated recommendations added specificity on the number of days per week and the minimum duration of a health-enhancing physical activity bout. It also included recommendations on vigorous physical activity. Healthy adults were recommended to accumulate at least 30 minutes of moderate physical activity (in bouts of 10 minutes or more) on five days each week or to accumulate at least 20 minutes of vigorous aerobic physical activity on three days each week or an equivalent combination of these intensities. In addition, adults were recommended to perform activities for muscular strength on at least two days each week. The World Health Organization (WHO) launched the Global Recommendations on Physical Activity for Health in 2010 [14]. As it is unclear whether 30 minutes of physical activity on 5 days a week is more favorable for health than, for example, 50 minutes on 3 days a week, the new WHO recommendations emphasize the total amount of physical activity each week rather than the number of days each week a person should be active on. Adults are recommended to accumulate at least 150 minutes of moderate physical activity or at least 75 minutes of vigorous physical activity throughout the week, or an equivalent combination of these intensities. The physical activities should be performed in bouts

of 10 minutes or more. For additional health benefits, adults are encouraged to accumulate twice the amount of physical activity described above throughout the week (i.e. 300 minutes of moderate physical activity or 150 minutes of vigorous physical activity or an equivalent combination of these intensities). WHO also recommends muscle-strengthening activities involving major muscle groups on at least two days each week. To match the different needs of physical activity across the lifespan, there are specific recommendations for children and adolescents (5–17 years old) and older adults (65 years old and above).

## Prevalence of physical activity in Sweden

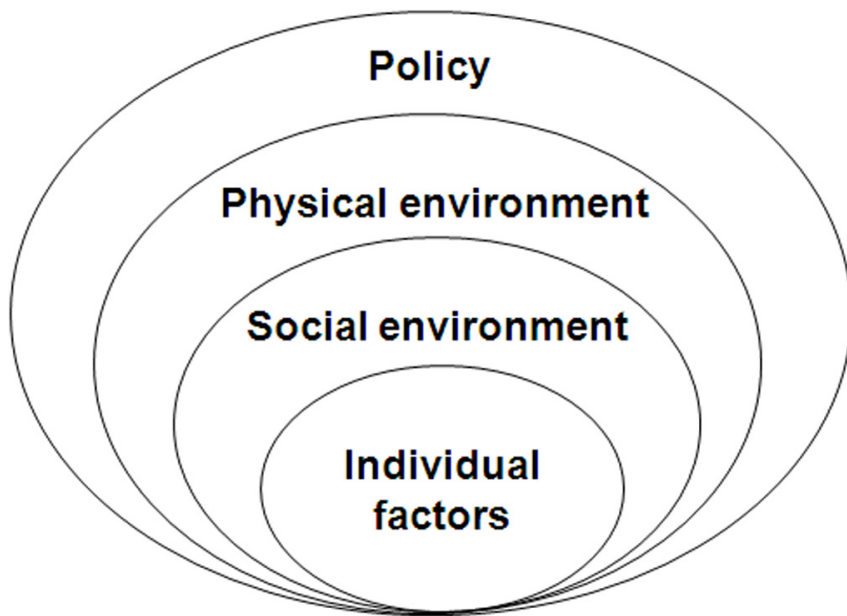
Despite the many well-known health benefits of physical activity, large proportions of populations worldwide are not sufficiently active [15]. Motor vehicles, dish washers, remote controls, escalators and other features of modern society have reduced the needs of physical activity in daily life. Being physically active has become more of an active choice. Insufficient physical activity is the fourth largest global risk factor for premature death and is estimated to cause 27% of the diabetes burden and 30% of the ischemic heart disease burden worldwide [16]. Due to the complexity of physical activity assessment, it is hard to estimate the levels of physical activity in the population. Early attempts to establish the prevalence of physical activity have often been based on subjective measures of leisure-time physical activity, and thus missing other domains such as occupational physical activity. For example, data on exercise frequency in the Swedish population have been collected by Statistics Sweden (in Swedish: Statistiska Centralbyrån) since 1975 as part of a national survey of living conditions. There has been a positive trend in the proportion of adults who report exercise at least twice a week since the early 1980s. In 2006, around 50% reported exercise at least twice a week compared to around 30% in 1980 [17]. However, measures of total physical activity, rather than exercise alone, are needed to estimate the number of people meeting the physical activity recommendations. The Swedish National Institute of Public Health (in Swedish: Statens Folkhälsoinstitut) have been collecting data on physical activity since 2004 using two questions: one on physical activity during the past 12 months and one on moderate physical activity during a normal week. From these questions, a total of 65% are estimated to be active on a level corresponding to 30 minutes of moderate to vigorous physical activity per day [18]. A study published in 2007 used accelerometers to provide an objectively assessed estimate of the prevalence of physical activity in the Swedish population. The results showed that 52% (57% and 48% in men and women, respectively) of the individuals aged 18–69 years accumulated 30 minutes of moderate to vigorous physical activity per day. However, that figure dropped to 1% when only including physical activities performed in continuous bouts of 10 minutes or more in accordance with the recommendations [19].

International comparisons of self-reported physical activity have indicated that the proportion of adults meeting the recommended levels of moderate to vigorous physical activity is lower [15, 20] but that the levels of active transportation are higher [15] in Sweden than in many other countries. These results, however, are not supported by a study comparing objectively assessed physical activity in Sweden and the U.S. In this Swedish-American study, Swedish men and women spent 36 and 32 minutes in moderate to vigorous physical activity per day respectively, while the corresponding figures for U.S. men and women were 33 and 19 minutes per day [21].

## Social-ecological models for physical activity

Why are some people physically active while others are not? Physical activity is a complex behavior and many studies have investigated its correlates and determinants. A number of models have been proposed to provide a framework and to explain differences in health behavior between individuals [22-24]. One of the models often referred to in physical activity research is the social-ecological model [25-27]. It describes the multi-component influence of individual factors, the social environment, the physical environment and policy factors on physical activity (Figure 1). Research has found that, for example, lower age [19, 28], male sex [19, 28], and high self-efficacy [29] are individual factors positively correlated with physical activity. Social support [30] and seeing others being physically active [31] are factors of the social environment that are correlated to physical activity. Physical activities are performed in physical environments, and some attributes of these environments may facilitate or hinder physical activity. The interest in environmental correlates of physical activity has increased rapidly in the past few years, and this is also the main focus of this thesis. Aesthetics [32], walkability [33-34] and availability of recreational facilities [35-36] have shown positive associations with physical activity. Aspects of the home environment may also be associated with physical activity [37]. The policy domain in the social-ecological models refers to legislation or policy making actions that have the potential to affect physical activity levels in the population. This could include, for example, policies to increase the use of physical activity on prescription within the health care system, workplace policies or city planning policies aimed at creating environments that promote physical activity [38].

**Figure 1. Social-ecological model of the multiple levels of influence on physical activity behavior.**



Adapted from references 25–27.

## Assessments of physical activity

Levels and patterns of physical activity in daily life are hard to measure, and there is no single golden standard method to do so. The methods used to assess physical activity are often divided into subjective and objective methods, both with their strengths and limitations.

### Subjective assessments of physical activity

Subjective physical activity measures, such as questionnaires or activity logs and diaries, are based on information reported by the study participants, i.e. subjective information. Activity logs and diaries are mostly used in small-scale intervention studies, because of their heavy participant burden, while questionnaires are commonly used over a broader scale of study designs [39]. There are a large number of physical activity questionnaires developed to assess different dimensions of physical activity

and designed for different target populations. For example, there are questionnaires suitable for research purposes [40-41] and there are questionnaires primarily developed for population surveillance purposes [40, 42]. There are also questionnaires specifically designed to assess physical activity in specific age groups such as adolescents [43] or older adults [44]. Depending on the design, physical activity questionnaires can collect detailed information on intensity, duration, frequency, volume, and type or context of the physical activity. Physical activity questionnaires are often used in large-scale studies as they are practical for the study participants and can be used at a low cost. There are, however, limitations with the use of subjective measures that should be considered [45]. Study participants are often asked to report their physical activities during a specific period, e.g. the past seven days or the past month, and the quality of the data therefore depends on the memory of the participants. This may introduce recall bias [46]. Over-reporting due to social desirability is another issue connected with subjective methods [47]. Two recent reviews on the reliability and validity of physical activity questionnaires concluded that many questionnaires were lacking sufficient evidence of validity and reliability [48] and that the validity, when evaluated against criterion methods, is moderate at best [49].

The International Physical Activity Questionnaire (IPAQ) is one of the most frequently used questionnaires in the current literature [48]. The IPAQ is a 7-day recall questionnaire available in a long and short form, both with versions for telephone- or self-administration. The short form, with seven items, is recommended for population surveillance purposes while the long form, with 27 items, may be more suitable for research purposes [50]. The short form assesses physical activity by asking about total frequency and duration of moderate and vigorous physical activity and walking. It also assesses sedentary behavior by asking a question on sitting time. Respondents are asked to report activities lasting for 10 minutes or longer. The long form of IPAQ is more detailed and separates physical activity into four domains: work-related, transportation-related, household-related and leisure-time physical activity. For example, walking is assessed by one item on walking at work, one item on walking for transportation and one item on walking for leisure. Sedentary behavior is also assessed in the long form. The performance of IPAQ has been tested for reliability and validity in several settings, and the first international study reported good reliability (median Spearman correlation coefficient of 0.8 between assessments) and fair to moderate validity (median Spearman correlation coefficient of 0.3 between IPAQ and criterion) when using accelerometry as criterion method [40]. A recent meta-analysis of the validity of IPAQ found correlations of 0.27–0.49 between IPAQ and other physical activity measures, mainly from accelerometers and pedometers [51]. Van der Ploeg and colleagues specifically evaluated the IPAQ (short form) questions on walking by comparing reported walking time per week from IPAQ with moderate physical activity assessed by accelerometers in individuals who did not

report any other moderate activities besides walking. The correlation between IPAQ walking and accelerometer-measured moderate physical activity was 0.39 for the self-administered version [52]. A validation study on a Swedish sample found that IPAQ (short form) identified 77% of those meeting the physical activity recommendations ( $\geq 30$  minutes of moderate to vigorous physical activity per day) but only 45% of those not meeting the recommendations, compared to accelerometry as criterion. IPAQ-measured time in moderate to vigorous physical activity (including walking) was also significantly higher than accelerometer-measured time in moderate to vigorous physical activity with a mean difference of 26 minutes per day [53]. Over-reporting was also found, mainly for vigorous physical activity, in a population-based Swedish study when comparing IPAQ (long form) physical activity with accelerometer-measured physical activity. The difference between IPAQ physical activity and accelerometer-measured physical activity increased as the IPAQ physical activity increased, suggesting that participants reporting high levels of physical activity over-reported more than participants reporting less physical activity [54].

## Objective assessments of physical activity

Objective physical activity assessments are based on measures of bodily movement or on physiological responses of physical activity, i.e. they are not based on information reported by the study participants. Indirect calorimetry and the doubly labeled water method, both based on physiological responses of physical activity, are considered to be criterion methods for assessing physical activity energy expenditure. Indirect calorimetry is based on respiratory gas analysis and measures oxygen uptake and carbon dioxide production [55]. As this method requires participants either to wear a facemask to collect the expiratory gas or to be confined in a metabolic chamber, it is not feasible for use in studies of physical activity in daily life. In contrast, the doubly labeled water method is possible to use under free-living conditions. The technique is based on the ingestion of two stable isotopes of water ( $^2\text{H}_2\text{O}$  and  $\text{H}_2^{18}\text{O}$ ). After ingestion, carbon dioxide including  $^{18}\text{O}$  and water including  $^{18}\text{O}$  and  $^2\text{H}$  are produced in the body during energy expenditure. Therefore, the oxygen isotope  $^{18}\text{O}$  is lost from the body as carbon dioxide and water while  $^2\text{H}$  is lost only as water. The difference in excretion rate of these isotopes in the urine is the basis for calculation of energy expenditure [56]. The doubly labeled water method is very precise in its assessment of energy expenditure, but it is expensive and it provides only a measure of the total amount of energy expended during the assessment period. It does not provide information on the intensity or duration of the physical activities, which are important components of the physical activity recommendations [5, 14]. Indirect calorimetry and the doubly labeled water method are mainly used as criterion measures when validating other methods, while other objective methods are more

suitable for large-scale studies in free-living conditions.

Pedometers and accelerometers are devices for direct assessment of bodily movement. The main outcome from pedometers is the number of steps taken during a specified time period, often per day. There are many models of pedometers available on the market and some of them are suitable for research purposes [57]. Pedometers are inexpensive, easy to use and the better models provide a valid and reliable measure of steps taken when direct observation is used as the criterion, but they do not assess the intensity or duration of physical activities and they do not assess non-ambulatory activities such as weightlifting and swimming [58]. Pedometers may produce reactivity among participants if they are allowed to view the step count display, causing an up to 15% increase in steps taken [58]. These feedback properties, however, make pedometers good tools for intervention studies [59-60].

Accelerometers are devices that measure bodily movement in terms of acceleration. They are often placed on the hip and can, depending on the model, measure acceleration in one, two or three axes. The earliest models were only able to collect data in the vertical axis. In addition to the total volume of physical activity, accelerometers can provide information on the intensity, duration and frequency of physical activity [61]. Until a few years ago, accelerometers used piezoelectric sensors to collect information on acceleration. These sensors incorporate a seismic mass that, when acceleration occurs, affects the shape of a piezoelectric material which in turn creates a voltage that can be detected and recorded. Newer accelerometers, such as the Actigraph models GT1M, GT3X and GT3X+, rely on differential capacitance sensors. These sensors are constructed with fixed plates and plates attached to a moving mass. The distance between the fixed and the moving plates changes during acceleration. The capacitance is dependent on the distance between the plates and as it can be detected and recorded the acceleration can be determined. These new accelerometers are sensible to gravitational acceleration (in addition to motion-induced accelerations) and can therefore register information on the inclination of the device and thereby the posture of the participant (e.g. standing or sitting). They are also cheaper and less battery-consuming than the older accelerometers [62]. Time spent in different physical activity intensities is commonly used as the outcome. Time spent in intensities is determined using validated cut-offs, usually derived from studies where individuals perform activities of varying intensity while wearing an accelerometer. The energy expenditure is assessed simultaneously by a criterion method and regression analysis is performed to describe the association between accelerometer output (counts) and physical activity intensity [63-64]. A number of different algorithms and cut-points have been used in research, which makes comparisons between studies harder [63]. Accelerometers are precise in their assessment of walking and running intensities but they underestimate the intensity of static and weight-bearing activities and they cannot assess water activities such as

swimming [65]. The validity of accelerometers has been evaluated using indirect calorimetry and the doubly labeled water method as criteria, showing moderate to strong validity with correlations ranging between 0.45 and 0.93 [66]. A review of validation studies found differences between the doubly labeled water method and accelerometer-estimated energy expenditure of around 0 to 2.7 megajoules (645 kcal) per day [67]. Accelerometers are often used as the criterion method when evaluating subjective methods [49, 51]. Accelerometers are more expensive than pedometers, but they provide detailed information on physical activity and they are feasible for use in large-scale studies. Accelerometers are now included as components in some national physical activity surveillance programs [28, 68].

## Assessment of neighborhood environment

As with physical activity, the methods used to assess neighborhood environment are often divided into subjective (also referred to as perceived) and objective methods, both having their strengths and limitations.

### Perceived neighborhood environment

Previous research on neighborhood environments and physical activity has often been based on self-reported, or perceived, neighborhood environment. There are a number of questionnaires designed to assess the perceived environment in varying detail and for different populations. There are questionnaires for the general population [69-71] and there are questionnaires specifically designed for specific age groups such as children and adolescents [72-73]. There are also questionnaires to assess environments for specific types of physical activity, such as active commuting [74-75]. In questionnaires, the neighborhood is often defined as the area within a specific walking distance, e.g. “a 10- to 15-minute walk from the home” [69-70], or it can simply rely on the participants own perception of the neighborhood area, e.g. “in your neighborhood” [70]. Self-report measures of the environment may include recall bias and they may be affected by exposure to the environment. For example, a physically active person may be more aware of the facilities and services in the neighborhood and thus report a “truer” picture of the facilities than a less active person [76]. Also, people commonly overestimate the distance to destinations, and less physically active individuals may overestimate on a higher level than physically active individuals [77]. However, self-reported measures of the neighborhood environment may be a separate construct, reflecting how the environment is perceived rather than being an assessment of the actual environment.



The most frequently used environmental questionnaire is the Neighborhood Environment Walkability Scale (NEWS) [78]. The NEWS assesses residential density, land use mix, street connectivity, walking/cycling facilities, aesthetics, traffic safety and crime safety. Most items are rated on a 4-point Likert scale where 1 represents “strongly disagree” and 4 represents “strongly agree”. The NEWS has shown moderate to high test-retest reliability with intraclass correlations ranging between 0.58 and 0.80 for the different items [70]. The questionnaire has also been validated against objective measures of the neighborhood environment, showing weak to moderate correlations with correlation coefficients ranging between 0.09 and 0.36 [76]. There is also an abbreviated version, NEWS-A, that is based on a factor analysis performed on the original NEWS instrument and includes 54 instead of 67 items [79].

## Objective neighborhood environment

Objective assessment of the neighborhood environment is often performed using Geographic Information Systems (GIS). GIS are defined as computer-based systems composed of hardware, software and data to create, store, manage, display and analyze location-based data in an integrated environment [80-81]. In physical activity research, GIS is mainly used to manage databases containing variables with spatial references. These data may be obtained from national or local data providers and include information on various characteristics of the neighborhood environment. Common GIS-derived measures in physical activity research are population density [82-83], street connectivity [84-85], access to parks and recreational facilities [86-87] and land use mix [83-84]. GIS assessment of neighborhood environment, like all other methods, has its limitations. It requires specific GIS competence, the databases may not be designed for research thus requiring substantial data management, data may not be complete, and different protocols on how to compute variables for physical activity research are used in different studies [81, 88-89]. In GIS, the neighborhood or area of exposure is often defined using predetermined administrative areas or by creating buffers around participants’ residences (Figure 2). The size of these areas differs and there is no consensus regarding the best approach. Census tracts, geographic regions defined as a basis for population statistics, have been used to define the neighborhood in physical activity research [90-91]. By using predefined areas, all participants living within these predefined areas are considered to have the

Figure 2. Comparison of four different methods used in GIS to define neighborhoods.



Prepared for this thesis by Klas Cederin.

same environmental exposure. It is likely, however, that the environment differs depending on where in this administrative area a person lives. To get a more individualized measure of the neighborhood environment, buffers around the participants' residences may be used to define the neighborhood. Buffers around the residences have been used, often ranging in sizes between 400 and 3,200 meters [78]. Circular buffers are easy to create but may include areas that are not accessible to participants, for example, due to rivers and other natural and unnatural barriers. Buffers based on the road network may provide a more accurate picture of the neighborhood facilities that are actually available to residents [92]. Network buffers can be polygon-based or line-based. Polygon-based network buffers are created by following the road network in all possible directions for a specified distance from the residence and then drawing a line to connect the endpoints, thus creating a polygon-shaped area (a buffer) surrounding the residence. Line-based network buffers are created by following the road network in all possible directions from the residence for a specific distance, and then creating a buffer zone (e.g. 50 meters) in all directions from the center of the road (Figure 2). Polygon-based buffers may provide a better measure when density (area) is of interest, while line-based buffers may provide a better measure when access to facilities is of interest, but this has not been investigated.

In addition to GIS, there are a number of audit tools to provide an objective measure of the neighborhood environment. These audit tools are used by researchers to systematically assess various aspects of the environment [93-94]. As audit tools require training and data collection on site, they are mostly used in studies where only a few neighborhoods are sampled and when the information of interest is not available in databases for GIS analysis. Aerial photos have also been used to assess the neighborhood environment, and are often analyzed using GIS [84, 95].

## Neighborhood environment and physical activity

Humans are exposed to environments in daily life, and the characteristics of these environments could have the potential to facilitate or hinder physical activity. Research on the relationship between environmental characteristics and physical activity has increased rapidly in the past few years. Studies have examined the relationship between proximity to and mix of destinations [96], population density [82-83], street connectivity [84-85], access to parks and recreational facilities [86-87, 97], land use mix [83-84] and physical activity.

Some environmental characteristics have been consequently associated with physical activity, while some have shown conflicting results. Studies examining the association between the availability of exercise facilities and physical activity have produced varying results. A review from 2008 found little or no evidence for an

association between availability of physical activity facilities and walking for transportation or recreational walking [98]. In contrast, a study from the U.S. found an association between density of exercise facilities and exercise prevalence in study participants from three areas with widely varying population densities [36]. This association, however, was modified by income and race/ethnicity, being stronger among those with low incomes and among non-Hispanic Black and Hispanic participants compared to their high-income and non-Hispanic White counterparts. Income was also found to be an effect modifier in another study, which found an association between the availability of gyms and physical activity in low-income women but not high-income women [90]. Hence, associations between the neighborhood environment and physical activity may be influenced by individual characteristics. If this is the case, it is possible that neighborhood characteristics aimed at increasing people's physical activity may not reach all population groups to an equal extent. Ding and Gebel performed a review of reviews on neighborhood environment and physical activity and concluded that investigation of potential moderators of the relationship between the environment and physical activity is the most frequently suggested direction for future research [99].

Composite measures, based on previous research into environmental correlates of physical activity, have also been proposed. Such composite measures may reflect different types of environments, rather than single aspects of the environment. Cervero and Kockelman combined environmental characteristics into the "3Ds", density, diversity and design by factor analysis and concluded that creating more compact, diverse, and pedestrian-orientated neighborhoods, in combination, can influence travel behavior [100]. Krizek proposed a neighborhood accessibility index that included measures of density, land use mix, and street patterns [101]. The walkability index, originally developed for the Neighborhood Quality of Life (NQLS) study in the U.S., is one of the most frequently used composite measures of the neighborhood environment in research. The original index included residential density, street connectivity, land use mix and retail floor area ratio. A higher street connectivity allows a more direct route between destinations, and land use mix represents the variation in land use within the neighborhood, indicating the variety of destinations available to residents. Retail floor area ratio is the ratio between retail building area and total retail area. A low retail floor area would indicate substantial parking areas around the retail buildings, while a high ratio would indicate a more pedestrian-friendly environment [102]. This four-component walkability index was later adopted in the Physical Activity in Localities and Community Environments (PLACE) study in Australia [103]. As defined by the walkability index, NQLS-participants living in highly walkable neighborhoods had 5.8 more minutes per day of accelerometer-measured moderate to vigorous physical activity compared to those living in less walkable neighborhoods. They also reported 31.5 more minutes of

walking for transportation per week but only 4.3 more minutes per day of walking for leisure. The differences in walking for transportation between high and low walkability neighborhoods were larger in high socioeconomic status (SES) neighborhoods than in low SES neighborhoods [34]. A 5% increase in the walkability index was associated with a 32% increase in time spent on active transportation (walking and cycling) [104]. The Australian PLACE study did not include accelerometry but it found associations between the walkability index and the frequency of walking for transportation, and a weak association for the amount of walking for transport but no association for walking for leisure.

## Gaps in previous research

The majority of the previous evidence of environmental correlates of physical activity has often been based on self-reported, or perceived, neighborhood environment and/or on self-reported physical activity. Also, much of the previous literature is based on studies from North America and Australia, and there is a need to examine whether the associations found in these countries hold up in a Swedish context. This is important as there are large environmental and cultural differences between countries in different parts of the world.

There are also other aspects of neighborhood walkability that need to be examined further. For example, previous research using accelerometry has been based on mean daily values. The influence of neighborhood walkability on physical activity may, however, vary over the day, and the use of mean daily values cannot reflect this potential variation and may also dilute potential associations. No previous study has investigated the influence of neighborhood walkability and accelerometer-measured hour-by-hour physical activity pattern across the day.

The inconsistent findings regarding the availability of exercise facilities and physical activity warrant further investigations. A majority of these studies were based on self-reported physical activity and and/or self-reported availability of exercise facilities. The biases incorporated in these measures can be avoided by using objective methods. Furthermore, previous studies have shown an association between time of year and physical activity, with lower levels of physical activity occurring during winter [105-107]. It has been hypothesized that exercise facilities could be important in supporting a physically active lifestyle throughout the year [108]. This suggests a stronger association between the availability of indoor exercise facilities and physical activity during the winter than during the summer. To our knowledge, no previous study using objective measures of availability of exercise facilities and physical activity has explored this hypothesis.

Previous cross-sectional studies have found negative associations between neighborhood walkability and vehicle ownership [109] and vehicle miles traveled [104, 110]. This implies that dense, well-connected areas with diverse land use could support less car-dependent living. Vehicle ownership and vehicle use are, in turn, negatively associated with physical activity [110-111]. We hypothesize that vehicle ownership may lie in the causal pathway between neighborhood walkability and physical activity. To our knowledge, no previous study has investigated the hypothesized mediating effect of vehicle ownership on the association between objectively assessed walkability parameters and physical activity.

As described earlier, associations between the neighborhood environment and physical activity may be influenced by individual characteristics, and it is possible that the influence of neighborhood characteristics on physical activity varies among different subgroups of the population. A recent review of reviews concluded that investigation of potential moderators of the relationship between the environment and physical activity is the most frequently suggested direction for future research [99].

# Aims

## Study 1

- To investigate, in a Swedish context, the associations between objectively assessed neighborhood walkability and walking for transportation, walking for leisure and accelerometer-measured moderate to vigorous physical activity and whether these hypothesized associations are modified by individual-level socio-demographic factors and neighborhood-level SES.
- To examine random effects in a multilevel fashion, in order to quantify how much of the total variance of the physical activity outcomes could be due to differences at the neighborhood level.

## Study 2

- To investigate both the mean daily physical activity and the hour-by-hour physical activity using accelerometry, and how they are associated with neighborhood walkability and individual SES (i.e., income).

## Study 3

- To investigate the associations between three walkability parameters (residential density, street connectivity, and land use mix) and physical activity outcomes, i.e. accelerometer-measured moderate to vigorous physical activity, walking for transportation and cycling for transportation.
- To investigate the hypothesized pathway between walkability parameters and physical activity through vehicle ownership using mediation analysis.
- To test whether the associations between the walkability parameters and physical activity are modified by vehicle ownership.

#### Study 4

- To investigate the association between objectively assessed availability of exercise facilities and accelerometer-measured physical activity outcomes.
- To test whether the hypothesized association between exercise facilities and physical activity are modified by socio-demographic factors and time of year.



# Methods

## The Swedish Neighborhood and Physical Activity (SNAP) study

This thesis is based on data from the Swedish Neighborhood and Physical Activity (SNAP) study. The SNAP study was designed to investigate the association between neighborhood walkability and physical activity in a Swedish context using objective and subjective methods for the assessment of both neighborhood environment and physical activity. Data for the SNAP study were collected between November 2008 and November 2009 in the city of Stockholm, except between 9 December 2008 and 12 January 2009 and between 16 June and 17 August 2009 (roughly corresponding to the winter and summer holidays in Sweden, respectively). The sampling of neighborhoods for the study was designed to ensure variation in neighborhood walkability and neighborhood income. The sampling procedure is described below.

The city of Stockholm is divided into 408 administrative units (in Swedish: *basområden*), containing approximately 2,000 individuals per unit. The geographic boundaries of these administrative units follow the road/street network and they are well-known geographic units that could be used for future health interventions. They constituted a basis for the creation of the 32 neighborhoods included in the SNAP study. The selection of the 32 neighborhoods for the study was based on neighborhood walkability (high or low) and neighborhood income (high or low). This resulted in four types of neighborhoods: high walkability/high income, high walkability/low income, low walkability/high income, and low walkability/low income, with 8 neighborhoods in each category. The walkability in each administrative area was assessed by calculating a walkability index using GIS. The index was partly based on a previously described walkability index [104] including four components: (1) residential density, (2) street connectivity, (3) land use mix, and (4) retail floor area ratio. As data on retail floor area ratio were not available in Sweden, the walkability index in the SNAP study included the first three components, i.e. residential density, street connectivity, and land use mix. Data on residential density were delivered by Statistics Sweden, the Swedish government-owned statistics bureau, and calculated as the number of residential units per square

Figure 3. Example of the road network including cycle paths and footpaths.



Prepared for this thesis by Klas Cederin.

kilometer (excluding water bodies). Street connectivity was based on data delivered by the City Planning Administration in Stockholm (in Swedish: Stockholms Stad, Stadsbyggnadskontoret) and was calculated as the number of “true” intersections (three or more “legs”) per square kilometer. Two or more intersections closer to each other than 10 meters were counted as one using a buffering function. Highways were not included in the calculations. Cycle paths and footpaths were included if they had an intersection with a street (Figure 3). The land use mix was calculated as the evenness in distribution between five categories of land use: (1) retail/service, (2) entertainment/physical activity, (3) institutional/healthcare, (4) office/workplace, and (5) dwellings. Categories 1 to 4 were based on data delivered by Teleadress, a company founded when the government-owned telecom sector was privatized. The Teleadress database is updated continuously and it includes businesses and services with a registered phone number, as well as those who actively have provided information about their business. Inclusion in their database is free of charge. The fifth category was based on data obtained from the City Planning Administration in Stockholm. The land use mix was based on point data and calculated by the Herfindahl-Hirschman Index (HHI) [112]. The HHI is calculated by summing the squared proportions of each land use category ( $HHI = p_1^2 + p_2^2 \dots + p_5^2$ ). A high HHI indicates a low level of land use mix.

Previous studies have mostly weighted connectivity by 2 [34, 102]. Frank et al. describe this weight as being “based on prior evidence regarding reported utilitarian walking distances and the resulting strong influence of street connectivity on non-motorized travel choice. Further input confirming this weighting scheme was obtained through iterations between alternative weighting schemes and resulting neighborhood types that emerged” [102]. We chose to weigh street connectivity by 1.5 since our walkability index was based on three instead of four components. The walkability index for each administrative area was calculated as the sum of the z-scores using the formula:

$$\text{Walkability index} = Z_{\text{Residential density}} + 1.5 * Z_{\text{Street connectivity}} + Z_{\text{Land use mix}}$$

Next, the walkability index scores were divided into deciles. Areas in the first to fourth walkability index deciles were considered less walkable, and those in the seventh to tenth deciles were considered highly walkable. This approach is in line with previous research [104].

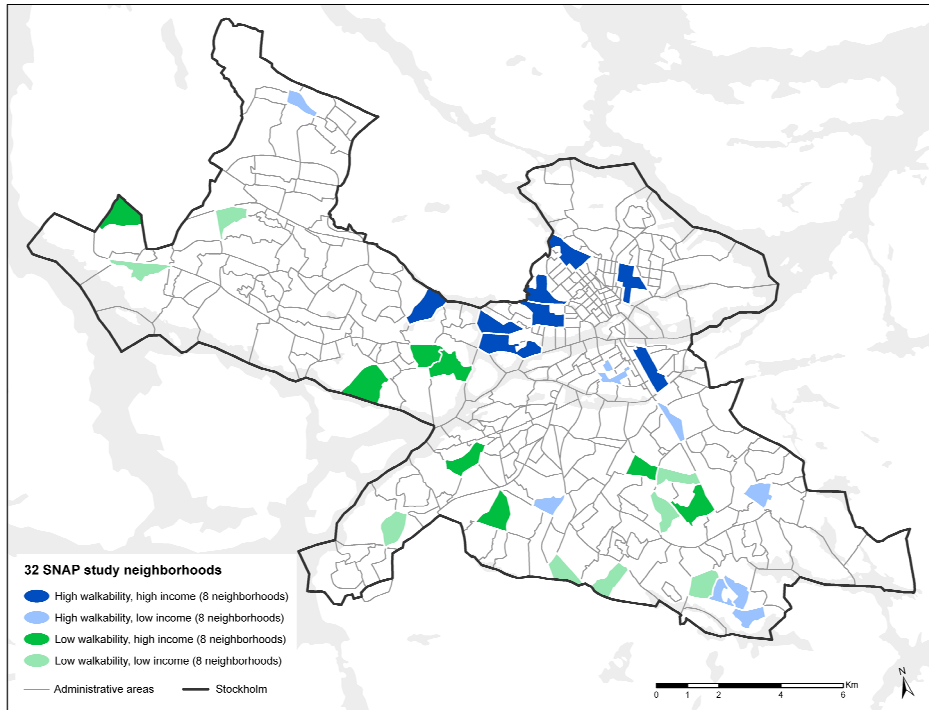
Neighborhood income was included in the selection process to ensure variation in SES and in order to account for possible differences in physical activity that could be explained by the socioeconomic structure of the neighborhood, which is also in accord with previous studies [33-34, 113]. Data on neighborhood income were provided by Statistics Sweden. Neighborhood income was based on the disposable median family income, which also took the number and age of the family members into account. For example, children and adolescents were given lower consumption

weights than adults. The median neighborhood family income for each administrative area was calculated and the administrative areas were divided into deciles. Areas in the second to fourth neighborhood income deciles were considered to be of low income, and those in the seventh to ninth deciles were considered to be of high income. The first and tenth deciles were excluded to avoid outliers in neighborhood income [104].

One hundred and twenty-seven of the 408 administrative areas in Stockholm City were assigned to one of the four neighborhood categories (high walkability/high income, high walkability/low income, low walkability/high income, and low walkability/low income). The size of these 127 administrative areas ranged between 0.03 and 2.73 square kilometers. We selected administrative areas with at least 500 households and a size of about 0.65 square kilometers. This area corresponds to the size of the neighborhoods created in the Twin Cities Walking Study [114], a study designed to examine the influences of the built environment on physical activity and walking. Administrative areas in the high walkability/high income category located in the city center were rather small. Therefore, some areas in this category were merged to create study neighborhoods. This procedure resulted in a final number of 32 neighborhoods (8 in each of the four categories) that were used for sampling of participants. The geographical distribution of the 32 neighborhoods is shown in Figure 4.

Our goal was to assess 75 individuals from each neighborhood, i.e., in total 2,400 participants, aged 20–65 years. The power calculations were partly based on previous research [33] and on an assumed mean difference of 5 minutes per day of moderate to vigorous physical activity between individuals from highly walkable neighborhoods and those from less walkable ones, an assumed standard deviation of 24, and a response rate of 40%. In order to reject the null hypothesis with a power (probability) of 0.8 and a type I error probability of 0.01, we needed to study 585 individuals in each of the two types of neighborhoods (high walkability versus low walkability), i.e. 1,170 in total. We chose, however, an approach of oversampling since our assumptions were based on information from very few previous studies. The Stockholm Office of Research and Statistics (in Swedish: Stockholms Stads Utrednings- och Statistikkontor) performed the simple random sampling of 250 individuals from each neighborhood (a total of 8,000 individuals) without including immigrants who had arrived in Sweden later than 2003 (i.e. five years before the start of the study) as our questionnaire was provided only in Swedish. This is in accord with previous studies from the U.S. and Australia, where only English-speaking individuals have been included. Of the 8,000 individuals, 6,089 had a listed landline or mobile phone number and were included in the recruitment procedure.

**Figure 4. The City of Stockholm and the geographical distribution of the 32 neighborhoods included in the SNAP study.**



Prepared for this thesis by Naomi Kawakami.

An information letter was sent to their home address, and a week later, a telemarketing company (Markör AB, Örebro, Sweden) contacted each individual by phone. Markör AB had previous experience in recruiting study participants for large-scale studies, and the author of this thesis provided detailed written and oral information to all personnel involved in the recruitment process. Inclusion criteria at this stage were the following: (1) being able to read and write Swedish, (2) having lived in the neighborhood for at least three months, and (3) having no serious difficulty in walking. Of the 4,747 individuals who were reached, 4,369 met the inclusion criteria and 3,226 agreed to participate in the study. Although being based on the same data collection, the number of participants included in the studies in this thesis ranges between 2,037 and 2,269 due to missing data in the different variables used in the studies. Also, different definitions for accelerometer non-wear time, which influence the number of participants included in the studies, were used in study 4 compared to studies 1–3. Details on the studies and the number of participants in

studies 1–4 are shown in Table 1. A telephone-based non-response analysis of 205 individuals, randomly selected from those who were reached by phone but declined participation, was performed. There was no difference in income between participants and non-participants, but the proportion of females was slightly higher among participants, and the participants were slightly older than non-participants.

## Data collection

Lists of enrolled participants were delivered to us on a weekly basis and a package containing an accelerometer, an accelerometer logbook, a questionnaire and a prepaid return envelope was sent to the residential address of each participant. Data were collected concurrently in all included neighborhoods. After participation, the participants received a pedometer, movie tickets or lottery tickets to a value of about 100 SEK.

**Table 1: Overview of the four studies included in this thesis.**

	<b>Study 1</b>	<b>Study 2</b>	<b>Study 3</b>	<b>Study 4</b>
<b>Data source</b>	SNAP	SNAP	SNAP	SNAP
<b>Number of participants</b>	2,269	2,252	2,178	2,037
<b>Neighborhood definition</b>	Administrative areas	1000m polygon-based network buffers	1000m polygon-based network buffers	950 + 50m line-based network buffers
<b>Explanatory variables</b>	– Walkability – Neighborhood SES	– Walkability – Individual income	– Residential density – Street connectivity – Land use mix	Availability of exercise facilities
<b>Outcome variables</b>	– MVPA – Walking for transportation – Walking for leisure	– MPA	– MVPA – Walking for transportation – Cycling for transportation	– MVPA
<b>Potential moderators</b>	– Neighborhood SES – Age – Gender – Family income – Marital status	None	– Vehicle ownership	– Time of year – Age – Gender – Income – Marital status
<b>Potential mediators</b>	None	None	– Vehicle ownership	None
<b>Statistical methods</b>	– Multilevel linear regression, bootstrap – Mixed-effects, mixed distribution model – Intraclass correlation	– Bootstrap p-values – Bootstrap confidence intervals	– Linear regression – Mediation analysis, bootstrap	– Linear regression, cluster bootstrap – Logistic regression, cluster corrected standard errors

SES: Socioeconomic status

SNAP: The Swedish Neighborhood and Physical Activity study

MVPA: Moderate to vigorous physical activity

MPA: Moderate physical activity

## Accelerometers

ActiGraph GT1M accelerometers, versions 2 to 4 and firmware 1 to 6, and ActiLife Data Analysis Software, versions 4 to 6 (ActiGraph, Pensacola, FL, USA), were used to provide an objective measure of physical activity. ActiGraph GT1M is highly reliable and useful in assessing a variety of walking and running intensities in adults [115-116], and the different versions of GT1M have been shown to provide similar outputs [115]. ActiGraph accelerometers have been used in previous research on neighborhood environment and physical activity [34]. Participants were asked to wear the accelerometer for seven consecutive days, except when sleeping or bathing/swimming, and were given the opportunity to choose accelerometer placement on the hip or lower back to increase compliance. A study comparing accelerometer placement on the hip or lower back under free-living conditions found no significant effect on the estimation of time spent in moderate and vigorous physical activity [117]. To further increase the compliance, four standardized text-messages were sent to the participants' cell phones during the 7-day measurement period. The accelerometers were set to register vertical accelerations and to accumulate data over 60-second periods (epoch-time). We were able to review accelerometer files from 2,669 participants. Unavailable files were due to discontinued participation, lost accelerometer, malfunction in the initiation of the accelerometer and error when downloading data. Non-wearing time was defined as  $\geq 60$  minutes (studies 1–3) or  $\geq 30$  minutes (study 4) of no registered physical activity (zero counts). Wear time was calculated by subtracting non-wearing time from 24 hours, and 10 hours of wear time was required to constitute a valid day. Freedson's cut-off points for accelerometer counts were used to determine time spent in moderate physical activity (1,952–5,724 counts/min) and time spent in moderate to vigorous physical activity ( $\geq 1,952$  counts/min) [64]. These cut-off points have been used in previous research on neighborhood environment and physical activity [34].

## The International Physical Activity Questionnaire (IPAQ)

The amount of walking for transportation and leisure and cycling for transportation was assessed by the long self-administered version of the International Physical Activity Questionnaire (IPAQ). The IPAQ has shown good reliability and fair to moderate validity when using accelerometers as the criterion [40, 51-52], and has previously been used in large-scale studies on the neighborhood environment and physical activity [33-34]. The frequency and duration of walking and cycling in the past seven days are reported using two questions per item. For example, walking for transportation was assessed by the questions (1) "On how many days during the last 7 days did you walk for at least 10 minutes at a time to go from place to place?" and (2)



“How much time did you usually spend on one of those days walking from place to place?” Data were cleaned and scored according to the official IPAQ scoring protocol [50]. Due to the low proportions of participants reporting cycling during November–March (7–13%), the analyses on cycling for transportation only included observations collected between April and October, when 20–32% of participants reported cycling for transportation during the past seven days (n=906).

## Explanatory variables Studies 1–4 (summarized in Table 1)

**Study 1.** Neighborhood walkability was categorized as high or low according to the description above. That is, the walkability index was calculated within the administrative areas and divided into deciles. Neighborhoods in the first to fourth walkability index deciles were considered less walkable, and those in the seventh to tenth deciles were considered highly walkable. Neighborhood SES was categorized as high or low on the basis of the disposable median family income according to the description above. Neighborhoods in the second to fourth neighborhood income deciles were considered to be of low SES, and those in the seventh to ninth deciles were considered to be of high SES. Age, gender, marital status and individual-level income were also included as explanatory variables.

**Study 2.** For this study, the walkability index was calculated within polygon-based network buffers around the participants’ residences. The buffers were created by following the road network including bicycle paths and footpaths in all possible directions for 1,000 meters from each residence and then drawing a line to connect the endpoints (Figure 2). Neighborhood walkability was divided into tertiles. Participants in the first and second tertile were classified as living in a less walkable neighborhood and participants in the third tertile were classified as living in a highly walkable neighborhood. Participants in the third tertile had considerably higher values of the walkability index than participants in the first and second tertiles, who had more similar values of the walkability index. Individual income was calculated by dividing the gross family income by the number of people living in the household, with children and adolescents under the age of 18 being given a consumption weight of 0.5. Individual income was then dichotomized at the median into low or high.

**Study 3.** In this study, neighborhood walkability parameters were investigated separately. That is, they were not summed as an index of walkability. Residential density, street connectivity and land use mix were calculated within 1,000-meter polygon-based network buffers using the same formula as in study 2. The HHI index (land use mix) was multiplied by –1 to facilitate interpretation of results, making a higher HHI correspond to a higher level of land use mix. Vehicle ownership was based on information from the study questionnaire where participants were asked

“How many roadworthy motor vehicles do you have in your household?” Vehicle ownership was categorized into three levels: no vehicle, one vehicle and two or more vehicles. Age, gender, marital status and individual income were also included as explanatory variables.

**Study 4.** The availability of exercise facilities was measured objectively within 1,000-meter line-based buffers around the participants’ residences using GIS. The buffers were created by following the road network including bicycle paths and footpaths in all possible directions for 950 meters from each residence, and then creating a 50-meter buffer zone in all directions from the center of the street (Figure 2). Data from 2008 on the location and business names of publicly and privately owned exercise facilities were provided by Teleaddress. The data were manually screened and exercise facilities not offering exercise on site for the adult population were excluded. Availability of exercise facilities was categorized into three levels: 0 facilities, 1–3 facilities and  $\geq 4$  facilities within the buffer zone. Time of year was defined by four periods of the year: January–March, April–June, July–September and October–December. Age, gender, marital status and individual income were also included as explanatory variables.

## Outcome variables Studies 1–4 (summarized in Table 1)

**Study 1.** This study had three outcome variables: time spent in moderate to vigorous physical activity from accelerometry, and walking for transportation and walking for leisure from IPAQ. We performed a variance analysis of our data for moderate to vigorous physical activity to determine the number of days required for inclusion in the analysis [118]. We included participants with 6 or 7 valid days of accelerometry, and the mean time spent in moderate to vigorous physical activity on these valid days was used as outcome (minutes/day). Walking for transportation and walking for leisure were both analyzed in a dichotomous fashion (participants reporting no walking vs participants reporting any walking) and in a continuous fashion (minutes of walking per week, excluding participants reporting zero walking from the analysis). This approach was performed to handle the large number of zeros in the variables. In total, about 20% of the participants did not report any walking for transportation and 30% did not report any walking for leisure during the past seven days.

**Study 2.** Accelerometer-measured mean time in moderate physical activity on all days, on weekdays and on weekend days, was used as outcome. As neighborhood walkability was developed as a measure of environments promoting active transportation (i.e. walking) [26], and vigorous physical activity mainly corresponds to activities of higher intensity than the normal walking intensity range [2], we only included moderate physical activity in study 2. Hourly values of moderate physical

activity of an average weekday and weekend day were also calculated and used to explore the hour-by-hour physical activity patterns. Participants with one valid weekday and one valid weekend day were included in the analyses.

**Study 3.** This study had three outcome variables: time spent in moderate to vigorous physical activity from accelerometry, and walking for transportation and cycling for transportation from IPAQ. We included participants with 6 or 7 valid days of accelerometry, and the mean time spent in moderate to vigorous physical activity on these valid days was used as outcome (minutes per day). Walking for transportation and cycling for transportation were investigated both as dichotomous variables (yes or no) and as log-transformed variables (including participants with values higher than zero). This approach was used to handle the large number of zeros in the variables.

**Study 4.** This study had two accelerometer-measured physical activity outcomes: time spent in moderate to vigorous physical activity (minutes per day) and meeting the physical activity recommendations (yes or no). Participants were considered to have met WHO's Global Recommendations on Physical Activity for Health [14] if they accumulated  $\geq 150$  minutes of moderate to vigorous physical activity in bouts of  $\geq 10$  minutes within a week. Bouts of moderate to vigorous physical activity were identified as 10 or more consecutive minutes with  $\geq 1,952$  counts per minute. During each bout of physical activity, the number of counts per minute was permitted to dip below this cut-off for 1–2 min. This approach, which allows for brief pauses in physical activity (for example when stopping at a red light or tying a shoelace), is recommended [119] and has been used previously [28]. Participants with 6 or 7 valid days were included in the analysis. Weekly time spent in bouts of moderate to vigorous physical activity for participants with 6 valid days were extrapolated to 7 days using the mean of the six valid days (mean value for the 6 valid days multiplied by seven).

## Statistical analyses

**Study 1.** The association between neighborhood walkability and moderate to vigorous physical activity was analyzed using multilevel linear regression models [120], with individuals at the first level and neighborhoods at the second level. Two consecutive models were developed. Model A included only neighborhood walkability. Model B also included the individual covariates age, gender, marital status, and family income, as well as neighborhood-level income. This is in line with previous studies on the association between neighborhood walkability and physical activity outcomes [33–34, 113] and it allowed us to investigate whether inclusion of these characteristics attenuated the association between neighborhood walkability and physical activity. The models were estimated by MLwiN using non-parametric

bootstrap estimates with 1,000 replicates and five sets in order to test for the possible effects of non-normal distributions and the accuracy of inferences about the parameter values [121]. Non-parametric bootstrapping is a method that constructs a number of resamples of the original dataset, each obtained by random replacements of the original dataset and assuming an identically distributed population. Bootstrapping techniques have been used in previous studies of the association between environmental attributes and physical activity [122]. Regression coefficients, in minutes per day, and 95% confidence intervals are presented as measures of association.

Walking for transportation and walking for leisure were analyzed using a mixed-effects, mixed-distribution model [123] due to the excessive number of participants who did not report any walking. In total, 431 individuals (20%) reported zero regarding walking for transportation while 657 (30%) reported zero regarding walking for leisure. The mixed-effects, mixed-distribution model is made up of two parts: the first is a logistic part for occurrence of the outcome, which estimates the probability of reporting any walking versus reporting zero walking. The second is a linear part that models the intensity (i.e. amount of walking in minutes/week) of the response, given that the response is greater than zero. The second part of the model did not include participants who reported zeros regarding walking for transportation or walking for leisure. In the second part of the mixed-effects, mixed-distribution model we assumed a normal distribution. In order to justify this assumption, we performed an additional analysis using bootstrap estimates in the linear part. This yielded almost identical results to those in the second part in the mixed-effects, mixed-distribution model, supporting our assumption of a normal distribution. The results of the mixed-effects, mixed-distribution models were presented as odds ratios with 95% confidence intervals for the occurrence of the outcomes, as well as the regression coefficients (minutes/week) with 95% confidence intervals for the amount of the responses. A random effect for the occurrence and a random effect for the amount were included in the model to account for clustering of individuals within neighborhoods. As we did for the investigations of walkability and moderate to vigorous physical activity, we developed two consecutive models for each outcome: a crude model including neighborhood walkability and a full model also including the individual covariates age, gender, family income, and marital status, as well as neighborhood-level income. Interactions between explanatory variables in the full models were examined. The models were estimated using SAS v. 9.2 (SAS Institute, Cary, NC, USA), with the MIXCORR macro developed by Tooze et al. [123]. To facilitate the interpretation of the variance at the neighborhood level, we calculated the intraclass correlation (ICC) (Snijders & Bosker, 1999). A large ICC would indicate that differences between the neighborhoods account for a considerable part of the individual differences in the physical activity outcomes, while an ICC close to

zero would indicate that the neighborhoods exert only a small influence on the total variance between individuals [124]. The ICC is the percentage of the total variance of the individual outcome attributable to the neighborhood level. ICC was calculated according to the following formula:

$$ICC = V_2 / (V_1 + V_2)$$

where  $V_1$  represents the variance between individuals (first-level variance) and  $V_2$  represents the variance between neighborhoods (second-level variance). However, in the logistic part of the mixed-effects, mixed-distribution model, the neighborhood level variance is measured on a different scale than the individual level variance and hence they are not comparable. We used the latent variable method to convert the individual level variance from the probability scale to the logistic scale [125]. This method assumes that the unobserved individual variable follows a logistic distribution with the individual variance equal to 3.29 ( $\pi^2/3$ ). The ICC is then calculated according to the equation above.

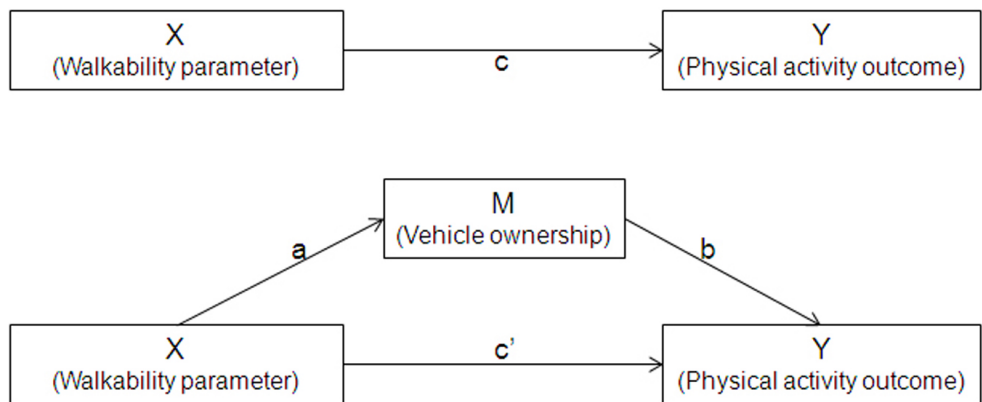
**Study 2.** To investigate the influence of neighborhood walkability on mean daily and hour-by-hour moderate physical activity, the participants were divided into four categories: (1) high walkability/high individual income (HWHII), (2) high walkability/low individual income (HWLII), (3) low walkability/high individual income (LWHII), and (4) low walkability/low individual income (LWLII). During the weekdays, we included moderate physical activity collected between 6:00 and 23:00 and during the weekend days between 8:00 and 23:00. Between these time-points the majority of the participants contributed wear time. Mostly, at least 90% of participants in each walkability-income category contributed physical activity data at each hour included, except for the first hour in the morning when it could go down to 53%.

The four walkability-income categories were compared for both the mean daily and mean hour-by-hour moderate physical activity. We used a non-parametric bootstrap approach as the physical activity data were skewed; especially the hour-by-hour data had a large proportion of observations with zero values. The bootstrap procedure was performed in the following way: for each mean daily and hour-by-hour comparison, 10,000 samples were drawn, with replacements, from the empirical distributions. For each drawn sample the mean value was determined and thus, as we had 10,000 samples and a mean value in each sample, a sampling distribution of the estimated mean was obtained. Bootstrap p-values were obtained from the sampling distributions for the difference between the estimated means of the walkability-income categories. For the daily means we also present 95% bootstrap confidence intervals. Because of the way the participants were divided into low walkability (first and second tertiles) and high walkability (third tertile), and since the variation of the

estimated mean is dependent on the sample size, the confidence intervals and p-values for the mean difference between the two income categories within the high walkability category (HWHII vs. HWLII) become larger than the two income categories within the low walkability category (LWHII vs. LWLII), even when the difference in means appears similar. The statistical analyses were performed in the statistical analysis software R [126].

**Study 3.** We investigated the association between three different walkability parameters and three different physical activity outcomes. Further, we investigated whether these associations were mediated and/or moderated by vehicle ownership.

**Figure 5. The associations between X and Y without (upper part) and with a mediator (lower part).**



X represents the explanatory variables; residential density, street connectivity or land use mix. Y represents the outcome variables; moderate to vigorous physical activity, walking for transportation or cycling for transportation. M represents the potential mediator; vehicle ownership.

The upper part of Figure 5 illustrates a potential direct effect of X (explanatory variable) on Y (outcome), while the lower part of Figure 5 illustrates the mediation design where the product of a and b ( $a*b$ ) is the potentially mediating effect of M (mediator) on the association between X and Y. Walking for transportation and cycling for transportation were investigated both as dichotomous variables (yes or no) and as log-transformed variables (including participants with values higher than zero). Linear regression was used to investigate the associations between the walkability parameters and the physical activity outcomes. To investigate the mediating effect of vehicle ownership on these associations we used an approach described by Preacher

and Hayes [127]. This approach uses bootstrapping to generate confidence intervals for the indirect effect. We also calculated the proportion mediated, by dividing  $a*b$  by  $c$ . To check the robustness of our results, we also performed non-parametric analyses using PROC GENMOD in SAS v. 9.2 (SAS Institute, Cary, NC, USA) with the identity link and specified the variance to be binomial as well as using ordinary logistic regression. The mediated proportions in these control results were very similar to the results shown in the tables. For all outcomes we also investigated the potential interaction between vehicle ownership and the different walkability parameters. For all outcomes, we first included the walkability parameter and then also age, gender, income, and marital status in the models.

**Study 4.** The association between availability of exercise facilities and time spent in moderate to vigorous physical activity was analyzed by linear regression using non-parametric cluster bootstrap estimates with 1,000 replications. Two models were created: a crude model including only availability of exercise facilities and physical activity, and a full model also including sex, age, income, marital status and time of year. The full model was also adjusted for accelerometer wear time since it was found to be a potential confounder (inclusion of this variable in the model resulted in a 10% change of the regression coefficients). Standard errors presented in the results were corrected for clustering effects as the data were collected within 32 neighborhoods. However, additional analyses without this correction for clustering effects showed similar results, and the ICC between neighborhoods was less than 0.5% in the full models. The regression coefficients represent differences in minutes per day compared to the reference group. Interactions and multicollinearity between the explanatory variables in the full model were examined. The association between availability of exercise facilities and whether or not participants met the physical activity recommendations (yes or no) was analyzed by logistic regression. Two models were created: a crude model including only availability of exercise facilities, and a full model also including sex, age, income, marital status and time of year. Accelerometer wear time was not a confounder and was not included in this model. Standard errors were corrected for clustering effects in the data. Interactions between explanatory variables in the full model were examined. Goodness of fit was estimated by the Hosmer-Lemeshow test [128]. All statistical analyses were performed using STATA 10.1 (StataCorp, College Station, Texas, USA) and statistical significance was determined at  $\alpha < 0.05$ .

# Results

## Associations between the neighborhood environment and physical activity

The results of study 1 showed that participants living in highly walkable neighborhoods were more physically active than participants living in less walkable neighborhoods. Participants in highly walkable neighborhoods spent 3.1 more minutes in moderate to vigorous physical activity per day (Table 2) and they had 77% higher odds of reporting any walking for transportation (Table 3) and 28% higher odds of reporting any walking for leisure (Table 4). Furthermore, participants in highly walkable neighborhoods reported 50 more minutes of walking for transportation than participants in less walkable neighborhoods. The ICC ranged between 0.0% and 2.1% in the full models.

The results of study 2 showed that living in a highly walkable neighborhood was associated with more time in moderate physical activity compared with living in a less walkable neighborhood, but that this association was attributed to specific time periods of the day. The highest levels of moderate physical activity were found in participants with high individual income living in highly walkable neighborhoods. These participants spent significantly more time in moderate physical activity on weekdays as well as on weekend days than did participants with high individual income living in less walkable neighborhoods (Table 5). There was also a tendency (close to statistical significance) towards more moderate physical activity, on weekdays as well as weekend days, among participants with low individual income living in highly walkable neighborhoods compared to participants with low individual income living in less walkable neighborhoods. Participants with high individual income living in highly walkable neighborhoods spent 5.8 more minutes per day in moderate physical activity than participants with low individual income living in less walkable neighborhoods (Table 5). The investigation of the hour-by-hour moderate physical activity showed different patterns on weekdays and weekend days. A weekday had three sharp peaks of moderate physical activity: one in the morning, one around noon, and one in the late afternoon/early evening (Figure 6). In contrast, a weekend day had only one broad peak (Figure 7). Both high and low-income participants in neighborhoods with high walkability had more moderate physical activity across



almost the entire day (both weekdays and weekend days) than participants from corresponding income categories in low walkability neighborhoods (○ vs. ◇, and ● vs. ◆). During weekdays, the difference between high and low walkability was more pronounced during the afternoon and early evening, especially among individuals with high income.

**Table 2: Multilevel linear regression for predictors of moderate to vigorous physical activity. Numbers represent  $\beta$ -coefficients (with 95% confidence intervals) in minutes/day. n = 2,269.**

	Model A <sup>a</sup>	Model B <sup>b</sup>
<i>Walkability (High vs. Low)</i>	3.4 (0.8–5.8)	3.1 (0.4–5.6)
<i>Neighborhood SES (High vs. Low)</i>		1.8 (–0.7–4.4)
<i>Male vs. Female</i>		3.2 (1.2–5.1)
<i>Age (years)</i>		
• 20–30		Reference
• 31–40		–5.1 (–8.5 – –1.6)
• 41–50		–5.2 (–8.4 – –1.9)
• 51–66		–6.7 (–10.0 – –3.5)
<i>Family income</i>		
• Low		Reference
• Middle		0.9 (–1.1–2.9)
• High		3.4 (0.6–6.3)
<i>Married/cohabiting vs. Single</i>		3.3 (1.1–5.8)
Random effects		
Variance <sub>individual</sub>	537 (506–566)	529 (498–556)
Variance <sub>neighborhood</sub>	4.7 (0.0–8.6)	4.7 (0.0–8.7)
Intraclass correlation	0.9%	0.9%
<sup>a</sup> Model A only includes walkability		
<sup>b</sup> Model B also includes all other variables		

**Table 3: Mixed-effects, mixed-distribution models for predictors of walking for transportation. n = 2,269.**

	Model A <sup>a</sup>	Model B <sup>b</sup>
<b>Occurrence (Logistic)<sup>c</sup></b>		
<i>Walkability (High vs. Low)</i>	1.92 (1.40–2.63)	1.77 (1.30–2.41)
<i>Neighborhood SES (High vs. Low)</i>		1.30 (0.96–1.76)
<i>Male vs Female</i>		0.67 (0.53–0.83)
<i>Age (years)</i>		
• 20–30		1 (Reference)
• 31–40		0.95 (0.60–1.50)
• 41–50		0.72 (0.47–1.11)
• 51–66		0.74 (0.49–1.12)
<i>Family income</i>		
• Low		1 (Reference)
• Middle		0.83 (0.62–1.09)
• High		0.97 (0.69–1.37)
<i>Married/cohabiting vs. Single</i>		0.89 (0.65–1.20)
Random effects		
Variance <sub>neighborhood</sub>	0.09 (0.00–0.18)	0.07 (0.00–0.15)
Intraclass correlation	2.6%	2.1%
<b>Amount (Linear)<sup>d</sup></b>		
<i>Walkability (High vs. Low)</i>	57 (26–88)	50 (20–81)
<i>Neighborhood SES (High vs. Low)</i>		–5 (–35–25)
<i>Male vs. Female</i>		–18 (–45–8)
<i>Age (years)</i>		
• 20–30		Reference
• 31–40		–14 (–62–35)
• 41–50		17 (–29–63)
• 51–66		52 (8–96)
<i>Family income</i>		
• Low		Reference
• Middle		–36 (–69 – –3)
• High		–84 (–124 – –44)
<i>Married/cohabiting vs. Single</i>		39 (4–74)
Random effects		
Variance <sub>individual</sub>	78,573	76,567
	(73,278–83,867)	(71,436–81,697)
Variance <sub>neighborhood</sub>	507 (0–1,499)	297 (0–1,198)
Intraclass correlation	0.6%	0.4%

<sup>a</sup>Model A only includes walkability  
<sup>b</sup>Model B also includes all other variables  
<sup>c</sup>Numbers in the fixed part of the regression are odds ratios (95% confidence intervals)  
<sup>d</sup>Numbers in the linear part of the regression are  $\beta$ -coefficients (95% confidence intervals) in minutes per week

**Table 4: Mixed-effects, mixed-distribution models for predictors of walking for leisure. n = 2,269.**

	Model A <sup>a</sup>	Model B <sup>b</sup>
<b>Occurrence (Logistic)<sup>c</sup></b>		
<i>Walkability (High vs. Low)</i>	1.22 (1.01–1.48)	1.28 (1.04–1.56)
<i>Neighborhood SES (High vs. Low)</i>		1.22 (0.96–1.76)
<i>Male vs. Female</i>		0.67 (0.56–0.81)
<i>Age (years)</i>		
• 20–30		1 (Reference)
• 31–40		0.92 (0.65–1.30)
• 41–50		1.11 (0.80–1.54)
• 51–66		1.71 (1.24–2.36)
<i>Family income</i>		
• Low		1 (Reference)
• Middle		1.14 (0.90–1.44)
• High		1.02 (0.77–1.35)
<i>Married/cohabiting vs. Single</i>		1.00 (0.78–1.29)
Random effects		
Variance <sub>neighborhood</sub>	0.00 (0.00–0.00)	0.00 (0.00–0.00)
Intraclass correlation	0.0%	0.0%
<b>Amount (Linear)<sup>d</sup></b>		
<i>Walkability (High vs. Low)</i>	18 (–8–45)	18 (–9–43)
<i>Neighborhood SES (High vs. Low)</i>		–3 (–28–22)
<i>Male vs. Female</i>		–29 (–54 – –5)
<i>Age (years)</i>		
• 20–30		Reference
• 31–40		–7 (–53–40)
• 41–50		33 (–11–77)
• 51–66		63 (21–104)
<i>Income</i>		
• Low		Reference
• Middle		–40 (–10 – –71)
• High		–58 (–22 – –95)
<i>Married vs. Single</i>		33 (1–64)
Random effects		
Variance <sub>individual</sub>	56,171 (52,118–60,225)	54,681 (50,743–58,618)
Variance <sub>neighborhood</sub>	352 (0–922)	44 (0–612)
Intraclass correlation	0.4%	0.1%

<sup>a</sup>Model A only includes walkability  
<sup>b</sup>Model B also includes all other variables  
<sup>c</sup>Numbers in the fixed part of the regression are odds ratios (95% confidence intervals)  
<sup>d</sup>Numbers in the linear part of the regression are  $\beta$ -coefficients (95% confidence intervals) in minutes per week

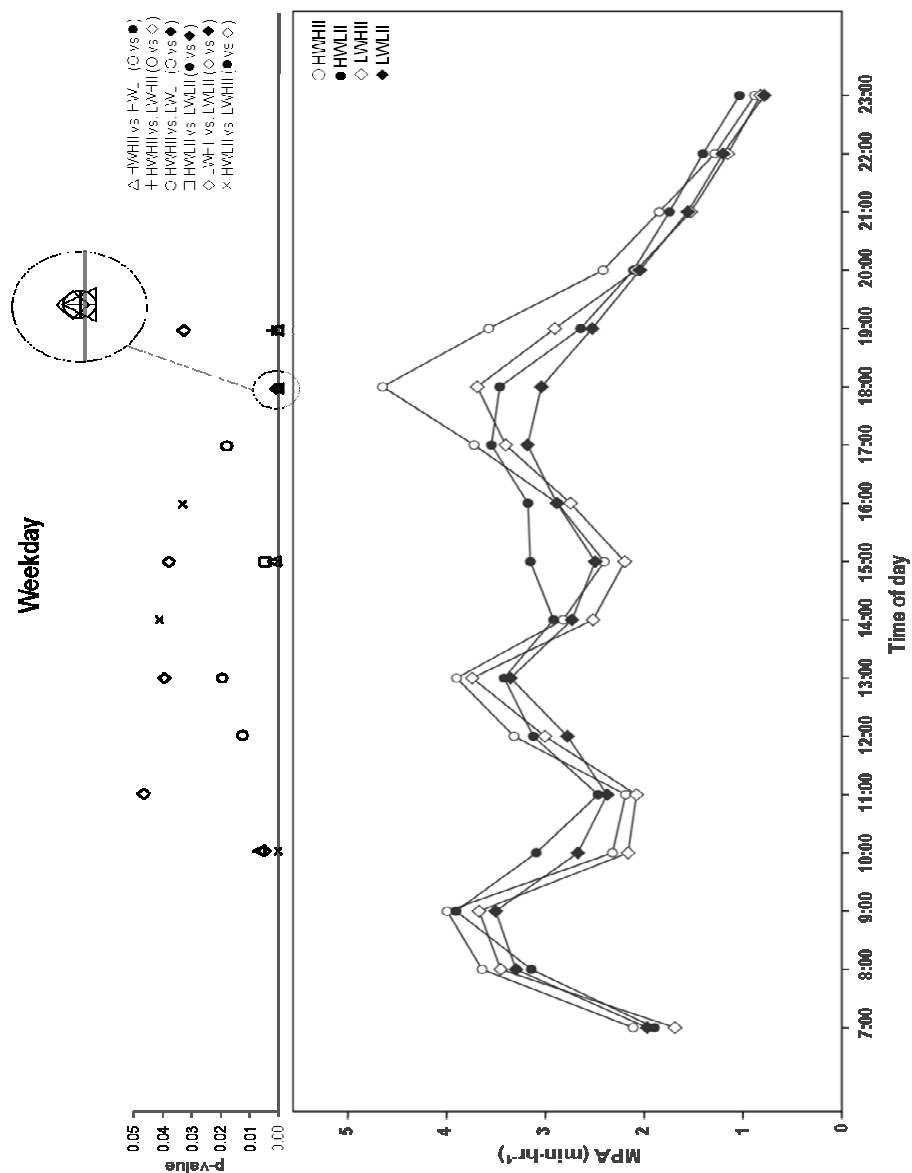
**Table 5. Comparison of mean daily moderate physical activity (minutes/day) for all days, weekdays (Mon-Fri) and weekend days (Sat-Sun) between all walkability-income categories. n=2,252.**

		Mean (95% CI) difference in MPA (min·d <sup>-1</sup> )		
		p-value		
		All days	Weekdays	Weekend days
A	<i>HWHII vs. HWLII</i>	3.1 (−0.0–6.1)	2.6 (−0.7–6.0)	4.4 (0.3–8.5)
		0.051	0.13	0.036
B	<i>HWHII vs. LWHII</i>	3.9 (1.4–6.3)	4.0 (1.5–6.7)	3.8 (0.3–7.3)
		0.002	0.003	0.037
C	<i>HWHII vs. LWLII</i>	5.8 (3.3–8.3)	5.4 (2.7–8.1)	7.0 (3.6–10.4)
		<0.001	<0.001	<0.001
D	<i>HWLII vs. LWLII</i>	2.7 (−0.0–5.5)	2.7 (−0.3–5.8)	2.7 (−0.9–6.2)
		0.052	0.075	0.14
E	<i>LWHII vs. LWLII</i>	1.9 (−0.1–4.0)	1.3 (−0.9–3.5)	3.3 (0.4–6.1)
		0.067	0.25	0.025
F	<i>HWLII vs. LWHII</i>	−0.8 (−3.5–1.9)	−1.4 (−4.4–1.5)	0.6 (−3.1–4.3)
		0.58	0.35	0.73

HW, high walkability; LW, low walkability; HII, high individual income; LII, low individual income; 95% CI, 95% confidence interval; MPA, moderate physical activity

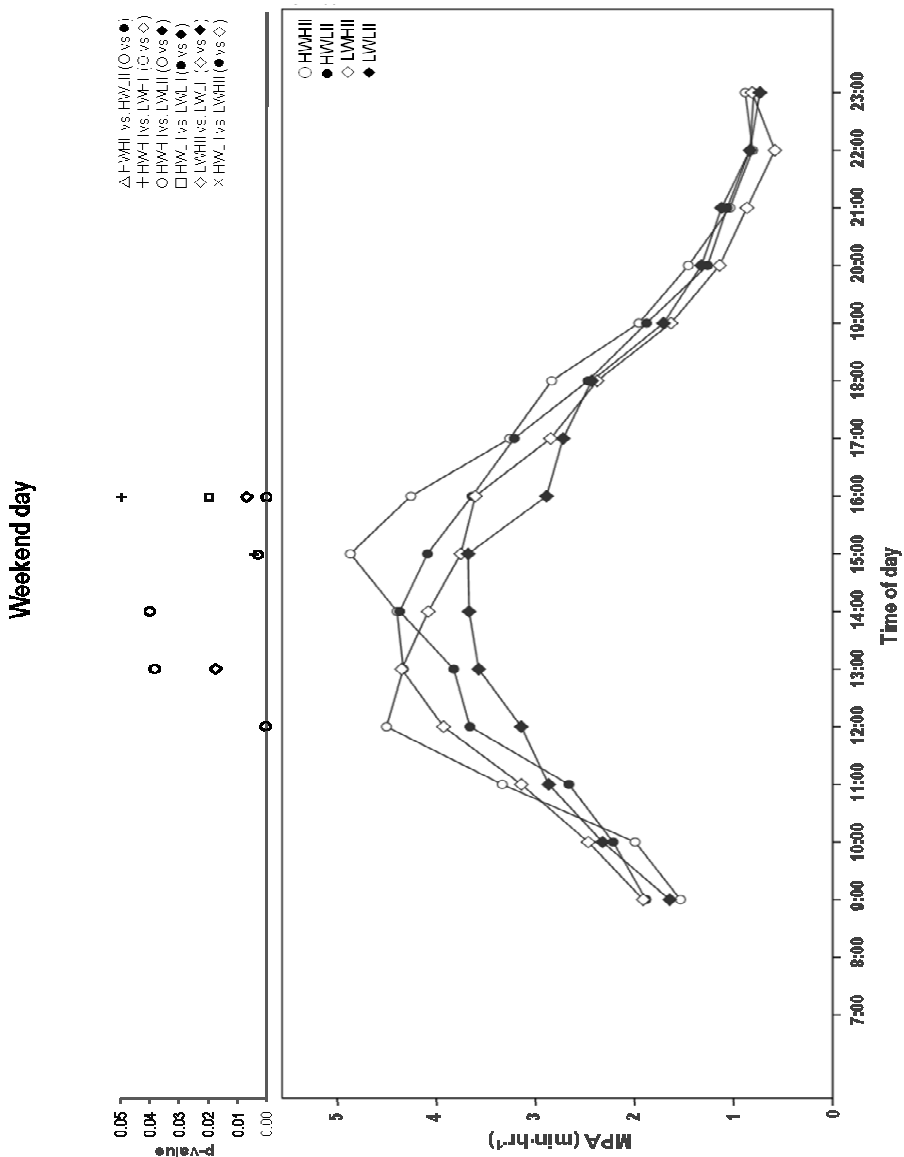
Study 3 investigated the association between three walkability parameters (residential density, street connectivity, and land use mix) and physical activity outcomes, i.e. accelerometer-measured moderate to vigorous physical activity, walking for transportation and cycling for transportation. The results of the regression analyses showed that residential density and land use mix were positively associated with time spent in moderate to vigorous physical activity (Table 6). An increase of residential density of 10,000 dwellings per square kilometer was associated with 5.9 more minutes per day of moderate to vigorous physical activity in the full model. For land use mix, an increase of the HHI by 10,000 was associated with 8.1 more minutes per day of moderate to vigorous physical activity. No significant association was found between street connectivity and time spent in moderate to vigorous physical activity. Residential density and land use mix were also significantly and positively associated with reporting walking for transportation (yes or no) and with the amount of walking for transportation (log-transformed minutes per week) in the full models as shown in Table 7 and Table 8 respectively. Street connectivity was weakly associated with walking for transportation in the linear regression analysis. None of the walkability parameters were associated with reporting cycling for transportation (yes or no) or with the amount of cycling for transportation (log-transformed minutes per week).

Figure 6. Hour-by-hour mean moderate physical activity by walkability-individual income category for an average weekday (lower panel). P-values <0.05 for group comparisons are presented for each hour (upper panel).



HW, high walkability index; LW, low walkability index; HII, high individual income; LII, low individual income.

Figure 7. Hour-by-hour mean moderate physical activity by walkability – individual income category for an average weekend day (lower panel). P-values <0.05 for group comparisons are presented for each hour (upper panel).



HW, high walkability index; LW, low walkability index; HII, high individual income; LII, low individual income.

**Table 6: Walkability parameters, vehicle ownership and moderate to vigorous physical activity. Numbers represent regression coefficients (95% confidence intervals). n=2,178.**

	a paths	b paths <sup>1</sup>	c paths	c' paths	Indirect effects (a paths*b paths)	Proportion mediated
<i>Residential density</i>	-0.53 (-0.60;-0.46)	-3.05 (-4.50;-1.59)	6.81 (4.35; 9.27)	5.20 (2.63; 7.77)	1.61 (0.81; 2.48)	24%
<i>Residential density (Full model<sup>2</sup>)</i>	-0.49 (-0.56;-0.42)	-2.95 (-4.45;-1.46)	5.86 (3.37; 8.35)	4.42 (1.84; 7.01)	1.44 (0.69; 2.31)	25%
<i>Street connectivity</i>	n/a	n/a	0.02 (-0.02; 0.07)	n/a	n/a	n/a
<i>Street connectivity (Full model<sup>2</sup>)</i>	n/a	n/a	n/a	n/a	n/a	n/a
<i>Land use mix</i>	-1.00 (-1.11;-0.88)	-3.07 (-4.55;-1.60)	10.30 (6.25; 14.35)	7.24 (2.95; 11.53)	3.06 (1.56-4.67)	30%
<i>Land use mix (Full model<sup>2</sup>)</i>	-0.90 (-1.02;-0.78)	-3.11 (-4.62;-1.60)	8.13 (3.94; 12.32)	5.33 (0.94; 9.72)	2.80 (1.32; 4.25)	34%

a paths: Associations between walkability parameters and vehicle ownership  
b paths: Associations between vehicle ownership and MVPA (minutes/day)  
c paths: Associations between walkability parameters and MVPA (minutes/day)  
c' paths: c paths adjusted for vehicle ownership  
<sup>1</sup>b paths are not based on the walkability parameters  
<sup>2</sup>Adjusted for age, gender, income and marital status  
n/a: Not applicable (as no significant association was found between the walkability parameter and the physical activity outcome)

**Table 7: Walkability parameters, vehicle ownership and walking for transportation (yes/no). Numbers represent regression coefficients (95 % CI). n=2,178.**

	a paths	b paths <sup>1</sup>	c paths	c' paths	Indirect effects (a paths*b paths)	Proportion mediated
<i>Residential density</i>	-0.53 (-0.60;-0.46)	-0.06 (-0.08;-0.03)	0.14 (0.10; 0.18)	0.11 (0.07; 0.15)	0.03 (0.02; 0.04)	22%
<i>Residential density (Full model<sup>2</sup>)</i>	-0.49 (-0.56;-0.42)	-0.05 (-0.08;-0.03)	0.13 (0.09; 0.17)	0.10 (0.06; 0.15)	0.03 (0.01; 0.04)	23%
<i>Street connectivity</i>	n/a	n/a	0.0003 (-0.000; 0.001)	n/a	n/a	n/a
<i>Street connectivity (Full model<sup>2</sup>)</i>	n/a	n/a	n/a	n/a	n/a	n/a
<i>Land use mix</i>	-1.00 (-1.11;-0.88)	-0.06 (-0.08;-0.03)	0.23 (0.16; 0.30)	0.18 (0.10; 0.25)	0.06 (0.03; 0.08)	26%
<i>Land use mix (Full model<sup>2</sup>)</i>	-0.90 (-1.02;-0.78)	-0.05 (-0.08;-0.03)	0.21 (0.14; 0.28)	0.16 (0.09; 0.24)	0.05 (0.03; 0.07)	24%

a paths: Associations between walkability parameters and vehicle ownership

b paths: Associations between vehicle ownership and walking for active transportation (dichotomous, yes/no)

c paths: Associations between walkability parameters and walking for active transportation (dichotomous, yes/no)

c' paths: c paths adjusted for vehicle ownership

<sup>1</sup>b paths are not based on the walkability parameters

<sup>2</sup>Adjusted for age, gender, income and marital status

n/a: Not applicable (as no significant association was found between the walkability parameter and the physical activity outcome)



**Table 8: Walkability parameters, vehicle ownership and walking for transportation (amount\*). Numbers represent regression coefficients (95 % CI). n=1747.**

	a paths	b paths <sup>1</sup>	c paths	c' paths	Indirect effects (a paths*b paths)	Proportion mediated
<i>Residential density</i>	-0.49 (-0.56; -0.41)	-0.11 (-0.18; -0.03)	0.26 (0.14; 0.38)	0.21 (0.08; 0.33)	0.05 (0.02; 0.09)	19%
<i>Residential density (Full model)<sup>2</sup></i>	-0.45 (-0.53; -0.37)	-0.11 (-0.18; -0.03)	0.28 (0.16; 0.40)	0.24 (0.12; 0.36)	0.05 (0.02; 0.08)	18%
<i>Street connectivity</i>	-0.002 (-0.004; -0.001)	-0.137 (-0.207; -0.067)	0.003 (0.000; 0.005)	0.002 (0.000; 0.004)	0.0003 (0.0001; 0.0007)	11%
<i>Street connectivity (Full model)<sup>2</sup></i>	n/a	n/a	0.002 (0.000; 0.005)	0.002 (-0.000; 0.004)	n/a	n/a
<i>Land use mix</i>	-0.98 (-1.12; -0.86)	-0.09 (-0.16; -0.02)	0.53 (0.33; 0.74)	0.44 (0.23; 0.66)	0.09 (0.02; 0.16)	17%
<i>Land use mix (Full model)<sup>2</sup></i>	-0.87 (-1.00; -0.74)	-0.09 (-0.17; -0.02)	0.58 (0.37; 0.79)	0.50 (0.27; 0.73)	0.08 (0.02; 0.15)	14%

\*Only individuals that have reported some walking are included and values are log-transformed.

a paths: Associations between walkability parameters and vehicle ownership.

b paths: Associations between vehicle ownership and walking for active transportation (log-transformed min/week).

c paths: Associations between walkability parameters and walking for active transportation (log-transformed min/week).

c' paths: c paths adjusted for vehicle ownership.

<sup>1</sup>b paths are not based on the walkability parameters.

<sup>2</sup>Adjusted for age, gender, income and marital status.

n/a: Not applicable (as no significant association was found between the walkability parameter and the physical activity outcome)

The results from the linear regression model in study 4 showed that participants with  $\geq 4$  exercise facilities within their 1,000 meter buffer zones spent 5.4 more minutes per day in moderate to vigorous physical activity than those with no exercise facilities within their buffer zones (Table 9). There was no significant difference in time spent in moderate to vigorous physical activity between participants with 1–3 exercise facilities within their buffer zones and those with no facilities. The logistic regression model showed that having  $\geq 4$  exercise facilities within the buffer zone was associated with 69% higher odds of meeting the physical activity recommendations compared to having no exercise facilities within the buffer zone (Table 10).

**Table 9: Linear regression analysis of predictors of moderate to vigorous physical activity. Numbers represent regression coefficients (with 95% confidence intervals) in minutes/day. n = 2,037.**

	Model A <sup>1</sup>	Model B <sup>2</sup>
<i>Availability of exercise facilities</i>		
• 0	Reference	Reference
• 1–3	0.5 (–1.4–2.4)	0.3 (–1.5–2.1)
• $\geq 4$	5.4 (2.2–8.5)	5.4 (2.3–8.5)
<i>Gender</i>		
• Male		Reference
• Female		–2.4 (–5.2–0.3)
<i>Age (years)</i>		
• 20–30		Reference
• 31–40		–6.0 (–10.2 – –1.7)
• 41–50		–7.1 (–11.4 – –2.8)
• 51–66		–8.1 (–12.7 – –3.5)
<i>Income</i>		
• Low		Reference
• Middle		0.9 (–2.0–3.8)
• High		3.0 (–0.8–6.8)
<i>Marital status</i>		
• Married/cohabiting		Reference
• Single		3.5 (0.8–6.2)
<i>Time of year</i>		
• January–March		Reference
• April–June		0.1 (–2.3–2.5)
• July–September		–0.8 (–4.3–2.8)
• October–December		–1.7 (–4.5–1.0)

<sup>1</sup>Univariate linear regression

<sup>2</sup>Multiple linear regression including all variables and adjusted for accelerometer wearing time in min/day

**Table 10: Logistic regression analysis of predictors of meeting physical activity recommendations. Numbers represent odds ratios (with 95% confidence intervals). n=2,037.**

	Model A <sup>1</sup>	Model B <sup>2</sup>
<i>Availability of exercise facilities</i>		
• 0	Reference	Reference
• 1–3	1.06 (0.86–1.31)	1.07 (0.86–1.33)
• ≥4	1.70 (1.39–2.08)	1.69 (1.39–2.05)
<i>Gender</i>		
• Male		Reference
• Female		1.04 (0.86–1.26)
<i>Age (years)</i>		
• 20–30		Reference
• 31–40		0.78 (0.56–1.07)
• 41–50		0.88 (0.66–1.18)
• 51–66		1.09 (0.83–1.43)
<i>Income</i>		
• Low		Reference
• Middle		1.18 (0.92–1.50)
• High		1.08 (0.79–1.48)
<i>Marital status</i>		
• Married/cohabiting		Reference
• Single		1.05 (0.87–1.26)
<i>Time of year</i>		
• January–March		Reference
• April–June		1.00 (0.82–1.24)
• July–September		0.90 (0.66–1.23)
• October–December		0.82 (0.65–1.03)

<sup>1</sup>Univariate logistic regression

<sup>2</sup>Multiple logistic regression including all variables

# Interaction analysis

Tests of interaction were performed in studies 1, 3 and 4 in order to investigate whether the associations between the explanatory variables and the outcomes were similar in different subgroups of the sample. Neighborhood-level SES, age, gender, marital status, or family income did not modify the associations between neighborhood walkability and physical activity outcomes (study 1). The associations between residential density, street connectivity, and land use mix and physical activity outcomes were not modified by vehicle ownership (study 3). Furthermore, the

association between availability of exercise facilities and physical activity was not modified by age, gender, marital status, individual income or time of year (study 4). In summary, none of the variables tested for effect modification showed statistically significant results. However, the results of the analysis of neighborhood walkability and mean daily time spent in moderate physical activity (study 2) may indicate a weak effect modification of individual income. The differences in time spent in moderate physical activity between participants living in high or low walkability neighborhoods were more pronounced in high-income participants than in low-income participants.

## Mediation analysis

There were negative associations between residential density as well as land use mix and vehicle ownership. There were also negative associations between vehicle ownership and time spent in moderate to vigorous physical activity. The results of the product of coefficients analysis showed that vehicle ownership mediated 25% of the association between residential density and time spent in moderate to vigorous physical activity in the full model, and this mediating effect was statistically significant (Table 6). For land use mix, the corresponding figure was 34%. There were also negative associations between vehicle ownership and walking for transportation in both the logistic and the linear regression analyses. Vehicle ownership mediated 23% of the logistic (Table 7) and 18% of the linear associations (Table 8) between residential density and walking for transportation, respectively. For land use mix, the corresponding figures were 24% and 14% for the logistic and linear associations, respectively, and these mediating effects were statistically significant.

## General results

The median time spent in moderate to vigorous physical activity was about 41 min per day. Overall, 35% of participants met the physical activity recommendation of  $\geq 150$  min of moderate to vigorous physical activity per week (Study 4). Participants reported a median of 125 minutes of walking for transport per week. Fifty-five percent of the participants were females and about a fourth of the participants were single (Table 11). Single participants spent more time in moderate to vigorous physical activity than their married/cohabiting counterparts, and participants aged 20–30 years spent more time in moderate to vigorous physical activity than those over the age of 30. The results of study 2 showed that, in both high walkability and low walkability neighborhoods, high individual income was associated with more moderate physical activity compared with low individual income on weekend days

(Table 5, comparison A and E). The differences were 4.4 and 3.3 minutes per day, respectively. However, the differences varied depending on the time of day. High-income participants had a higher amount of moderate physical activity than low-income participants (○ vs. ●, and ◇ vs. ◆) around noon and in the afternoon/early evening on weekdays (Figure 6). In contrast, low-income participants had higher amounts of moderate physical activity than high-income participants in the time periods between the three peaks. During the weekend, there was a more consistent difference in moderate physical activity across the day between high- and low-income participants (Figure 7).

**Table 11. Descriptive statistics on the study participants, variables mainly from study 3.**

	Median or percent	Interquartile range	Min; max
<i>Residential density (residential units <math>\times 10^{-4}/\text{km}^2</math>)</i>	0.23	0.14; 0.43	0.06; 1.77
<i>Street connectivity (intersections/<math>\text{km}^2</math>)</i>	86.4	73.4; 102.1	30.5; 155.3
<i>Land use mix (<math>\text{HHI} \times 10^{-4} \times (-1)</math>)<sup>a</sup></i>	-0.76	-0.86; -0.36	-0.98; -0.24
<i>Age:</i>			
20–30	11%		
31–40	21%		
41–50	28%		
51–66	40%		
<i>Gender (females)</i>	55%		
<i>Income (SEK/year)<sup>b</sup>:</i>			
<150,000	19%		
150,000–349,999	56%		
≥350,000	25%		
<i>Marital status (married/cohabiting)</i>	75%		
<i>Vehicle ownership:</i>			
0	18%		
1	48%		
≥2	34%		
<i>Moderate to vigorous physical activity (min/day)</i>	41.3	27.1; 57.9	0.1; 183.7
<i>Walking for transportation (min/week)</i>	125	30; 300	0; 1260
<i>Walking for leisure (min/week)</i>	60	0; 180	0; 1260
<i>Cycling for transportation (min/week)<sup>c</sup></i>	0	0; 20	0; 1260

<sup>a</sup>In study 3, a higher Herfindahl-Hirschman Index correspond to a higher level of land use mix

<sup>b</sup>Calculated by dividing the gross family income by number of people living in the household, with children/adolescents under the age of 18 being given a consumption weight of 0.5

<sup>c</sup>Observations collected between April and October (n=906)

# Discussion

## Main findings

This is the first large-scale Swedish study investigating the associations between objectively assessed neighborhood environment and objective and self-reported physical activity. We found that individuals living in highly walkable neighborhoods, compared to those living in less walkable neighborhoods, spent more time in moderate to vigorous physical activity per day, had higher odds for walking for transportation and walking for leisure and reported more minutes of walking for transportation per week. The results of the hour-by-hour analysis of accelerometer data showed, for the first time, that the influence of neighborhood walkability on physical activity varies across the day, and that it was more pronounced during the time periods when a large proportion of people are likely to be exposed to their neighborhood environment. These findings provide further support for an association between neighborhood walkability and physical activity. Study 3 showed that two of three parameters of the walkability index (residential density and land use mix, but not street connectivity) were associated with physical activity. Significant proportions of these associations were mediated by vehicle ownership, i.e. individuals living in dense neighborhoods with a variety of services and facilities owned fewer vehicles and were more physically active. Also, in study 4, we found that the availability of exercise facilities within the neighborhood was positively associated with time spent in moderate to vigorous physical activity and with higher odds of meeting the recommended levels of physical activity. The associations in this thesis did not differ between different subgroups of the population. That is, people living in dense mixed-use neighborhoods may benefit from these environments regardless of age, gender, income and vehicle ownership status.

## Associations between the neighborhood environment and physical activity

We found more moderate to vigorous physical activity among individuals living in highly walkable neighborhoods, which was in agreement with findings from the

NQLS in the U.S. [34] and a study on neighborhood walkability and physical activity from Belgium, the Belgian Environmental Physical Activity Study (BEPAS) [113]. The finding of the association between neighborhood walkability and different forms of walking was partly in agreement with previous studies. In the NQLS and BEPAS studies, positive associations between neighborhood walkability and walking for transportation as well as walking for leisure were found, whereas the PLACE study from Australia found an association with walking for transportation but not with walking for leisure [33]. Our study found that neighborhood walkability was associated with walking for transportation (yes vs. no) and reported minutes of walking for transportation per week as well as walking for leisure (yes vs. no). Walkability was not associated with reported minutes of walking for leisure per week in this study. As SNAP, NQLS, PLACE and BEPAS are based on very similar study design, the small differences between studies may be due to environmental differences or social and cultural differences between countries rather than study design issues. A Swedish study found the degree of urbanization to be associated with more walking but lower odds of having high levels of total physical activity (being in the top quartile of total physical activity) [129]. That study was based on self-reported neighborhood environment and self-reported physical activity, and the relationship between self-reported degree of urbanization and objectively assessed neighborhood walkability is unclear. The authors discuss that urban environments may support walking but that other environments may support physical activity at higher intensities. There have been a few longitudinal studies on neighborhood environment and physical activity. For example, an Australian study measuring neighborhood environment and physical activity before, and twelve months after, relocation found that participants moving to less walkable neighborhoods reported less walking for transport but more walking for leisure in the new environment. However, in those who gained access to destinations after relocation, both walking for transport and walking for recreation were positively associated with the number of walking-related destinations [130]. These findings provide further support for an association between neighborhood walkability and walking for transportation, and stress the importance of destinations within the neighborhood.

As this was the first study to investigate the influence of neighborhood walkability on the hour-by-hour pattern of physical activity, it is hard to compare to previous findings. However, the findings support an association between neighborhood walkability and moderate physical activity. We found a rather strong association between neighborhood walkability and moderate physical activity in the afternoon/early evening, suggesting an influence of neighborhood walkability on physical activity, as this is a time when a large proportion of people are likely to be exposed to their neighborhood environment. People living in neighborhoods with higher walkability are exposed to a variety of services and facilities within walking distance, which they may reach by walking after working hours. In contrast, participants living in neighborhoods with lower walkability have less availability of

facilities within walking distance and may be more prone to use a car for their errands after work. Interestingly, walkability and income seem to have a synergetic influence on moderate physical activity in the afternoon/early evening on weekdays, as participants in the high walkability/high income category had substantially higher levels of moderate physical activity than participants in the other categories in this part of the day. On weekend days, participants living in neighborhoods with high compared to low walkability spent consistently more time in moderate physical activity across the day, and the most pronounced differences were found in the middle of the day. On weekend days compared to weekdays, participants may spend more time in their neighborhoods, i.e. the influence of neighborhood walkability on moderate physical activity may be exerted over longer periods of the day.

The analysis of the separate walkability parameters in study 3 showed that residential density and land use mix were positively associated with time spent in moderate to vigorous physical activity and walking for transportation. This is in line with previous research investigating objectively assessed residential density and land use mix as separate measures [83], and supports the inclusion of these parameters in the walkability index. Street connectivity was weakly associated with the amount of walking for transportation, but it was not associated with any of the other physical activity outcomes in this study. This is in contrast to some earlier findings. For example, Frank et al. found street connectivity to be significantly associated with moderate physical activity [83]. However, the street connectivity in this study was higher (range 31–155 and a median of 86 intersections per km<sup>2</sup>) compared to the street connectivity found by Frank and colleagues in the U.S. (range 0–104 and a mean of 37 intersections per km<sup>2</sup>). The relatively high connectivity in this Swedish context may explain the lack of association. A review by Saelens and Handy on environmental correlates of walking found that, while residential density and land use mix were consistently associated with walking for transportation, the findings for street connectivity were more equivocal [98].

We did not find any significant associations between walkability parameters and cycling for transportation. Some previous studies have examined the association between walkability and cycling for transportation. For example, participants in the BEPAS study living in highly walkable neighborhoods reported 40 more minutes of cycling for transportation per week than participants living in less walkable neighborhoods [113], and a Belgian-Australian study found that higher neighborhood walkability was associated with higher odds of using cycling for transportation at least once a week [131]. Furthermore, results from an American study showed positive associations between objectively assessed population density, street connectivity and land use mix and cycling for transportation [132]. Even though we included the cycling infrastructure in our data, there are some possible explanations for the lack of association. For example, walkability was developed as a



measure of supportive environments for walking and not cycling. Furthermore, it may be more common for cyclists to commute from residences in low walkable neighborhoods to workplaces in dense inner city areas than the opposite scenario, in order to avoid traffic congestion and parking problems. This would dilute an association between walkability within the neighborhood and cycling for transportation. A study performed in the same metropolitan area as the SNAP study found higher levels of stimulating environmental characteristics for bicycle commuting and higher levels of traffic safety in suburban areas (less walkable) than in inner urban areas (highly walkable) [74]. Hence, the combination of walkable neighborhoods and safe and stimulating environments for cycling may be a promising goal for the public health agenda.

The units of residential density and land use mix shown in Tables 6–8 and 11 were residential units per square kilometer divided by 10,000 and HHI values divided by 10,000, respectively. This was done in order to make the unit in the explanatory variable and the regression coefficients easier to interpret, representing a meaningful difference in the neighborhood environment. For example, one increase in the unit of residential density used in the analyses (10,000 residential units per km<sup>2</sup>), corresponded to a shift from the lowest density to a mid-range density in this sample. One increase in the unit of land use mix (10,000 original units of HHI), corresponded to a shift from the lowest land use mix to a rather high land use mix.

The findings of an association between neighborhood availability of exercise facilities and physical activity add to the knowledge base by using objective measures in a large study. We found that individuals with four or more exercise facilities within the 1,000-meter buffer zones around their residences spent more time in moderate to vigorous physical activity, and were more likely to meet the physical activity recommendations, than participants with no exercise facilities within their buffer zones. The previous findings on exercise facilities are inconsistent and often based on self-reported physical activity. For example, a previous study from the U.S. showed a significant association between objectively assessed density of exercise facilities within circular buffer zones and self-reported frequency of exercise [87]. Another study from the U.S. that investigated the association between density of exercise facilities within circular buffer zones of different sizes and a range of self-reported physical activities presented similar results, although the association for the smallest buffer zones (radius 0.5 miles/805 meters) was not statistically significant [36]. In contrast to these studies, a Spanish study found no association between numbers of exercise facilities per 10,000 inhabitants and self-reported physical activity [133]. That study, however, measured the availability of exercise facilities at the province level, and the large area of exposure used in this study may explain the lack of association. It has been suggested that the use of large buffer zones may mask within-area variation [78]. A further study from the U.S. found no association between objectively assessed

availability of exercise facilities and leisure-time physical activity, as assessed using the International Physical Activity Questionnaire [134]. That study was based on relatively small circular buffers (radius 400 meters) and a dichotomized measure of availability of exercise facilities (yes or no). The association between availability of exercise facilities and physical activity that was identified in this thesis could be explained by a number of possible mechanisms. Having a large number of exercise facilities near one's home may increase the chance of finding a mode of exercise that is attractive in terms of type of activity, cost and social atmosphere. This may explain why participants with  $\geq 4$  exercise facilities within their buffer zones were more physically active than those with no facilities, while participants with 1–3 facilities were not. Having just a few exercise facilities within the neighborhood may not provide sufficient variation in terms of what the facilities may offer. The mere presence of exercise facilities, by putting physical activity in the minds of passers-by, could also increase the overall levels of physical activity and not just exercise performed at these facilities. In agreement with this hypothesis, Sallis et al. showed that the presence of exercise facilities close to the individuals' homes did not seem to be associated with participation in the specific activities offered at those facilities, but rather with an increased overall exercise frequency [87].

Parks and green areas within cities are often subject to public debate. This thesis does not include parks or green areas as a measure of neighborhood environment, but there is some research that has touched on the interplay between neighborhood walkability, parks and physical activity. A recent study from Australia found a negative association between park area within 800- and 1,200-meter buffers around participants' residences and walking (all purposes). The authors discussed that neighborhoods containing high levels of parkland may be situated in outer low-density suburbs with poor connectivity and low land use mix [135]. These thoughts are supported by an American study where greenness within 1,000 buffers around the residences was negatively associated with accelerometer-measured time spent in moderate to vigorous physical activity performed within these buffers. In that study, greenness was strongly and negatively associated with the walkability parameters residential density and land use mix (which were positively associated with physical activity within the buffers), and the authors warrant research on the interactive effects of greenness and other built environment variables [136]. A Dutch study found a stronger association between the amount of green space and leisure-time physical activity in slightly urbanized (intermediate walkability) areas compared to rural (low walkability) and urban areas (high walkability) where the associations were weak [137]. A review from 2008, however, found some weak evidence for a positive association between parks and physical activity [138] and greenery may be of importance along routes for commuters using active transport [74]. Furthermore, it is possible that the quality, in addition to the amount, of green areas is important for

physical activity [139]. Green areas may also have other effects on health than providing a place to be physically active. They may, for example, reduce traffic noise annoyances and the prevalence of stress-related psychosocial symptoms by providing opportunities for relief from environmental stress [140]. An observational study on over 40 million people in England found a lower incidence of circulatory diseases and all-cause mortality in the greenest areas compared to the least green areas, independent of income. In the discussion, the authors point out that the effects of green areas on health may be mediated by other mechanisms than physical activity [141].

## Interaction analysis

Neighborhood-level SES, age, gender, marital status, or family income did not modify the associations between neighborhood walkability and physical activity outcomes. The associations between the walkability parameters (residential density, street connectivity, land use mix) and physical activity outcomes were not modified by vehicle ownership. Furthermore, the association between availability of exercise facilities and physical activity was not modified by age, gender, marital status, individual income or time of year. In summary, none of the variables tested for effect modification in this thesis showed statistically significant results. However, the results of the analysis of neighborhood walkability and mean daily time spent in moderate physical activity in study 2 may indicate a weak effect modification of individual income. The differences in time spent in moderate physical activity between participants living in high or low walkability neighborhoods were more pronounced in high-income participants than in low-income participants. These findings are mainly in line with previous research, but some interactions have been found. For example, the Australian PLACE study found an effect modification of individual SES. The association between walkability and walking was stronger among high SES (education) than among low SES participants [33]. Effect modification of SES on the association between walkability and physical activity, however, was not found in the U.S. or Belgium [34, 113]. We did not find any significant effect modification by vehicle ownership on the associations between walkability parameters and physical activity outcomes. This is in contrast to some previous findings where vehicle ownership, or similar vehicle-related measures, moderated the relationship between the environment and physical activity. For example, driving status modified the association between convenience of bus services and physical activity in a Japanese study [142], and preference for passive transport modified the association between walkability and numbers of steps per day in a Belgian setting [143]. In the Belgian study, living in a highly walkable neighborhood was associated with taking more steps per day and this association was stronger among participants with a preference for

passive transportation than among participants with a preference for active transportation. The present study and the studies from Japan [142] and Belgium [143] used different explanatory as well as outcome measures. For example, preference for passive transport may have a different influence on the association between walkability parameters and physical activity compared to vehicle ownership. None of the socio-demographic variables (sex, age, income or marital status) modified the association between availability of exercise facilities and physical activity. This is in contrast to some previous findings. A study from the U.S. found the association between density of exercise facilities and exercise prevalence to be stronger among those with low incomes and non-Hispanic Black and Hispanic participants compared to their high-income and non-Hispanic White counterparts [36]. Income was also found to be an effect modifier in another study, which found an association between the availability of gyms and physical activity in low-income women but not high-income women [90]. One possible explanation for the absence of significant socioeconomic interactions in Sweden may be the relatively low level of income inequality. It has been proposed that the availability of exercise facilities could increase the opportunities to be physically active all year round in wet or cold climates [108]. We found no significant interaction between time of year and availability of exercise facilities in any of our analyses, suggesting that availability of exercise facilities is of equal importance for physical activity throughout the year.

The lack of effect modification in this study is good from a public health point of view. Participants living in dense mixed-use neighborhood environments may benefit from these environments regardless of age, gender, income and vehicle ownership status. If this is the case, it is possible that neighborhood characteristics aimed at increasing people's physical activity may reach many population groups to an equal extent. As this thesis was based on participants aged 20–66 years, our findings cannot be generalized to younger or older persons. There is, however, research on neighborhood environment and physical activity in other age groups. A study from Belgium found a positive association between neighborhood walkability and accelerometer-measured time spent in moderate to vigorous physical activity among adolescents in low but not in high SES neighborhoods [144], and a review from 2011 found land use mix and residential density to be the most supported environmental correlates of children and adolescents' physical activity [145]. There are also studies on older adults where neighborhood walkability has been positively associated with physical activity [146-147]. A review from 2010, however, did not find any consistent associations between neighborhood environment and physical activity among older adults [148].

## Mediation analysis

The results of the mediation analysis showed that vehicle ownership mediated significant proportions, 14–34% in the full models, of the associations between walkability parameters (residential density and land use mix) and physical activity (time spent in moderate to vigorous physical activity and walking for transportation). To our knowledge, no previous studies have investigated vehicle ownership as a mediator between objectively assessed walkability parameters and physical activity outcomes. Therefore, our results are hard to compare with previous research. However, our results are in line with the findings of a study by Sehatzadeh et al. in which fewer vehicles were owned by households in walkable neighborhoods and where the number of vehicles in the household was negatively associated with frequency of walking [109]. This is also supported by results from a longitudinal study on 101 adults from the U.S., where participants who moved to a denser neighborhood with mixed land use increased their levels of walking for both recreation and transportation and also decreased their automobile travel [149]. Furthermore, Frank et al. found positive associations between walkability parameters and walking, and negative associations between walkability parameters and driving [150]. In another study by Frank and colleagues, a 5% increase in the walkability index was associated with 6.5% less vehicle miles traveled and less vehicle emissions per capita [104]. Many trips by car are very short, about half of the trips by car in Sweden are less than 5 kilometers [151]. Reducing the number of short car trips and increasing the number of bicycle trips may provide significant health, environmental and economic benefits [152].

## General results

The median time spent in moderate to vigorous physical activity was about 41 minutes per day. Compared to another population-based Swedish sample [19], our sample spent more time in moderate to vigorous physical activity (median time 41 versus mean time 33 minutes/day). The other study was conducted in 2001 and its sample also included rural participants. In contrast, our sample was exclusively urban and was recruited in the capital of Sweden. The mean time spent in moderate to vigorous physical activity in the Belgian BEPAS was 35 minutes per day [113] and in the American NQLS about 32 minutes per day. Participants in this study reported a median of 125 minutes of walking for transport per week compared to a mean of about 63 minutes per week in BEPAS [113] and a median of 90 minutes per week in the Australian PLACE study [33]. The results of study 2 showed that, in both high walkability and low walkability neighborhoods, high individual income was associated with more moderate physical activity compared with low individual income on

weekend days. However, the differences varied depending of the time of day. High-income participants had a higher amount of moderate physical activity than low-income participants around noon and in the afternoon/early evening on weekdays. In contrast, low-income participants had higher amounts of moderate physical activity than high-income participants in the time periods between the three peaks. During the weekend, there was a more consistent difference in moderate physical activity across the day between high- and low-income participants. This is in line with the findings in a study by Bauman and colleagues where high-income participants were more physically active during leisure time but less active when at work compared to low-income participants [153]. Low income may be associated with manual work and thereby higher levels of work-related physical activity, while high income may be associated with sedentary deskwork. The higher levels of physical activity during lunchtime among participants with high compared to low income may be due to their better economic possibilities to buy their lunch at nearby restaurants, and thereby obtain some transport-related physical activity on the way to the restaurant and back. Furthermore, optional exercise during the lunch break as part of occupational health care programs may be more common among high-income workers. The higher level of physical activity during the late afternoon/early evening is in line with previous research where income has been associated with leisure-time physical activity [153-155]. As described earlier, walkability and income seem to have a synergetic influence on moderate physical at this time of day, as participants in the high walkability/high income category had substantially higher levels of moderate physical activity than participants in the other categories. Participants with high compared to low income were also more physically active across the weekend days, giving further support for an association between individual income and leisure-time physical activity.

## Strengths, limitations and methodological issues

This thesis is based on a cross-sectional study and causality cannot be determined. There may also be unmeasured confounders not controlled for (i.e. residual confounding may exist). We cannot exclude the possibility that physically active people chose to live in activity-friendly environments and we cannot exclude the possibility that gyms and other exercise facilities may be established in neighborhoods where physically active people live. However, adjusting for neighborhood self-selection in the NQLS study produced only minor changes to the associations between neighborhood walkability and physical activity [34]. The analyses in the PLACE study were also adjusted for neighborhood self-selection [33]. Also, the neighborhood environment may have an influence on physical activity even if self-selection is present. For example, results from an American study showed that participants who placed greater importance on neighborhood open space such as

parks were not more likely to live near more parkland compared to participants who attached low importance to neighborhood open space. However, participants who placed a low importance on living near parks but lived near much park space anyway were significantly more likely to engage in park-based physical activity than participants who also placed low importance on parks but had less nearby park space [156].

Strengths of this thesis include that it is based on objective assessments of the neighborhood environment. Objective measures, as compared to self-report, are free from recall bias and they are not affected by participants' exposure to the environment. Objective measures may also provide valuable evidence for policy makers and city planners. It is important, however, to point out that people's perceptions of the environment may also have an impact on their physical activity levels. For example, a study by Gebel et al. found both objective and perceived neighborhood walkability to be associated with walking for transportation [157]. These findings were supported by results from the SNAP study, where perceived neighborhood walkability was associated with more walking and more time spent in moderate to vigorous physical activity independently of the objectively assessed neighborhood walkability [158]. About one-third of the individuals in neighborhoods with high objectively assessed walkability perceived their neighborhood as less walkable. The highest levels of physical activity were found among participants living in neighborhoods with high objectively assessed walkability who also perceived the neighborhood as highly walkable [158], implying that the perception of the environment, in addition to the actual environment, may be a potential target for intervention.

We used different definitions of the neighborhood in the different studies. In study 1 we used administrative areas to define the neighborhoods. These areas may be relevant as they are well-known units that are used for public analysis and statistics, but they do not provide an individualized measure of the neighborhood environment. All participants in the administrative area are considered to have the same exposure regardless of where in the area they actually live. In study 2 and study 3 we used polygon-based network buffers to define the neighborhood. Network-buffers, as compared to administrative areas, provide a measure of the environment actually surrounding the participants' residences. They have also some advantages over circular buffers as they do not include unreachable areas, such as areas on the other side of rivers or other natural or unnatural barriers. In study 4 we investigated the availability of exercise facilities within line-based network buffers. We chose these buffers as we did not include any measure of area in study 4 as we did in studies 1–3 (e.g. intersections per km<sup>2</sup>). A majority of previous studies using network buffers have been based on the road network only. The network buffers in this thesis were based on detailed network data, including the road network as well as bicycle paths and

footpaths. This provides a more relevant area of exposure for cyclists and pedestrians than network buffers based solely on the road network.

The definitions of the neighborhood used in the studies in this thesis may differ from the participants' perceptions of their neighborhood. A study from England, comparing GIS-defined neighborhoods to perceived neighborhoods drawn on a map by the study participants, found large differences between participants' perceived neighborhood areas. The perceived neighborhood areas ranged from 0.6 to 284% compared to a 1,000-meter polygon-based network buffer [159]. There is no consensus about the "perfect" size of a buffer zone in physical activity research. However, 1,000-meter buffers are commonly used in physical activity research, and studies have found that it is a distance many people are willing to walk in their daily life [104, 160]. Also, the use of larger buffer zones may mask within-area variation [78]. On the other hand, a 1,000-meter buffer may be too small to capture a relevant area of exposure for cyclists (study 3). A study conducted in the city of Stockholm investigating route distances in 110 street-recruited bicycle commuters found a mean commuting distance of 6.7 and 8.0 kilometers for women and men, respectively [161]. However, even smaller buffer zones than 1,000 meters have been used in previous research on environmental correlates of cycling for transportation [132].

The original walkability index was based on four items and weighted street connectivity by 2 [34, 102]. We weighted street connectivity by 1.5 as our walkability index had three items instead of four. This difference was probably of low importance, as study 3 showed that there are no associations between street connectivity and physical activity in this sample. We did not include retail floor area ratio in this study as no such data were available in Sweden. Retail floor area ratio may add some value to a measure of walkability. A recent American study found a positive association between retail floor area ratio and time spent in moderate to vigorous physical activity and walking for transportation [162]. Participants living in areas with the highest levels of retail floor area ratio spent 6.7 more minutes per day in accelerometer-measured moderate to vigorous physical activity compared to participants living in areas with low retail floor area ratio [162]. However, other studies have also calculated the walkability index without retail floor area ratio due to lack of data [113]. The categories of land uses in the land use mix calculations were in line with previous studies [102]. Other land uses, such as public open space and sporting infrastructure, may however be of greater importance for leisure walking than walking for transportation [163].

As in most of the previous studies of the neighborhood environment and physical activity, we do not know where the participants were physically active. Furthermore, we did not assess the environments around the participants' workplaces or other locations where they might spend time. Assessing the activity space, the space where people are physically active, may increase the specificity of studies on



environmental influences on physical activity. So far there are only a few studies published using Global Positioning System (GPS) in research on the environment and physical activity, but a combination of accelerometry and GPS has been suggested for the assessment of location-specific physical activity and, indirectly, domain-specific physical activity [164]. The present technical limitations of GPS may interfere with intact data collection in large-scale studies [165], but it is a promising technique that may help improve the understanding of environmental influences on physical activity [166]. Troped et al. used accelerometers and GPS to investigate associations between neighborhood environment, work environment and location-based physical activity [136]. He did not find neighborhood characteristics (residential density, street connectivity and land use mix) to be associated with total moderate to vigorous physical activity, but they were associated with moderate to vigorous physical activity performed within a 1,000-meter buffer around the residences. In that study, about one fifth of the total time spent in moderate to vigorous physical activity was within the 1,000-meter residential buffers. Residential density around the workplace was associated with physical activity performed within 1,000 buffers around the workplace [136].

The physical activity outcomes in this thesis were based on accelerometer and self-reported physical activity using IPAQ. It is possible that misclassification occurred when assessing by accelerometry whether the physical activity recommendations were met. Accelerometers may also underestimate the intensity of some physical activities (e.g. resistance training, gardening, cycling and swimming) due to lack of mid-bodily movement and the device not being water-resistant. We used different definitions of accelerometer non-wearing time in study 4 compared to studies 1–3. These definitions had some impact on the number of valid days but the differences were small, as shown by the similar number of participants in the studies. Also, the different non-wearing time definitions had, as expected [167], only minor effects on the outcomes used in this thesis (moderate and moderate to vigorous physical activity). The IPAQ was used to provide domain-specific measures of physical activity, i.e. walking and cycling for transportation and walking for leisure. Self-reported physical activity may include recall bias [46] and over-reporting [47]. However, these biases are likely to have similar magnitudes across neighborhoods (i.e. non-differential bias).

A strength of this study is the large sample size, which makes it one of the largest studies so far using objective measures of the neighborhood environment and objectively assessed and self-reported physical activity. Also, we collected data over a year to exclude possible seasonal bias.

## Implications and future perspectives

The differences found between participants living in highly walkable compared to less walkable neighborhoods may have a significant public health impact. We found, for example, that individuals in highly walkable neighborhoods had 50 more minutes of walking for transportation per week. A recent cohort study with about 650,000 participants showed that leisure-time physical activity at a level equivalent to 75 minutes of brisk walking per week was associated with a gain in life expectancy of 1.8 years compared to no leisure-time activity [168]. That study assigned a similar MET value to brisk walking as IPAQ does for walking for transportation (3 vs. 3.3 MET) [50]. Also, a meta-analysis of 12 longitudinal studies with a total of 295,177 participants indicated a dose-response relationship between walking and coronary heart disease, where an increment of 1 hour of walking per week was associated with an approximate risk reduction of 6% [169]. From a public health perspective, this risk reduction may be significant as almost 2 million deaths are caused by coronary heart disease in Europe every year [170].

The amount of research on neighborhood environment and physical activity has increased rapidly in the past few years. Two reviews from 2012 found neighborhood walkability to be a consistent correlate of physical activity in Europe [171] and worldwide [172]. The findings in this thesis together with the previous available knowledge base support the creation of dense neighborhoods with high availability of services and facilities. Designing activity friendly environments has been presented as a key component in effective physical activity promotion at population level [59] and urban design and land use policies have the potential to increase population levels of physical activity [173]. As residential density and land use mix are associated with more physical activity and less car-dependent living, these factors seem promising for smart growth. As a majority of the present evidence is based on cross-sectional data, well-designed longitudinal studies are encouraged to further increase the understanding of environmental influences on physical activity.

The assessment of outcomes and indicators is essential to further increase our knowledge and to give evidence of the impact of policies and environmental changes aimed at creating activity-promoting environments [174]. Evidence-based measures for evaluating the economic and public health impact of environmental changes are also important tools for the implementation of research findings. One such evidence-based tool is the Health Economic Assessment Tool (HEAT), which can be used to calculate the benefit-cost ratio and savings in mortality when investments in walking and cycling infrastructure are being made [175]. The HEAT is now being used by the U.K. and Austrian governments as a tool in planning procedures.

# Conclusions

The articles included in this thesis represent the first large-scale Swedish studies investigating the associations between objectively assessed neighborhood environment characteristics and objectively assessed and self-reported physical activity. Novel contributions were the investigation of the influence of neighborhood walkability on the hour-by-hour physical activity pattern across the day, and the investigation of whether the associations between neighborhood environment characteristics and physical activity were mediated by vehicle ownership.

The results showed that the walkability index was associated with higher levels of moderate to vigorous physical activity and walking for transportation and for leisure. The results of the hour-by-hour analysis of accelerometer data showed that the influence of neighborhood walkability on moderate physical activity varies across the day, and that it was more pronounced during the time periods when a large proportion of people are likely to be exposed to their neighborhood environment. These findings provide further support for an association between neighborhood walkability and physical activity. Study 3 showed that two of three parameters of the walkability index (residential density and land use mix, but not street connectivity) were associated with physical activity. Significant proportions of these associations were mediated by vehicle ownership, i.e. individuals living in dense mixed-use neighborhoods owned fewer vehicles and were more physically active. Also, in study 4, we found that the availability of exercise facilities within the neighborhood was positively associated with moderate to vigorous physical activity and with meeting the recommended levels of physical activity. None of the associations found in this thesis were modified by individual factors, i.e. people living in dense mixed-use neighborhoods may benefit from these environments regardless of age, gender, income and vehicle ownership status.

These results add to a growing body of evidence suggesting that policy makers and city planners have the potential, by designing environments that promote physical activity, to increase the levels of physical activity in the population and thereby improve public health. Neighborhood environments have the potential to have an impact on large proportions of the population over a long time.

# Financial support

This work was supported by grants from the Swedish Council for Working Life and Social Research, FAS (2006-0386 and 2007-1754), the Swedish Research Council for Environment, Agricultural Sciences, and Spatial Planning, Formas (2006–1196) and the Swedish Research Council, VR (K2009-70X-15428-05-3; K2012-70X-15428-08-3). Funding was also granted by the Postgraduate Education Committee at the Faculty of Medicine, Lund University (2012-03-28) and ALF Region Skåne.

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# Acknowledgments

I would like to express my sincere gratitude to those who made this thesis possible.

Kristina Sundquist, my main supervisor, for your support and guidance in the world of research and for your excellence in scientific thinking and writing. Thanks for believing in me and for trusting my skills.

Daniel Arvidsson, my co-supervisor, for your wise thoughts on physical activity behavior and assessments and for our collaboration on writing scientific manuscripts. Thanks for all the laughter and memories from Toronto, Olomouc, Jakriborg and other places.

Jan Sundquist for introducing me to academic world, for your vibrant and positive personality and for your generous support throughout my PhD studies.

My co-authors Henrik Ohlsson and Sara Larson Lönn, for your statistical excellence and your ability to describe advanced statistical methods using “human” language.

Naomi Kawakami and Klas Cederin, for your work with the GIS data and for your help in preparing some of the figures for this thesis.

Klaus Gebel, for your valuable contributions as co-author of study 3.

Lars Skog, for your expertise and your work with the GIS data and for your contributions as co-author of study 1.

Stephen Gilliver, for revising some of my manuscripts regarding English spelling and grammar.

Sven-Erik Johansson, for your excellence in epidemiology and statistics, for teaching me about effect modification and for our conversations about exercise and your stories about mountain backpacking.

Maria Hagströmer, for your valuable contributions in the early stages of my PhD studies.

Emma Szulkin Östlund, Michael Nilsson and Paiman Karim, for your persistent efforts in putting thousands of questionnaires into our study dataset.

Johan Faskunger, for being an inspiring advocate for public health and for many memories from Hovsjö and Geneta.

Stella, Axel, Jojje, Kim, Marita, Anita, Anna, Emelie, Matti, Bertil and Karolina, for creating a positive and inspiring working environment.

All SNAP participants, for your contribution to research on the neighborhood environment and physical activity by wearing an accelerometer for seven days and for answering a large number of questions in our study questionnaire.

Daphne, for your valued help with posters, presentations and the cover of this thesis, for your joyful voice in the corridor, and for many good memories.

Robert, for being a good friend, for our discussions about life as a PhD student, for being an excellent statistician in my office, for your pedagogic skills in Los Guajares, for trusting my driving in Madrid, and for the best beer experience so far, in the sunset, overlooking the Mediterranean Sea and the Atlantic Ocean. My PhD studies would not have been the same without you.

Göran, Birgitta and Tine, for introducing me to working life and for many other reasons.

Kristofer, for our laid-back discussions on research and life in general, for our freaky but lovely dinners and for being a true friend.

My family, for always being there, for your endless support and for making me who I am. I love you.

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# Study 1





## Neighborhood walkability, physical activity, and walking behavior: The Swedish Neighborhood and Physical Activity (SNAP) study

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### ARTICLE INFO

#### Article history:

Available online 21 March 2011

#### Keywords:

Neighborhoods  
Physical activity  
Sweden  
Walking

### ABSTRACT

More knowledge concerning the association between physical activity and objectively measured attributes of the built environment is needed. Previous studies on the association between objectively measured neighborhood walkability, physical activity, and walking have been conducted in the U.S. or Australia and research findings are available from only one country in Europe – Belgium. The first aim of this Swedish study of 2269 adults was to examine the associations between neighborhood walkability and walking for active transportation or leisure, and moderate-to-vigorous physical activity (MVPA) and whether these hypothesized associations are moderated by age, gender, income, marital status and neighborhood-level socioeconomic status. The second aim was to determine how much of the total variance of the walking and physical activity outcomes can be attributed to neighborhood-level differences. Neighborhood walkability was objectively measured by GIS methods. An index consisting of residential density, street connectivity, and land use mix was constructed to define 32 highly and less walkable neighborhoods in Stockholm City. MVPA was measured objectively during 7 days with an accelerometer and walking was assessed using the validated International Physical Activity Questionnaire (IPAQ). Multilevel linear as well as logistic models (mixed-effects, mixed-distribution models) were used in the analysis. The statistically significant and “adjusted” results for individuals living in highly walkable neighborhoods, as compared to those living in less walkable neighborhoods, were: (1) 77% and 28% higher odds for walking for active transportation and walking for leisure, respectively, (2) 50 min more walking for active transportation/week, and (3) 3.1 min more MVPA/day. The proportion of the total variance at the neighborhood level was low and ranged between 0.0% and 2.1% in the adjusted models. The findings of the present study stress that future policies concerning the built environment must be based on context-specific evidence, particularly in the light of the fact that neighborhood redevelopments are time-consuming and expensive.

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### Introduction

Physical activity is associated with a number of positive health outcomes, such as increased longevity (Sundquist, Qvist, Sundquist, & Johansson, 2004) and decreased risks of cardiovascular disease (Sesso, Paffenbarger, & Lee, 2000; Sundquist, Johansson, Qvist, & Sundquist, 2005; Sundquist, Qvist, Johansson, & Sundquist, 2005), diabetes mellitus type 2 (Burchfiel, Sharp, Curb, Rodriguez, Hwang,

Marcus et al., 1995; Manson et al., 1992), and some types of cancer (Ratnasinghe, Modali, Seddon, & Lehman, 2010). The World Health Organization (WHO) has stated that it is important to increase people's levels of physical activity in order to decrease the global burden of these widespread diseases (WHO, 2010).

However, it is difficult to change people's behavior towards a healthier lifestyle, such as including more physical activity in their daily lives. Physical activity is influenced by a complex array of personal, behavior-specific, socioenvironmental and physical environmental factors (Giles-Corti, Timperio, Bull, & Pikora, 2005). Recently, there has been an increasing focus on studies of the association between physical activity and attributes of the built environment, such as neighborhood walkability. However, few

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studies have been based on objectively measured neighborhood walkability. Previous studies on the association between objective neighborhood walkability, physical activity, and walking were conducted in the U.S. (Sallis, Saelens, Frank, Conway, Slymen, Cain et al., 2009) or Australia (Owen et al., 2007) and research findings are available from only one country in Europe – Belgium (Van Dyck et al., 2010). The concept of neighborhood walkability includes such items as residential density (number of residential units per residential square kilometer), street connectivity (number of intersections per square kilometer), land use mix (the evenness of distribution of residential, commercial, and office developments), and the retail floor area ratio (ratio of retail building floor area to land area) (Frank, Schmid, Sallis, Chapman, & Saelens, 2005; Leslie et al., 2007).

Previous studies from the U.S. and Australia have found positive associations between neighborhood walkability and physical activity in adults. The Neighborhood Quality of Life Study (NQLS), conducted in the U.S., found positive associations between neighborhood walkability and walking for active transportation, walking for leisure, and accelerometer-measured moderate-to-vigorous physical activity (MVPA). Individuals living in highly walkable neighborhoods had 31.5 more minutes per week of walking for active transportation, 4.3 more minutes per week of walking for leisure and 5.8 more minutes per day of MVPA compared to individuals living in less walkable neighborhoods (Sallis, Saelens, Frank, Conway, Slymen, Cain et al., 2009). The Physical Activity in Localities and Community Environments (PLACE) study, conducted in Australia, found positive associations between neighborhood walkability and walking for active transportation. In addition, the relationship between neighborhood walkability and walking for active transportation was stronger for weekly frequency of walking than it was for weekly minutes spent walking (Owen et al., 2007).

There is, however, a need to examine whether the associations found in the U.S. and Australia also hold up in a European context. This is important because there are large differences in the built environment between Europe and the U.S. or Australia. In addition, Europe is characterized by a high degree of heterogeneity in the approximately 750 million people living in around 50 countries. This heterogeneity can be seen in the very different economic and political systems, the cultural mix across the European continent, and the many languages spoken.

The first European study on the association between neighborhood walkability and physical activity was conducted in 2010 in Ghent, Belgium. The Belgian Environmental Physical Activity Study (BEPAS) confirmed that the previously found associations between neighborhood walkability and physical activity in the U.S. and Australia also exist in Belgium (Van Dyck et al., 2010), although some discrepancies in the main results were found. For example, Belgian adults living in highly walkable neighborhoods had more accelerometer-measured minutes of MVPA, more walking for active transportation, and more walking for recreation than those living in less walkable neighborhoods. The authors of that study concluded, "...conducting European studies is important because walkability is likely to be a context-relative construct..." and "...other European investigators are encouraged to examine SES interactions with walkability..." Previous studies of the association between neighborhood walkability and physical activity have included measures of neighborhood-level socioeconomic status (SES), although the results of the association between neighborhood-level SES and physical activity are inconsistent (Owen, Cerin, Leslie et al., 2007; Sallis, Saelens, Frank et al., 2009; Van Dyck et al., 2010).

The first aim of this large Swedish study of adults was to examine the associations between objective neighborhood walkability and walking for active transportation, walking for leisure and accelerometer-measured MVPA and whether these hypothesized

associations are moderated by individual-level sociodemographic factors and neighborhood-level SES. The second aim was to examine random effects in a multilevel fashion, which quantifies how much of the total variance of the walking and physical activity outcomes could be due to differences at the neighborhood level. This second aim constitutes a novel contribution and has the potential to provide important information to decision-makers and city planners because a knowledge of the magnitude of the total variance at the neighborhood level could contribute to cost-effective decisions concerning developments of new and redevelopments of already existing urban neighborhoods. Another strength of the present study is that the study design is similar to the designs of the NQLS, the PLACE Study, and the BEPAS, which entails the potential to make results comparable across countries.

## Methods

### Neighborhood walkability

Data for the Swedish Neighborhood and Physical Activity (SNAP) Study were collected in the city of Stockholm in Sweden. The city of Stockholm is divided into 408 small administrative units with homogeneous types of buildings. They contain approximately 2000 individuals per unit. The geographic boundaries of the administrative units follow the road/street network and they are also well-known geographic units that could be used for future health interventions. They constituted a basis for the creation of the 32 neighborhoods included in the present study.

The selection of the 32 neighborhoods for the study was based on neighborhood walkability (high or low) and neighborhood income (high or low). This resulted in four types of neighborhoods: high walkability/high income, high walkability/low income, low walkability/high income, and low walkability/low income, i.e. 8 neighborhoods in each category. The walkability in each administrative unit in Stockholm City was established by calculating a walkability index using Geographic Information Systems (GIS). The index was partly based on a previously described walkability index (Frank et al., 2006) including four components: (1) residential density, (2) street connectivity, (3) land use mix, and (4) retail floor area ratio. In this study, the walkability index included the first three components, i.e. residential density, street connectivity, and land use mix. The retail floor area ratio was not included because data on retail building floor area are not available in Sweden. Data on residential density were delivered by Statistics Sweden, the Swedish Government-owned statistics bureau, and calculated as the ratio of the number of residential units per square kilometer (excluding water bodies). Street connectivity was based on data provided by the City Planning Administration in Stockholm and was calculated as the number of "true" intersections (three or more "legs") per square kilometer. Two or more intersections closer to each other than 10 m were counted as one using a buffering function. Highways were not included in the calculations. Bicycle and foot paths were included if they had an intersection with a street. A higher connectivity corresponds to a higher density of intersections allowing for a more direct path between destinations. Land use mix, or the entropy score, was calculated as the evenness of the distribution of the five categories (see below) included in the land use mix and indicates the degree to which a diversity of land use types occurs in a certain geographic area. The calculations of the evenness in the land use mix were based on geocoded point data. We created five categories of residential, commercial, and office developments for the calculation of land use mix: (1) Retail/service, (2) Entertainment/physical activity, (3) Institutional/health care, (4) Office/workplace, and (5) Dwellings. The Herfindahl-Hirschman Index (HHI index) was used to assess the level of land

use mix. The higher the value of the HHI Index, the lower the level of land use mix (Forsyth, 2007).

The data for the first four categories in the land use mix were delivered by Teledress, which is a private company that was established when parts of the Swedish government-owned Telecom were privatized. The data from Teledress included businesses and services that have a registered telephone number and/or those that had provided information about their existence to Teledress. Inclusion in their database is free of charge and Teledress also purchases additional information about businesses from Statistics Sweden.

Previous studies have mostly weighted connectivity  $\times 2$  (Frank, Sallis, Conway et al., 2006). We chose, however, to use the weight 1.5 instead because our walkability index was based on three items instead of four. The following formula was used:

$$\text{Walkability index} = Z_{\text{Residential density}} + 1.5 \times Z_{\text{Street connectivity}} + Z_{\text{Land use mix}}$$

The walkability index for each neighborhood was calculated as the sum of the z-scores for the three components included in the index, i.e. residential density, street connectivity, and land use mix. Next, the walkability index scores were divided into deciles. Administrative areas within the first, second, third, and fourth deciles were considered less walkable areas and those within the seventh, eighth, ninth, and tenth deciles were considered highly walkable areas. This approach is in line with previous research (Owen, Cerin, Leslie et al., 2007; Sallis, Saelens, Frank et al., 2009; Van Dyck et al., 2010).

#### Neighborhood-level socioeconomic status

Neighborhood income was included in the selection process in order to account for possible neighborhood differences in physical activity that could be explained by the socioeconomic structure of the neighborhood, which is also in accord with previous studies (Owen, Cerin, Leslie et al., 2007; Sallis, Saelens, Frank et al., 2009; Van Dyck et al., 2010). Data on neighborhood income was delivered by Statistics Sweden. Neighborhood income was based on the disposable median family income, which also took into account the number and age of the family members. For example, children and adolescents were given lower consumption weights than adults. The median neighborhood family income for each administrative area was calculated and the administrative areas were divided into deciles. The second, third, and fourth deciles constituted low neighborhood income and the seventh, eighth, and ninth deciles represented high neighborhood income.

#### Neighborhood selection

One hundred and twenty-seven of the 408 small administrative areas in Stockholm City were assigned to one of the following four categories: high walkability/high income, high walkability/low income, low walkability/high income, and low walkability/low income. The size of these 127 administrative areas ranged between 0.03 and 2.73 square kilometers. We selected the administrative areas that were as close as possible in size to the area 0.65 square kilometers. This area corresponds to the size of the neighborhoods created in the Twin Cities Walking Study (Forsyth, 2007). We partly used a clustering process to create the study neighborhoods in the category high walkability/high income because the administrative areas in that category were rather small. Practically all administrative areas in the category high walkability/high income were, however, located in the inner city, where the administrative areas

are well connected to each other. Clustering of administrative geographic units to create study neighborhoods has also been used in previous research (Frank, Sallis, Conway et al., 2006; Leslie, Coffee, Frank et al., 2007). This procedure yielded 8 study neighborhoods in each category, i.e., in total, 32 neighborhoods with at least 500 households.

#### Study sample

Our goal was to assess 75 individuals from each neighborhood, i.e., in total, 2400 participants, aged 20–65. The power calculations were partly based on previous research (Owen, Cerin, Leslie et al., 2007) and on an assumed mean difference of 5 min/day of MVPA between individuals from highly walkable neighborhoods and those from less walkable ones, an assumed standard deviation of 24, and a response rate of 40%. In order to reject the null hypothesis with a power (probability) of 0.8 and a type I error probability of 0.01, we needed to study 585 individuals in each of the two types of neighborhoods (high walkability versus low walkability), i.e. 1170 in total. We chose, however, an approach of oversampling because our assumptions were based on information from very few previous studies. The Stockholm Office of Research and Statistics performed the simple random sampling of 250 individuals from each neighborhood (a total of 8000 individuals) without including immigrants who had arrived in Sweden later than 2003 (i.e. five years before the start of the study) as our questionnaire was provided only in Swedish. This is in accord with previous studies from the U.S. and Australia, where only English-speaking individuals have been included. Of the 8000 individuals, 6089 had a listed landline or mobile phone number and were included in the recruitment procedure. An information letter was sent to their home address one week before a telemarketing company (Markör AB, Örebro, Sweden) contacted the individuals by phone. Inclusion criteria at this stage were the following: (1) being able to read and write Swedish, (2) having lived in the neighborhood for at least three months, and (3) having no serious impaired ability to walk. Of the 4747 individuals who were reached, 4369 met the inclusion criteria and 3226 agreed to participate in the study. After exclusion of participants due to dropouts, lost accelerometers, technical errors in the accelerometers, and incomplete wearing time of the accelerometer (see definition below), the final study population for analyses consisted of 2269 individuals, which gave a response rate of 52% (2269/4369).

The telemarketing company (see above) had previous experience in recruiting study participants for research purposes, and one of the co-authors of this study (UE) provided detailed written and oral information to all personnel involved in the recruitment process. Individuals from all of the 32 neighborhoods were recruited between November 2008 and November 2009. Every week a list of recruited individuals was sent to us from the company. Then, an accelerometer, a logbook, a questionnaire, and a prepaid return envelope were sent to the individuals. No data were collected during the Christmas and summer vacation periods, which, in Sweden, correspond to weeks 50 to 2 and weeks 25–33, respectively.

#### Objective measures of physical activity

The uniaxial accelerometer Actigraph GT1M (ActiGraph, Pensacola, Florida, USA) was used to objectively assess the individuals' level of physical activity. It gives a valid and reliable measure of physical activity in adults under free-living conditions (Abel et al., 2008).

The individuals were asked to wear the accelerometer on the hip or the lower back during all waking hours for seven consecutive



days, except when engaging in water activities. The ActiGraph was set to add up physical activity data in 60-s epochs, which represents the predominantly used period to integrate and analyze accelerometer data in adults (Owen et al., 2007; Sallis, Saelens, Frank, Conway, Slymen, Cain et al., 2009; Trost, McIver, & Pate, 2005; Van Dyck et al., 2010). Non-wearing time was defined as  $\geq 60$  consecutive minutes of no registered physical activity (zero counts), which is in line with previous research (Van Dyck et al., 2010). Time spent on MVPA was identified using Freedson's cut points for accelerometer data, which for MVPA amount to  $\geq 1952$  counts per minute (Freedson, Melanson, & Sirard, 1998; John, Tyo, & Bassett, 2010). Ten-minute bouts of MVPA was defined as at least 10 consecutive minutes ( $\geq 1952$  counts per minute) allowing for 1–2-min drops below this threshold. The mean daily time accumulated in 10-min bouts of MVPA is shown in Table 1. A variance analysis of our data for MVPA was performed to determine the required number of days for inclusion (Matthews, Ainsworth, Thompson, & Bassett, 2002). The final inclusion criteria for valid days were set at  $\geq 10$  h of wearing time per day for  $\geq 6$  days, including at least one weekend day. Time spent on MVPA was calculated as the mean of all valid days. Around 3.2% of the accelerometers were lost in the mailing process.

#### Self-reported measures of physical activity

Walking for active transportation and walking for leisure were assessed using questions from the long version of the International Physical Activity Questionnaire (IPAQ). The IPAQ is a self-administered 7-day recall physical activity questionnaire that has been tested for validity and reliability (Meeus, Van Eupen, Willems, Kos, & Nijis, 2010; Papathanasiou et al., 2009) and used in population-based studies (Sodergren, Sundquist, Johansson, Sundquist, & Hagstromer, 2010).

The two questions used to assess walking for active transportation were the following: (1) "On how many days during the last 7 days did you walk for at least 10 min at a time to go from place

to place?" and (2) "How much time did you usually spend on one of those days walking from place to place?" Walking for leisure was assessed with the questions: (1) "Not counting any walking you have already mentioned, on how many days during the last 7 days did you walk for at least 10 min at a time during your leisure time?" and (2) "How much time did you usually spend on one of those days walking during your leisure time?" Data were processed in accordance with the official guidelines for IPAQ (<http://www.ipaq.ki.se/scoring.htm>).

#### Individual-level sociodemographic variables

Age, gender, marital status, and family income were based on self-reports. Age was categorized into four groups: 20–30 years (reference), 31–40 years, 41–50 years, and 51–66 years. Marital status was categorized into two groups married/cohabiting with a partner and single (reference). Family income was categorized into three groups: low ( $<300,000$  SEK/year, reference), middle (300,000–800,000 SEK/year), and high ( $>800,000$  SEK/year).

#### Statistical analysis

The association between neighborhood walkability and individual MVPA was analyzed using multilevel linear regression models (Goldstein, 2003), with individuals at the first level and neighborhoods at the second level. We developed two consecutive models. Model A (crude) only included neighborhood walkability. Model B also included the individual covariates age, gender, marital status, and family income, as well as neighborhood-level income, which is in line with previous studies on the association between neighborhood walkability and physical activity outcomes (Owen, Cerin, Leslie et al., 2007; Sallis, Saelens, Frank et al., 2009; Van Dyck et al., 2010). This allowed us to investigate whether these characteristics moderated the association between neighborhood walkability and individual MVPA. The model was estimated by MLwiN using non-parametric bootstrap estimates (1000 replicates).

**Table 1**  
Descriptive statistics on the 2269 individuals included in the study.

	All		Type of neighborhood							
			High Walkability High Income		High Walkability Low Income		Low Walkability High Income		Low Walkability Low Income	
	Median	St dev	Median	St dev	Median	St dev	Median	St dev	Median	St dev
Moderate-to-vigorous physical activity (min/day)	41	23	47	23	39	25	39	23	40	23
Time in 10-minute bouts of moderate-to-vigorous physical activity (min/day)	14	18	17	18	12	18	14	18	13	19
Walking for active transportation (min/week)	125	275	180	287	150	300	100	254	100	267
Walking for leisure (min/week)	60	222	90	225	68	248	60	216	60	208
Gender	n	%	n	%	n	%	n	%	n	%
• Male	1014	45%	201	42%	162	39%	378	48%	273	47%
• Female	1255	55%	278	58%	252	61%	411	52%	314	53%
Age (years)										
• 20–30	251	11%	82	17%	68	16%	42	5%	59	10%
• 31–40	461	20%	115	24%	88	21%	139	18%	119	20%
• 41–50	645	28%	104	22%	111	27%	242	31%	188	32%
• 51–66	912	40%	178	37%	147	36%	366	46%	221	38%
Family income										
• Low	766	34%	205	43%	220	53%	152	19%	189	32%
• Middle	959	42%	179	37%	173	42%	325	41%	282	48%
• High	544	24%	95	20%	21	5%	312	40%	116	20%
Marital status										
• Single	590	26%	186	39%	154	37%	106	13%	144	25%
• Married/Cohabiting	1679	74%	293	61%	260	63%	683	87%	443	75%

and five sets) in order to test for the possible effects of non-normal distributions and the accuracy of inferences about the parameter values (Rasbash, Steele, & Browne, 2003). Beta coefficients and 95% confidence intervals are presented as measures of association. The beta coefficients represent minutes/day.

Individual *Walking for active transportation* and individual *Walking for leisure* were analyzed using a mixed-effects, mixed-distribution model due to the excessive number of zeros in the outcome variables (Tooze, Grunwald, & Jones, 2002). In total, 431 individuals (20%) reported zero regarding *Walking for active transportation* while 657 (30%) reported zero regarding *Walking for leisure*. The model is made up of two parts: the first is a logistic part for occurrence of the outcome, which estimates the probability of a positive value versus zero. The second is a linear part that models the intensity (i.e. amount in minutes/week) of the response, given that the response is greater than zero. The second (linear) part of the model did not include those individuals who reported zeros regarding *Walking for active transportation* or *Walking for leisure*. In the second part of the mixed-effects, mixed-distribution model we assumed a normal distribution. In order to justify this assumption, we performed an ancillary analysis using bootstrap estimates in the linear part. This yielded almost identical results as in the second part in the mixed-effects, mixed-distribution model, supporting our assumption of a normal distribution. The mixed-effects, mixed-distribution model allowed us to interpret the occurrence of the outcome presented as an odds ratio with a 95% confidence interval, as well as the amount of the response presented as a beta coefficient (minutes/week) with a 95% confidence interval. A random effect for the occurrence and a random effect for the amount were included in the model to account for clustering of individuals within neighborhoods. We developed two consecutive models for each outcome. Model A included *Neighborhood walkability* and Model B also included the individual covariates *age*, *gender*, *income*, and *marital status*, as well as *neighborhood-level income*. This allowed us to investigate whether inclusion of these characteristics attenuated the association between *Neighborhood walkability* and *Walking for active transportation* or *Walking for leisure*. The model was estimated using SAS v. 9.2 (SAS Institute, Cary, NC, USA), with the MIXCORR macro developed by Tooze et al. (Tooze et al., 2002).

To facilitate the interpretation of the variance at the neighborhood level, we calculated the intraclass correlation (ICC) (Snijders & Bosker, 1999). A large ICC would indicate that differences between the neighborhoods account for a considerable part of the individual differences in our studied outcomes. On the other hand, an ICC close to zero would indicate that the neighborhoods exert only a small influence on the total variance between individuals (Snijders & Bosker, 1999). The ICC is the percentage of the total variance of the individual outcome attributable to the neighborhood level.

ICC was calculated according to the following formula:

$$V_2 / (V_1 + V_2)$$

where  $V_1$  = variance between individuals (first-level variance) and  $V_2$  = variance between neighborhoods (second-level variance). However, in the logistic part of the mixed-effects, mixed-distribution model, the neighborhood level variance is measured on a different scale than the individual level variance and hence they are not comparable. We used the latent variable method to convert the individual level variance from the probability scale to the logistic scale (Goldstein, Browne, & Rasbash, 2002). This method assumes that the unobserved individual variable follows a logistic distribution with the individual variance equal to 3.29 ( $\pi^2/3$ ). The ICC is then calculated according to Eq. (1).

A non-response analysis of 205 persons (interviewed by phone) revealed that there were slightly more women among the respondents than among the non-respondents. Respondents were

also slightly older than non-respondents. No statistical difference was found in individual SES between respondents and non-respondents. The study was approved by the Ethics Committee of the Karolinska Institute, Stockholm.

## Results

### Descriptive statistics on the 2269 individuals

Table 1 shows that the median objectively measured MVPA of SNAP participants amounted to 41 min/day (SD = 23 min). The participants reported a median of 125 min/week of walking for active transportation (SD = 275 min) and a median of 60 min/week of walking for leisure (SD = 222). The proportion of female participants was 55% and the proportion of married/cohabiting participants was 74% of the entire study sample. Forty percent were over 50 years old and 42% were found among those with middle income. Differences in the income distribution between individuals living in the four types of neighborhoods also appeared which justifies the inclusion of, for example, individual income as a covariate.

### Models

Interaction tests included, for example, testing for possible neighborhood-level SES interactions, but none were found. Table 2 shows the multilevel linear regression analysis for models including MVPA as the outcome variable. Model A shows that individuals living in highly walkable neighborhoods had 3.4 more minutes of MVPA/day than individuals living in less walkable neighborhoods, and this difference was statistically significant. After including neighborhood-level SES and the individual-level variables, the difference between highly walkable neighborhoods and less walkable ones remained significant and decreased only slightly to 3.1 min of MVPA/day. The calculation of ICC showed that 0.9% of the total variance was at the neighborhood level (both models A and B).

Table 3 shows the mixed-effects, mixed-distribution model for occurrence (logistic) and amount in minutes/week (linear),

**Table 2**

Multilevel linear regression for predictors of moderate-to-vigorous physical activity. Numbers represent  $\beta$ -coefficients (with 95% confidence intervals) in minutes/day.  $n = 2269$ .

	Model A <sup>a</sup>	Model B <sup>b</sup>
<i>Walkability (High vs. Low)</i>	3.4 (0.8–5.8)	3.1 (0.4–5.6)
<i>Neighborhood SES (High vs. Low)</i>		1.8 (–0.7–4.4)
<i>Male vs. Female</i>		3.2 (1.2–5.1)
<i>Age (years)</i>		
• 20–30		Reference
• 31–40		–5.1 (–8.5 to –1.6)
• 41–50		–5.2 (–8.4 to –1.9)
• 51–66		–6.7 (–10.0 to –3.5)
<i>Family income</i>		
• Low		Reference
• Middle		0.9 (–1.1–2.9)
• High		3.4 (0.6–6.3)
<i>Married/cohabiting vs. Single</i>		3.3 (1.1–5.8)
<b>Random effects</b>		
Variance individual	537 (506–566)	529 (498–556)
Variance neighborhood	4.7 (0.0–8.6)	4.7 (0.0–8.7)
Intraclass correlation	0.9%	0.9%

<sup>a</sup> Model A only includes walkability.

<sup>b</sup> Model B also includes all other variables.

**Table 3**Mixed-effects, mixed-distribution models for predictors of Walking for active transportation. *n* = 2269.

	Model A <sup>c</sup>	Model B <sup>d</sup>
Occurrence (Logistic) <sup>a</sup>		
Walkability (High vs. Low)	1.92 (1.40–2.63)	1.77 (1.30–2.41)
Neighborhood SES (High vs. Low)		1.30 (0.96–1.76)
Male vs. Female		0.67 (0.53–0.83)
Age (years)		
• 20–30		1 (Reference)
• 31–40		0.95 (0.60–1.50)
• 41–50		0.72 (0.47–1.11)
• 51–66		0.74 (0.49–1.12)
Family income		
• Low		1 (Reference)
• Middle		0.83 (0.62–1.09)
• High		0.97 (0.69–1.37)
Married/cohabiting vs. Single		0.89 (0.65–1.20)
Random effects		
Variance neighborhood	0.09 (0.00–0.18)	0.07 (0.00–0.15)
Intraclass correlation	2.6%	2.1%
Amount (Linear) <sup>b</sup>		
Walkability (High vs. Low)	57 (26–88)	50 (20–81)
Neighborhood SES (High vs. Low)		–5 (–35–25)
Male vs. Female		–18 (–45–8)
Age (years)		
• 20–30		Reference
• 31–40		–14 (–62–35)
• 41–50		17 (–29–63)
• 51–66		52 (8–96)
Family income		
• Low		Reference
• Middle		–36 (–69 to –3)
• High		–84 (–124 to –44)
Married/cohabiting vs. Single		39 (4–74)
Random effects		
Variance individual	78 573 (73 278–83 867)	76 567 (71 436–81 697)
Variance neighborhood	507 (0–1499)	297 (0–1198)
Intraclass correlation	0.6%	0.4%

<sup>a</sup> Numbers in the fixed part of the regression are odds ratios (95% confidence intervals).<sup>b</sup> Numbers in the linear part of the regression are  $\beta$ -coefficients (95% confidence intervals) in minutes per week.<sup>c</sup> Model A only includes walkability.<sup>d</sup> Model B also includes all other variables.

including walking for active transportation as the outcome variable. The logistic part shows that the odds for walking for active transportation were 92% higher (reference = 1; CI = 1.40–2.63) among individuals who lived in highly walkable neighborhoods than among those living in less walkable neighborhoods (Model A). After including neighborhood-level SES and the individual-level variables (Model B), the odds decreased to 1.77 (i.e. 77% higher odds) but remained significant (CI = 1.30–2.41). The ICC was 2.1% in Model B in the logistic part of the analysis.

Model A in the linear part of the analysis shows that individuals who lived in highly walkable neighborhoods had 57 more minutes/week of walking for active transportation than individuals who lived in less walkable neighborhoods. In the adjusted model (Model B), the difference between highly and less walkable neighborhoods in minutes/week decreased to 50 min but remained significant. The ICC was 0.4% in Model B in the linear part of the analysis.

Table 4 shows the results of the analysis of the association between neighborhood walkability and walking for leisure, using

**Table 4**Mixed-effects, mixed-distribution models for predictors of Walking for leisure. *n* = 2269.

	Model A <sup>c</sup>	Model B <sup>d</sup>
Occurrence (Logistic) <sup>a</sup>		
Walkability (High vs. Low)	1.22 (1.01–1.48)	1.28 (1.04–1.56)
Neighborhood SES (High vs. Low)		1.22 (0.96–1.76)
Male vs. Female		0.67 (0.56–0.81)
Age (years)		
• 20–30		1 (Reference)
• 31–40		0.92 (0.65–1.30)
• 41–50		1.11 (0.80–1.54)
• 51–66		1.71 (1.24–2.36)
Family income		
• Low		1 (Reference)
• Middle		1.14 (0.90–1.44)
• High		1.02 (0.77–1.35)
Married/cohabiting vs. Single		1.00 (0.78–1.29)
Random effects		
Variance neighborhood	0.00 (0.00–0.00)	0.00 (0.00–0.00)
Intraclass correlation	0.0%	0.0%
Amount (Linear) <sup>b</sup>		
Walkability (High vs. Low)	18 (–8–45)	18 (–9–43)
Neighborhood SES (High vs. Low)		–3 (–28–22)
Male vs. Female		–29 (–54 to –5)
Age (years)		
• 20–30		Reference
• 31–40		–7 (–53–40)
• 41–50		33 (–11–77)
• 51–66		63 (21–104)
Income		
• Low		Reference
• Middle		–40 (–10 to –71)
• High		–58 (–22 to –95)
Married vs. Single		33 (1–64)
Random effects		
Variance individual	56 171 (52 118–60 225)	54 681 (50 743–58 618)
Variance neighborhood	352 (0–922)	44 (0–612)
Intraclass correlation	0.4%	0.1%

<sup>a</sup> Numbers in the fixed part of the regression are odds ratios (95% confidence intervals).<sup>b</sup> Numbers in the linear part of the regression are  $\beta$ -coefficients (95% confidence intervals) in minutes per week.<sup>c</sup> Model A only includes walkability.<sup>d</sup> Model B also includes all other variables.

the mixed-effects, mixed-distribution model for occurrence (logistic) and amount in minutes/week (linear). The logistic part shows that the odds for walking for leisure were 22% higher (reference = 1; CI = 1.01–1.48) among individuals who lived in highly walkable neighborhoods than among those living in less walkable neighborhoods (Model A). After including neighborhood-level SES and the individual-level variables (Model B), the odds remained significant and changed only slightly from 1.22 to 1.28 (CI = 1.04–1.56). The ICC in the logistic part was 0%.

Model A and Model B in the linear part of the analysis show that individuals who lived in highly walkable neighborhoods had 18 more minutes/week of walking for leisure than individuals who lived in less walkable neighborhoods, but this difference was non-significant. The ICC was 0.1% in Model B in the linear part of the analysis.

## Discussion

The main findings of the present study of the association between objectively measured neighborhood walkability, physical

activity, and walking behavior, conducted in a Swedish context, are mainly in agreement with previous research from the U.S., Australia, and Belgium. In the adjusted models, we found the following statistically significant results among individuals living in highly walkable neighborhoods, compared to those living in less walkable neighborhoods: (1) 77% and 28% higher odds for walking for active transportation and walking for leisure, respectively, (2) 50 min more walking for active transportation/week, and (3) 3.1 min more MVPA/day. No significant differences in minutes/week of walking for leisure were found between highly walkable and less walkable neighborhoods. There were no significant interactions. The values of the ICC calculations ranged between 0.0% and 2.1% in the adjusted models, indicating that the proportion of the total variance at the neighborhood level is low.

So far, objective results from only three countries have been presented and therefore more research from different parts of the world on the possible influence of the built environment on physical activity is needed. The present study was therefore conducted to allow for a more comprehensive comparison of findings between countries. The finding of more MVPA in highly walkable neighborhoods was in agreement with the NQLS from the U.S. (Sallis, Saelens, Frank et al., 2009) and the BEPAS from Belgium (Van Dyck, Cardon, Deforche, Sallis, Owen, De Bourdeaudhuij, 2010). The finding of the association between neighborhood walkability and walking behavior was partly in agreement with previous studies. The NQLS (Sallis, Saelens, Frank et al., 2009) and the BEPAS (Van Dyck, Cardon, Deforche et al., 2010) found positive associations between neighborhood walkability and walking for active transportation, as well as walking for leisure, whereas the PLACE Study from Australia found an association with walking for active transportation, but not with walking for leisure (Owen, Cerin, Leslie et al., 2007). Our study found that neighborhood walkability was associated with walking for active transportation (yes vs. no) and time spent on walking for active transportation as well as walking for leisure (yes vs. no), but not with time spent on walking for leisure. Although our findings were mainly in agreement with previous studies, there were also differences. These differences could be explained by differences in the built environment as well as social and cultural differences between countries.

The similarities between countries are important to note, but the observed differences between countries are also important to keep in mind because every country's policy agenda should be based on available evidence from that country. For example, only Australia had a significant interaction between SES and neighborhood walkability (Owen, Cerin, Leslie et al., 2007), i.e. high-SES Australian adults may benefit more from living in highly walkable neighborhoods than low-SES adults. In contrast, residents living in low-SES neighborhoods in the U.S., Belgium, and Sweden seem to benefit to the same extent from a highly walkable environment as residents living in high-SES neighborhoods. One possible explanation for the absence of significant SES interactions in Sweden is the relatively low level of income inequality in the country as a whole. Future studies could examine possible interactions between a broad array of individual sociodemographic characteristics and neighborhood walkability.

The present study has several strengths. First, the assessment of neighborhood walkability was based on objective GIS-based measurements (Leslie, Coffee, Frank et al., 2007) rather than on perceived subjective measurements (Panter & Jones, 2008). This is a key strength because it is likely that the participants' perception of their neighborhood will vary in ways that affect their self-reported behavior. In addition, previous research has demonstrated correlates of non-concordance between perceived and objective measures of walkability (Gebel, Bauman, & Owen, 2009). It is important to note that the strength of using objective GIS-based

measurements depends on the accuracy of the data. However, the data sources used in the present study were the best available to us and largely similar to the data sources used in previous studies from U.S., Australia, and Belgium. Second, the use of small geographic units is another strength, because small neighborhood units are more likely to reflect how the residents themselves define their neighborhoods (Bond Huie, 2001; Smith, Gidlow, Davey, & Foster, 2010). Third, the study sample in the SNAP study was randomly selected and included 2269 persons, which puts it in the position of one of the largest studies to date. Finally, the assessments of physical activity were based on both objective and self-reported measures.

There are also limitations. First, residual confounding is possible because SES cannot be measured fully and precisely. Second, it is possible that a response bias exists if those who are more physically active are also more prone to wear an accelerometer and fill out a questionnaire. However, it is unlikely that this bias would have a different magnitude across neighborhoods. Moreover, there were no differences in SES between respondents and non-respondents. Third, the association between neighborhood walkability, physical activity, and walking behavior could be an artifact, if neighborhood walkability simply reflects other unknown neighborhood factors, or if choice of more walkable residential areas depends on walking behavior and preferences for walking. Moreover, it is a common approach in neighborhood research to adjust neighborhood-level characteristics using individual-level characteristics. However, it is possible that a certain proportion of the association between neighborhood-level characteristics and the studied outcome factors comes from the confounding effect of systematically neglected factors, including the unknown influences between individual-level and neighborhood-level factors. However, the consistent findings from the U.S., Australia, Belgium, and now Sweden indicate the existence of an association between neighborhood walkability, physical activity, and walking behavior, particularly for walking for active transportation. Fourth, it is possible that the recruitment process suffered from selection bias since some low-SES adults might not have access to a telephone. However, not having access to a telephone is unusual in Sweden. Fifth, the use of predefined administrative areas could have constituted a limitation because predefined areas do not necessarily reflect a neighborhood in social and cultural terms. Finally, the statistically significant findings of the present study do not necessarily mean that they are clinically meaningful.

## Conclusions

The findings of this study show a positive association between objective neighborhood walkability and physical activity outcomes in a Swedish context. Although these average effects were significant, the low values in the calculations of ICC indicate that the variance at the neighborhood level is low; the largest proportion of the total variance was at the individual level. Moreover, the objective assessment of the individuals' level of physical activity showed a relatively slight difference of 3.1 min of MVPA/day between individuals living in highly walkable and less walkable neighborhoods. Therefore, possible policy implications of the present study remain to be examined, preferably in interdisciplinary collaborations between health researchers, city planners, economists, and decision-makers as physical redevelopments of already existing urban neighborhoods are time-consuming and expensive. Governmental initiatives should therefore be based on context-specific empirical evidence, including multidimensional correlates of physical activity.

## Acknowledgments

This work was supported by grants to Dr Kristina Sundquist from the Swedish Council for Working Life and Social Research, FAS (2006-0386), and The Swedish Research Council for Environment, Agricultural Sciences, and Spatial Planning, Formas (2006-1196). Though listed as first and second authors, Sundquist and Eriksson contributed equally to this article.

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## Study 2



# Neighborhood walkability, income and hour by hour physical activity patterns

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Medicine & Science in Sports & Exercise (Accepted for publication 15 October 2012)

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This study was supported by grants to Dr Kristina Sundquist from the Swedish Council for Working Life and Social Research (FAS, 2006-0386) and The Swedish Research Council for Environment, Agricultural Sciences, and Spatial Planning (Formas, 2006-1196).



## **Abstract**

**Purpose:** To investigate both the mean daily physical activity and the hour by hour physical activity pattern across the day using accelerometry, and how they are associated with neighborhood walkability and individual income.

**Methods:** Moderate physical activity (MPA) was assessed by accelerometry in 2,252 adults in the City of Stockholm, Sweden. Neighborhood walkability (residential density, street connectivity, land use mix) was objectively assessed within 1,000m network buffers around the participants' residence and individual income was self-reported.

**Results:** Living in a high walkability neighborhood was associated with more mean daily MPA compared with living in a low walkability neighborhood on weekdays and weekend days. Hour by hour analyses showed that this association appeared mainly in the afternoon/early evening during weekdays, while it appeared across the middle of the day during weekend days. Individual income was associated with mean daily MPA on weekend days. On weekdays, the hour by hour analyses showed that high income was associated with more MPA around noon and in late afternoon/early evening, while low income was associated with more MPA at the hours before noon and in the early afternoon. During the weekend, high income was more consistently associated with higher MPA.

**Conclusions:** Hour by hour accelerometry physical activity patterns provides a more comprehensive picture of the associations between neighborhood walkability and individual income and physical activity and the variability of these associations across the day.

**Key words:** Accelerometer, Geographic Information Systems, road network buffers, moderate physical activity.

## Introduction

Neighborhood walkability encompasses attributes of the built environment that promotes physical activity, such as active transportation (23). Several research groups have shown that neighborhood walkability, defined by Geographic Information Systems (GIS), is positively associated with time spent in moderate and vigorous physical activity (24, 27, 28). However, the physical activity outcomes in previous studies only refer to the average daily value. The influence of neighborhood walkability on physical activity may vary across the day, and the use of the average daily value will therefore not reflect this potential variability. One approach to overcome this may be to use the time-stamped data collected by objective methods to investigate the hour by hour physical activity pattern.

Since the start of this millennium there has been a tremendous increase in the number of studies investigating physical activity using objective methods (e.g. pedometers, accelerometers, heart rate monitors). The accelerometers are commonly used and evaluated objective methods and register the intensity of ambulatory physical activity. Calibration studies have been performed to relate the accelerometer primary output (counts) to the criterion measure of physical activity intensity derived from indirect calorimetry, i.e. metabolic equivalents (METs), which is the quotient of total energy expenditure during a specific activity and the resting energy expenditure (3). Accelerometer cut-points for moderate and vigorous physical activity intensity have been defined from MET-values and have been used to assess time spent in moderate and vigorous physical activity and compliance with physical activity recommendations. Physical activity outcome measures from accelerometers used in research have almost exclusively been average daily values. However, recent hardware and software developments have rendered it possible to collect and store data at a higher frequency and to more easily display and explore daily physical activity patterns.

In neighborhood walkability studies, it has been shown that individual socioeconomic status (SES) is associated with accelerometer outcomes (27, 28). However, there may be different patterns of physical activity across the day depending on individual SES. While low individual SES may be associated with more occupational physical activity (due to more manual work) and less leisure physical activity, high individual SES may be associated with less occupational physical activity and more leisure physical activity. This has been shown in research on domain-specific physical activity using self-report methods, i.e., questionnaires (4). Also, more similar amounts of physical activity between SES levels have been

shown when studying total physical activity from accelerometry compared to when studying physical activity from self-report capturing only leisure-time (11). Investigating hour by hour physical activity patterns with accelerometers may provide a more detailed description of the influence of SES on physical activity compared to using daily average values only.

The aim of the present study was to investigate both the mean daily physical activity and the hour by hour physical activity using accelerometry, and how they are associated with neighborhood walkability and individual SES (i.e., income). To our knowledge this has not been done previously.

## **Methods**

### **Study design**

The present study used data collected in the Swedish Neighborhood And Physical activity (SNAP) study, a cross-sectional study in the City of Stockholm, Sweden (2, 27). Data were collected on attributes of the built environment, physical activity, and sociodemographic characteristics in adults. The City of Stockholm is divided into 408 administrative areas, each containing about 2,000 individuals. One hundred and twenty seven of these areas were assigned to one of four categories based on their median disposable family income (low/high) assessed from data delivered from Statistics Sweden and walkability index (low/high) assessed by GIS. A clustering procedure was performed among the high walkability index/high income areas as they were rather small, resulting in a final number of 32 neighborhoods (eight in each of the four categories) that was used for sampling of participants (Figure 1). In the present study, neighborhood walkability was recalculated within a polygon-based network buffer using the participant's geocoded residential address and accelerometry data was explored as daily means and hour by hour.

### **Participants**

Two hundred and fifty individuals were randomly sampled from each of the 32 neighborhoods. 6,089 had a listed phone number and were included in the recruitment procedure. An information letter was sent to each home address, and a week later, a telemarketing company (Markör AB, Örebro, Sweden) contacted each individual by phone. Data were collected between November 2008 and November 2009. The inclusion criteria for participation were as follows: 1) being able to read and write Swedish, 2) living in the neighborhood for at least 3 months, and 3) having no serious

difficulty in walking. Of the 4,747 individuals who were successfully contacted, 4,369 met the inclusion criteria, and 3,226 agreed to participate in the study (3,226/4,369; 74%). A non-response analysis of 205 randomly selected non-participants (interviewed by phone) revealed that there were slightly more women and older individuals among participants compared to non-participants. There were no differences in socioeconomic characteristics between these groups. An accelerometer, a logbook, a questionnaire, and a prepaid return envelope were sent to the participants. No data were collected during the Christmas and summer vacation periods. We were able to review accelerometer-files from 2,669 participants. Unavailable files were due to discontinued participation, lost accelerometer, malfunction in the initiation of the accelerometer and error when downloading data. Those with at least one weekday and one weekend day were included for further analyses, which resulted in physical activity data from 2,411 participants (2,411/4,369; 55%). The final number of participants with complete data on all variables included in the present study was 2,252, which corresponds to a 51% response rate (2,252/4,369). The SNAP study was approved by the Ethics Committee of Karolinska Institutet, Stockholm, Sweden. Written informed consent was obtained from all participants.

### **Neighborhood walkability**

Neighborhood walkability was objectively assessed by GIS and calculated as an index comprised of three parameters: residential density, street connectivity and land use mix. Walkability parameters were assessed within a polygon-based network buffer which was created by following the road network including bicycle paths and footpaths in all possible directions for 1,000 meters from the residence and then drawing a line to connect the endpoints. Buffers of 1,000 meters have often been used in previous research as studies have found that it is a distance many people are willing to walk in their daily life (15). Data on residential density were delivered by Statistics Sweden, the Swedish Government-owned statistics bureau, and calculated as the number of residential units per square kilometer (excluding water bodies). Street connectivity was based on data provided by the City Planning Administration in Stockholm and was calculated as the number of “true” intersections (three or more “legs”) per square kilometer. Two or more intersections closer to each other than 10m were counted as one using a buffering function. Highways were not included in the calculations. Cycle paths and footpaths were included if they had an intersection with a street. Land use mix was assessed as the evenness of the distribution of the five categories of residential, commercial, and office developments (see below) and indicates the variety of land use types in a certain geographic area. The five categories were: (1)

Retail/ service, (2) Entertainment/physical activity, (3) Institutional/health care, (4) Office/workplace, and (5) Dwellings. The Herfindahl-Hirschman Index (HHI) was used as a numeric measure of the level of land use mix and is calculated by summing the squared proportions of each land use category ( $HHI = p_1^2 + p_2^2 \dots + p_5^2$ ). A high HHI indicates a low level of land use mix. The calculations of the evenness in the land use mix were based on geocoded point data. The data for the first four categories in the land use mix were delivered by Teleaddress, which is a private company that was established when parts of the Swedish government-owned Telecom were privatized. Data for the last category was delivered by the City Planning Administration in Stockholm. Neighborhood walkability index was calculated by the sum of the standard scores (z-scores) of residential density, street connectivity and land use mix (z-score of the reversed value of land use mix, as high values indicate low land use mix) using an adjusted version of the formula in the Neighborhood Quality of Life Study (8, 24):

$$\text{Walkability index} = Z_{\text{Residential density}} + 1.5 * Z_{\text{Street connectivity}} + Z_{\text{Land use mix}}$$

Retail floor area ratio has previously been included in the walkability index and street connectivity has been weighted by 2 (8, 24). In the present study, retail floor area ratio was not included as this data is not available in Sweden. Street connectivity was then weighted by 1.5 as the index included three instead of four components.

The neighborhood walkability was divided into tertiles. Participants in tertile 1 and 2 were classified as living in low walkability neighborhoods and participants in tertile 3 were classified as living in high walkability neighborhoods, based on the distribution of the neighborhood walkability values. The values of the walkability index were considerably higher in tertile 3 than in tertile 1 and 2, which had more similar values of the index.

## **Individual income**

Individual income was used as a measure of individual SES. It was calculated by dividing the gross family income by the number of people living in the household, both assessed from the study questionnaire, with children/adolescents under the age of 18 being given a consumption weight of 0.5. Individual income was then dichotomized at the median into low and high.

## Physical activity

Previous studies on walkability and objectively assessed physical activity have included both moderate and vigorous physical activity in the outcome (24, 27, 28). However, vigorous physical activity mainly corresponds to activities of higher intensities than the walking intensity range of interest for neighborhood walkability (1, 13, 29). As neighborhood walkability was developed as a measure of environments promoting active transportation (i.e. walking) (23), we only included MPA in the present study. ActiGraph GT1M accelerometers (version 2 to 4, firmware 1 to 6) and ActiLife Data Analysis Software 6 (ActiGraph, Pensacola, FL, USA) were used to assess moderate physical activity (MPA). ActiGraph GT1M is highly reliable and useful in assessing a variety of walking and running intensities in adults (13, 25). The different versions of GT1M have shown to provide similar outputs (13), and also in comparison to the earlier model 7164 (10, 14, 22) used in previous walkability studies (24, 28). Participants were asked to wear the accelerometer for seven consecutive days, except when sleeping or bathing/swimming, and were given the opportunity to choose accelerometer placement on the hip or lower back to increase compliance. A study comparing accelerometer placement on the hip or lower back under free-living conditions found no significant effect on the estimation of time spent in moderate and vigorous physical activity (29). To further increase the compliance, four text-messages were sent to participants' cell-phone during the measurement period. The accelerometers were set to register vertical accelerations and to accumulate data over 60-s periods (epoch-time). Non-wearing time was defined as  $\geq 60$  min of no registered physical activity (zero counts), which has shown to provide lower frequency of misclassification compared to other protocols (20 min, 30 min) (5). MPA was defined as 1,952-5,724 counts per minute (9). Days with  $\geq 10$  hours of wearing time were considered valid. As the number of valid days may be related to socioeconomic factors (17) and we investigated the influence of individual income on the outcome, we applied a less strict inclusion criterion of at least one valid weekday and one valid weekend day for further analyses.

The "eyeball test" indicated that the pattern of MPA was similar between the five weekdays, and between the two weekend days, but that it differed between weekdays and weekend days. Hence, for further analyses we calculated the mean MPA of the weekdays and the mean MPA of the weekend days for each participant. If a participant only had one weekday or one weekend day, this single value was used in the analysis. The calculations were performed on both daily and hourly values, representing the daily ( $\text{min}\cdot\text{d}^{-1}$ ) and hourly ( $\text{min}\cdot\text{hr}^{-1}$ ) MPA of an average weekday or weekend day.

## Statistics

To investigate the influence of neighborhood walkability on mean daily and hour by hour MPA, the participants were divided into four categories: 1) high walkability/high individual income (HWHII), 2) high walkability/low individual income (HWLII), 3) low walkability/high individual income (LWHII), and 4) low walkability/low individual income (LWLII). During the weekdays, we included MPA collected between 6:00 and 23:00 and during the weekend days between 8:00 and 23:00 o'clock. Between these time-points the majority of the participants contributed with wear time (see results section).

The four walkability-income categories were compared for both the mean daily and mean hour by hour MPA. We used a non-parametric bootstrap approach because the physical activity data was skewed; especially the hour by hour data had a large proportion of observations with zero values. The bootstrap procedure was performed in the following way: for each mean daily and hour by hour comparison, 10,000 samples were drawn, with replacements, from the empirical distributions. For each drawn sample the mean value was determined and thus, as we had 10,000 samples and a mean value in each sample, a sampling distribution of the estimated mean was obtained. Bootstrap p-values were obtained from the sampling distributions for the difference between the estimated means (walkability-income categories). For the daily means we also present 95% bootstrap confidence intervals. Because of the way the participants were divided into high (1/3) and low (2/3) walkability, and that the variation of the estimated mean is dependent on the sample size, the confidence intervals and p-values for the mean difference between the two income categories within the high walkability category (HWHII vs. HWLII) becomes larger compared to the two income categories within the low walkability category (LWHII vs. LWLII), even when the difference in means appears similar. The statistical analyses were performed in the statistical computing and graphical software R (21).

## Results

### *Descriptive statistics on the study participants (Table 1)*

The mean age of the entire study population was 46 years and 55% were women. Around one quarter was single. The four walkability-income categories showed no large differences in the amount of wear time and the number of valid days. The mean wear time for all participants was 16 hours during a weekday and 15 hours during a weekend day. All participants had at least 3 valid days. In total, 94% had at least 6 valid days and 90% had

two valid weekend days. On average, participants spent 40 min·d<sup>-1</sup> in MPA (42 min·d<sup>-1</sup> on weekdays and 36 min·d<sup>-1</sup> on weekend days).

### *Mean daily moderate physical activity (Table 2)*

Bold type indicates results with a p-value <0.05. Living in a high walkability neighborhood was associated with more MPA compared with living in a low walkability neighborhood. For those participants with high individual income, the p-value was <0.05 on weekdays as well as weekend days (comparison B). However, for those participants with low income the p-values were >0.05 when comparing high vs. low walkability (comparison D), although a tendency was seen with a possible association between neighborhood walkability and MPA (2.7 min·d<sup>-1</sup> on weekdays as well as weekend days). In both high walkability and low walkability neighborhoods, high individual income was associated with more MPA compared with low individual income on weekend days (comparison A and E). The differences were 4.4 and 3.3 min·d<sup>-1</sup>, respectively. The largest differences were found when comparing the high neighborhood walkability and high individual income category with the other categories.

### *Hour by hour physical activity (Figure 2)*

Figure 2 shows the mean MPA hour by hour for weekdays (Figure 2A) and for weekend days (Figure 2B). The values are the accumulation of minutes in MPA during the last hour. For example, the MPA at 9:00 is the accumulation of MPA between 8:00 and 9:00. P-values are shown for each hour by hour comparison in the upper part of Figure 2 if p <0.05. Mostly, at least 90% of participants in each walkability-income category contributed with physical activity data at each hour included, except for the earliest hour in the morning where it could go down to 53%. To illustrate the four neighborhood walkability-individual income categories, we used circles to indicate high walkability and squares for low walkability, and unfilled symbols to indicate high individual income and filled symbols for low individual income. For example, an unfilled circle (○) represents the high walkability-high individual income category.

Overall, differences between weekdays and weekend days in the physical activity patterns appeared. A weekday had three sharp peaks of MPA: one in the morning, one around noon, and one in the late afternoon/early evening (Figure 2A). In contrast, a weekend day had only one broad peak (Figure 2B).



Both high and low-income participants had more MPA across almost the entire day (both weekdays and weekend days) in neighborhoods with high walkability compared to low walkability (○ vs. ◇, and ● vs. ◆). During weekdays, the difference between high and low walkability was more pronounced during the afternoon and early evening and especially among individuals with high income. High-income participants had higher amount of MPA than low-income participants (○ vs. ●, and ◇ vs. ◆) around noon and in the afternoon/early evening. In contrast, low-income participants had higher amounts of MPA than high-income participants in the time-periods between the three peaks. During the weekend, there was a more consistent difference in MPA across the day between high and low-income participants.

## Discussion

We found that neighborhood walkability was associated with more mean daily MPA on weekdays as well as on weekend days. High individual income was associated with more mean daily MPA on weekend days. The findings on mean daily MPA are in line with previous studies (24, 27, 28).

To the best of our knowledge, the present study is the first to use accelerometry to investigate the influence of neighborhood walkability and individual income on the hour by hour physical activity pattern across the day. On weekdays, participants living in neighborhoods with high compared to low walkability spent more time in MPA across the day. The differences were most pronounced in the afternoon/early evening among high-income participants and in the afternoon among low-income participants. These findings are novel and are therefore not directly comparable with previous research; up to this date, studies of the built environment and hour by hour physical activity patterns across the day have not been performed although there is an interest in studying hour by hour physical activity patterns across the day. For example, a few studies have explored the daily physical activity patterns in children (6, 12, 20, 26). Some of these studies identified times of the day with more pronounced differences between overweight and normal-weight children (6, 20).

The finding in the present study of a strong association between neighborhood walkability and MPA in the afternoon/early evening suggests an influence of neighborhood walkability on physical activity, as this is a time where a large proportion of people are likely to be exposed to their neighborhood environment. People living in neighborhoods with higher walkability (most of them located in the dense inner city) are

exposed to a variety of services and facilities within walking distance, which they may reach by walking after working hours. In contrast, participants living in neighborhoods with lower walkability (mostly house/villa neighborhoods or suburban neighborhoods with multifamily houses but low land use mix) have less availability of facilities within walking distance and may be more prone to use a car for their errands after work.

On weekend days, participants living in neighborhoods with high compared to low walkability spent consistently more time in MPA across the day and the most pronounced differences were found at the middle of the day. Compared to weekdays, when many people work, participants may spend more time in their neighborhoods during weekend days, which may explain the smoother distribution of the association between neighborhood walkability and physical activity across the day.

The influence of income on MPA differed across the weekday; high-income participants were more physically active at lunchtime and during the late afternoon/early evening whereas low income participants were more physically active in the time-periods in between the three peaks (Figure 1A). This is in line with the findings of Bauman and colleagues investigating associations between income and domain-specific physical activity (4). They found that high income participants were more physically active during leisure-time but less active when at work compared to low income participants. Low income may be associated with manual work and thereby higher levels of work-related physical activity while high income may be associated with sedentary deskwork. The higher levels of physical activity during lunchtime among participants with high compared to low income may be due to their better economical possibilities to buy their lunch at nearby restaurants, and thereby obtain some transport-related physical activity on the way to the restaurant and back. Furthermore, optional exercise during the lunch break as part of occupational health care programs may be more common among high-income workers in Sweden. The higher level of physical activity during the late afternoon/early evening is in line with previous research where income has been associated with leisure-time physical activity (4, 16, 18). Participants with high compared to low income were also more physically active across the weekend days, giving further support to an association between individual income and leisure-time physical activity.

This study has several strengths. It is the first study to explore the influence of neighborhood walkability and individual income on hour by hour physical activity patterns across the day. Further strengths are the large and randomly selected study sample and the high response rate, compared to previous studies. The detailed data on the road networks when creating the polygon-based network buffers is an additional strength. In contrast to most previous studies, where buffers often are based on the street network only, we included the street network as well as the bicycle paths and footpaths. This may provide a better picture of the “true” area of exposure. A novel strength of this study includes the use of objectively assessed MPA as an outcome instead of a combination of moderate and vigorous physical activity, which has been used as an outcome in previous studies although vigorous physical activity mainly corresponds to activities of higher intensities than walking for transportation (24, 27, 28).

There are also some limitations of this study. It is a cross-sectional study and causality can therefore not be determined. An important limitation is that we could not discriminate physical activity performed within the neighborhood of residence from that performed outside the neighborhood of residence. A combination of accelerometry and GPS has been suggested for the assessment of location-specific physical activity and, indirectly, domain-specific physical activity (7). However, the present technical limitations of GPS interfere with intact data collection (19), which decreases its usefulness. Finally, no adjustments for multiple testing were made. As each comparison was made individually, the issue of multiple testing needs to be considered in the interpretation of the overall results.

## **Conclusion**

The present study of the hour by hour physical activity patterns provides a more comprehensive picture of the associations between neighborhood walkability and individual income and physical activity and the variability of these associations across the day. These findings may be useful for potential interventions among individuals with different income levels in different types of neighborhoods. Future studies should use objective methods to further explore location- and domain-specific activities.

## **Acknowledgements**

This study was supported by grants to Dr Kristina Sundquist from the Swedish Council for Working Life and Social Research (FAS, 2006-0386) and The Swedish Research Council for Environment, Agricultural Sciences, and Spatial Planning (Formas, 2006-1196).

## Conflicts of interests

The authors disclose no professional relationships with companies or manufacturers who will benefit from the results of the present study. The results of the present study do not constitute endorsement by ACSM.

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Table 1. Descriptive statistics on the study participants, by categories of neighborhood walkability and individual income.

	All participants N=2,252	HWHII N=406	HWLII N=340	LWHII N=780	LWLII N=726
WI (z-value), mean (SD)	-0.1 (2.6)	3.2 (1.6)	2.8 (1.7)	-1.7 (1.1)	-1.5 (1.3)
Income <sup>1</sup> (SEK·10 <sup>-3</sup> ), median (IR)	254 (132)	350 (150)	150 (67)	317 (98)	157 (69)
Sex <sup>1</sup> (female), %	55	56	61	50	57
Age <sup>1</sup> (years), mean (SD)	46 (12)	46 (12)	43 (12)	48 (11)	45 (11)
Marital status <sup>1</sup> (single), %	24	38	25	19	22
Accelerometry					
MPA ( <i>min·d<sup>-1</sup></i> ), mean (SD)					
All days	40 (21)	44 (21)	41 (22)	40 (20)	38 (20)
Weekdays	42 (22)	45 (23)	43 (24)	41 (21)	40 (22)
Weekend days	36 (28)	40 (28)	36 (28)	36 (30)	33 (27)
Wear time ( <i>hr·d<sup>-1</sup></i> ), mean (SD)					
All days	16 (1)	16 (1)	15 (1)	16 (1)	16 (1)
Weekdays	16 (1)	16 (1)	16 (1)	16 (1)	16 (1)
Weekend days	15 (2)	15 (2)	15 (2)	15 (2)	15 (2)





Table 2. Comparison of mean daily moderate physical activity (min·d<sup>-1</sup>) for all days, weekdays (Mon-Fri) and weekend days (Sat-Sun) between all walkability-income categories.

N=2,252		Mean (95% CI) difference in MPA (min·d <sup>-1</sup> ) <i>p-value</i>					
		All days	Weekdays		Weekend days		
A	HWHII vs. HWLII	3.1 0.051	(-0.0-6.1)	2.6 0.13	(-0.7-6.0)	4.4 <b>0.036</b>	<b>(0.3-8.5)</b>
B	HWHII vs. LWHII	<b>3.9</b> <b>0.0022</b>	<b>(1.4-6.3)</b>	<b>4.0</b> <b>0.0030</b>	<b>(1.5-6.7)</b>	<b>3.8</b> <b>0.037</b>	<b>(0.3-7.3)</b>
C	HWHII vs. LWLII	<b>5.8</b> <b>&lt;0.001</b>	<b>(3.3-8.3)</b>	<b>5.4</b> <b>&lt;0.001</b>	<b>(2.7-8.1)</b>	<b>7.0</b> <b>&lt;0.001</b>	<b>(3.6-10.4)</b>
D	HWLII vs. LWLII	2.7 0.052	(-0.0-5.5)	2.7 0.075	(-0.3-5.8)	2.7 0.14	(-0.9-6.2)
E	LWHII vs. LWLII	1.9 0.067	(-0.1-4.0)	1.3 0.25	(-0.9-3.5)	<b>3.3</b> <b>0.025</b>	<b>(0.4-6.1)</b>
F	HWLII vs. LWHII	-0.8 0.58	(-3.5-1.9)	-1.4 0.35	(-4.4-1.5)	0.6 0.73	(-3.1-4.3)
<b>HW</b> , high walkability; <b>LW</b> , low walkability; <b>HII</b> , high individual income; <b>LII</b> , low individual income; <b>95% CI</b> , 95% confidence interval; <b>MPA</b> , moderate physical activity. <b>Bold type</b> : p-value <0.05.							

Figure 1. The City of Stockholm and the distribution of the 32 neighborhoods included in the SNAP study.

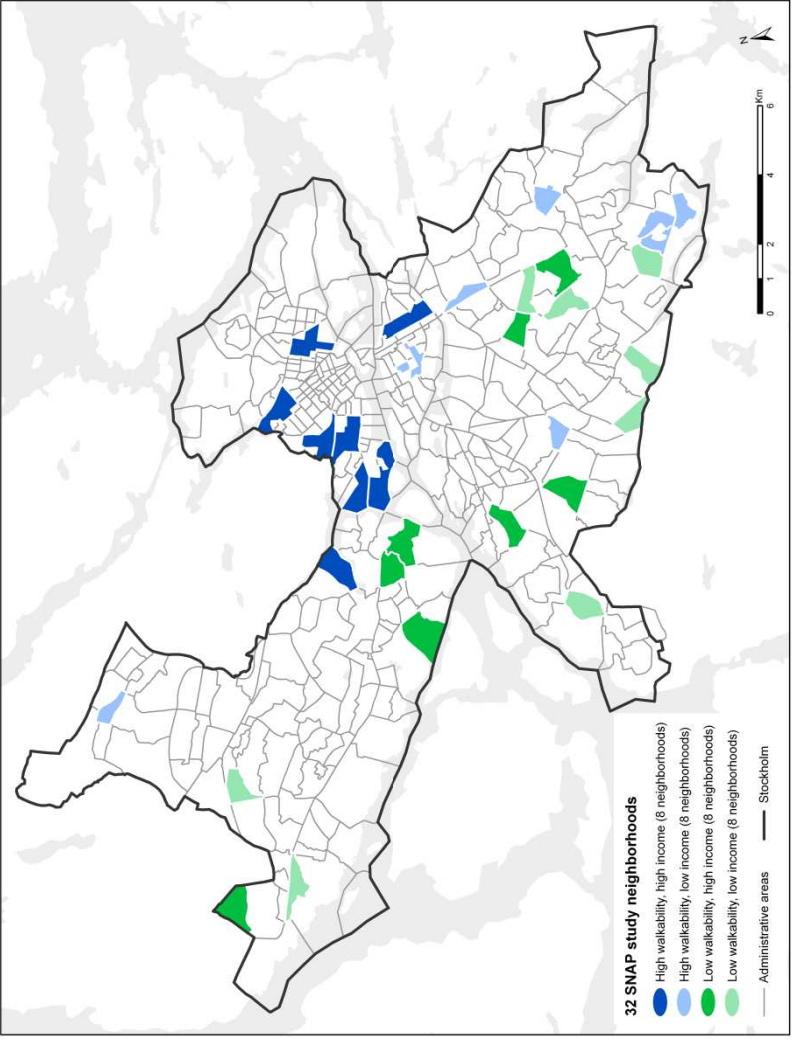
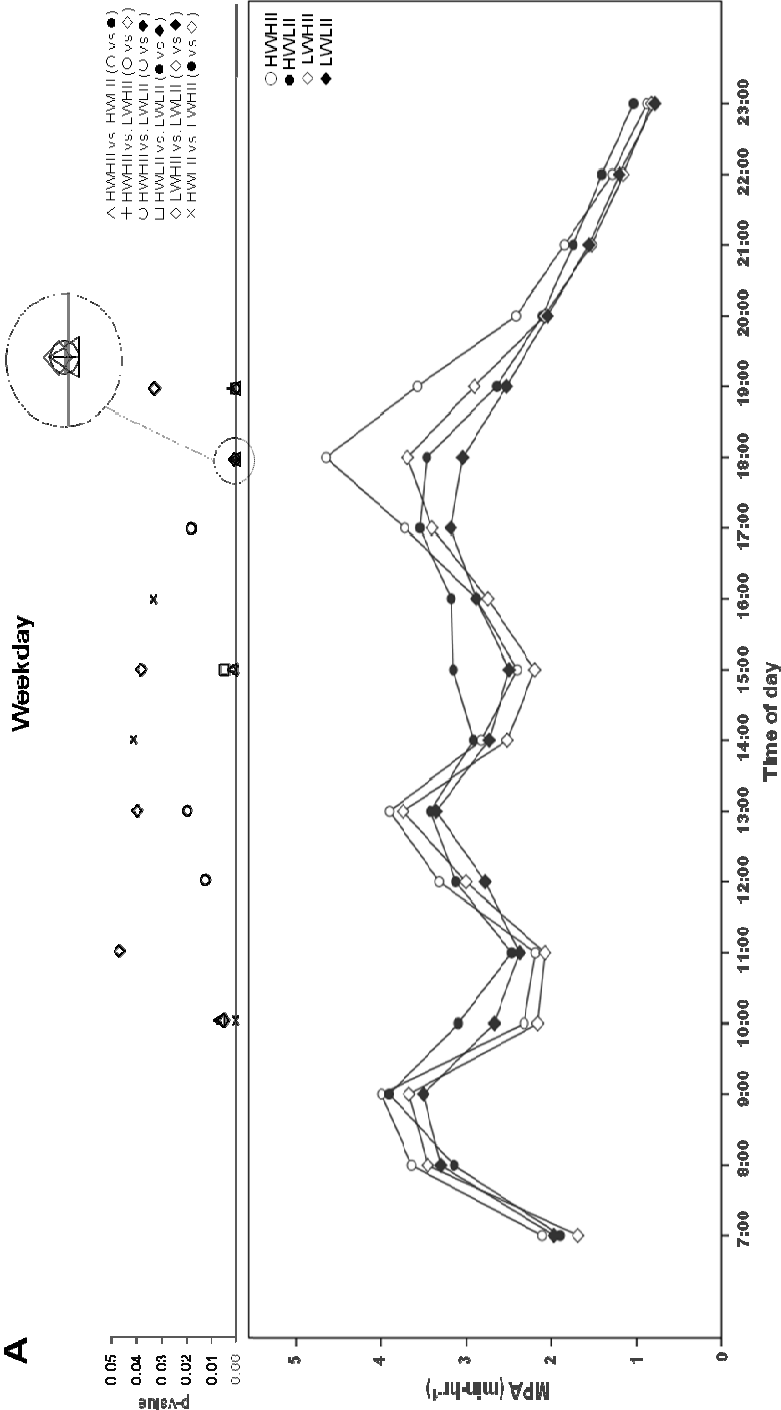
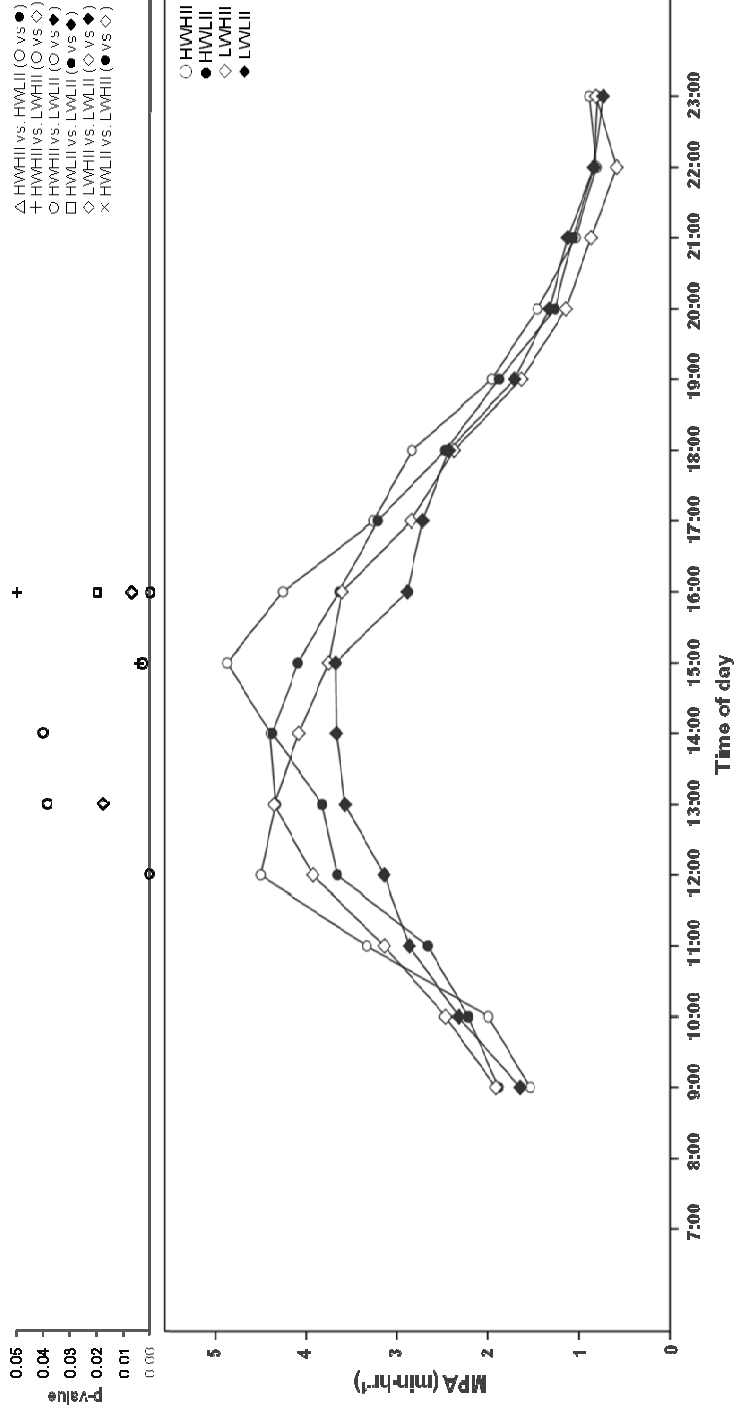


Figure 2 A-B. Hour by hour mean moderate physical activity by walkability-individual income category for A) an average weekday and B) an average weekend day (lower panel). P-values <0.05 for group comparisons are presented for each hour (upper panel). HW, high walkability index; LW, low walkability index; HII, high individual income; LII, low individual income.



**B**

**Weekend day**





## Study 3





RESEARCH

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# Walkability parameters, active transportation and objective physical activity: moderating and mediating effects of motor vehicle ownership in a cross-sectional study

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## Abstract

**Background:** Neighborhood walkability has been associated with physical activity in several studies. However, as environmental correlates of physical activity may be context specific, walkability parameters need to be investigated separately in various countries and contexts. Furthermore, the mechanisms by which walkability affects physical activity have been less investigated. Based on previous research, we hypothesized that vehicle ownership is a potential mediator. We investigated the associations between walkability parameters and physical activity, and the mediating and moderating effects of vehicle ownership on these associations in a large sample of Swedish adults.

**Methods:** Residential density, street connectivity and land use mix were assessed within polygon-based network buffers (using Geographic Information Systems) for 2,178 men and women. Time spent in moderate to vigorous physical activity was assessed by accelerometers, and walking and cycling for transportation were assessed by the International Physical Activity Questionnaire. Associations were examined by linear regression and adjusted for socio-demographic characteristics. The product of coefficients approach was used to investigate the mediating effect of vehicle ownership.

**Results:** Residential density and land use mix, but not street connectivity, were significantly associated with time spent in moderate to vigorous physical activity and walking for transportation. Cycling for transportation was not associated with any of the walkability parameters. Vehicle ownership mediated a significant proportion of the association between the walkability parameters and physical activity outcomes. For residential density, vehicle ownership mediated 25% of the association with moderate to vigorous physical activity and 20% of the association with the amount of walking for transportation. For land use mix, the corresponding proportions were 34% and 14%. Vehicle ownership did not moderate any of the associations between the walkability parameters and physical activity outcomes.

**Conclusions:** Residential density and land use mix were associated with time spent in moderate to vigorous physical activity and walking for transportation. Vehicle ownership was a mediator but not a moderator of these associations. The present findings may be useful for policy makers and city planners when designing neighborhoods that promote physical activity.

**Keywords:** Accelerometer, Neighborhood walkability, Geographic information system, Mediator, Moderator

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## Background

The interest in environmental determinants of physical activity behavior has been rapidly increasing over the past few years. Ecological models are often used as a basis to describe the multi-component influence of individual factors, the social environment and the physical environment on physical activity [1-3]. Objective measures of neighborhood walkability, a construct commonly including residential density, street connectivity and land use mix, have been associated with physical activity in several studies [4-7]. For example, participants from the Swedish Neighborhood and Physical Activity (SNAP) study living in highly walkable neighborhoods spent more time in moderate to vigorous physical activity (MVPA) and reported more walking for leisure and walking for transportation compared to participants living in less walkable neighborhoods [6]. That study investigated the association between an overall walkability index and physical activity, but it did not stratify the analyses by the different components of walkability (residential density, street connectivity, and land use mix). As associations between the environment and physical activity are context-specific, it is of interest to investigate the effects of the separate walkability parameters on physical activity under various conditions. To our knowledge, no previous study has investigated the association between objectively assessed walkability parameters and physical activity in a northern European context.

Previous cross-sectional studies have found negative associations between neighborhood walkability and motor vehicle ownership (further referred to as vehicle ownership) [8] and vehicle miles traveled [9,10]. This implies that dense, well connected areas with diverse land use could support a less car-dependent living. Vehicle ownership and vehicle use are, in turn, negatively associated with physical activity [8,11]. We hypothesize that vehicle ownership may lie in the causal pathway between neighborhood walkability and physical activity. To our knowledge, no previous study has investigated the hypothesized mediating effect of vehicle ownership on the association between objectively assessed walkability parameters and physical activity.

Vehicle ownership may also moderate associations between the physical environment and physical activity. A recent study found a positive association between convenience of bus services and physical activity in non-drivers, but not in drivers [12]. Furthermore, a Belgian study found significantly more steps per day among participants with a preference for passive transport living in highly walkable neighborhoods compared to participants with the same preference living in less walkable neighborhoods. This difference was not found in participants with a preference for active transport, but their number

of steps per day was generally higher [13]. To examine potential moderators of the relationship between the environment and physical activity is the most frequently suggested direction for future research outlined in reviews on environment and physical activity research [14].

The first aim of this study was to investigate the associations between objectively assessed residential density, street connectivity, and land use mix and physical activity outcomes, i.e. time spent in MVPA, walking for transportation and cycling for transportation. The second aim was to investigate the hypothesized pathway between walkability parameters and physical activity through vehicle ownership using mediation analysis. The third aim was to test whether the associations between the walkability parameters and physical activity are modified by vehicle ownership.

## Methods

### Study design

The present study uses cross-sectional data from the Swedish Neighborhood and Physical Activity (SNAP) study, collected between November 2008 and November 2009 in Stockholm. Stockholm municipality covers 188 square kilometers and has a population of about 850,000 inhabitants. It is the central city in a metropolitan area with about 2.1 million inhabitants. Participants for the SNAP study were recruited from neighborhoods differing in walkability assessed by Geographic Information Systems (GIS) and neighborhood-level income as described below. A full description of the design of the SNAP study has been provided elsewhere [6].

The city of Stockholm is divided into 408 administrative areas, with about 2,000 people living in each area. These areas were used as a basis for the calculations of the neighborhood-level variables. Neighborhood walkability was calculated as an index comprising of the sum of z-scores of residential density, street connectivity and land use mix. Some previous studies included retail floor area ratio as one of the components of their walkability measure and weighted street connectivity by 2 [15]. In this study, where information of retail floor area ratio was not available, street connectivity was weighted by 1.5. Administrative areas within the first to fourth deciles of walkability index were considered to be less walkable and the seventh to tenth deciles were considered to be highly walkable. Neighborhood-level income was calculated as the median family income, taking the age and numbers of family members into account. The second to fourth deciles of neighborhood-level income were considered as low neighborhood-level income and the seventh to ninth deciles were considered as high. The first and tenth deciles were

excluded to avoid outliers in neighborhood-level income. A total of 127 administrative areas were classified into the following four categories: high walkability/high income, high walkability/low income, low walkability/high income or low walkability/low income. Administrative areas in the high walkability/high income category located in the city center were rather small. Therefore, some areas in this category were merged to create study neighborhoods. A total of 32 neighborhoods, eight in each of the four categories, were included in the study.

### Study sample

A total of 8,000 individuals (250 from each neighborhood) aged 20 to 65 were randomly selected. Of these, 6,089 had a listed landline or cell phone number and were included in the recruitment procedure. A week after an information letter was sent to the individuals, a telemarketing company (Markör AB, Örebro, Sweden) called them to recruit participants and to answer any questions that they might have. To be included in the study, participants had to meet three inclusion criteria: 1) being able to read and write in Swedish, 2) having no serious impaired ability to walk and 3) having lived in the neighborhood for at least three months. Of the 4,747 individuals who were reached by phone, 4,369 met the inclusion criteria and 3,226 agreed to participate in the study. Recruitment was done concurrently in all 32 neighborhoods and data were collected throughout the year except for weeks 50 to 2 and weeks 25 to 33, corresponding to the Christmas and summer holidays. Lists of enrolled participants were delivered to the research group on a weekly basis. A package containing an accelerometer, an accelerometer logbook, a questionnaire and a pre-paid return envelope was sent to the participants. After participation, the participants received a pedometer, movie tickets or lottery tickets at a value of about 100 SEK (1 SEK=0.11 EUR or 0.15 USD). A total of 2,178 participants had complete GIS, accelerometer and self-report data and were included in the analyses.

### Neighborhood walkability parameters

Neighborhood walkability parameters were objectively measured using GIS. Each participant's residential address was geo-coded and 1,000-meter polygon-based network buffers were created around the residences using the Network Analyst extension in ArcGIS/ArcInfo 9.2 (ESRI Inc., Redlands, California, USA). Network buffers, compared to predefined administrative areas or circular buffers, may better reflect a "true" area of exposure. Polygon-based network buffers (further referred to as buffers) were created by following the road network including bicycle paths and footpaths in all possible directions for 1,000 meters from the residence and

then drawing a line to connect the endpoints, thus creating a polygon shaped area (a buffer) surrounding the residence. Buffers of 1,000 meters have often been used in previous research as studies have found that it is a distance many people are willing to walk in their daily life [16]. Detailed network data were delivered by the City Planning Administration in Stockholm and included the road network as well as bicycle paths and footpaths. Highways were excluded from the data.

**Residential density** was based on data obtained from Statistics Sweden and calculated as the number of residential units (in ten thousands) per square kilometer. **Street connectivity** was based on the same network data as when creating the buffer zones. That is, the data was delivered by the City Planning Administration in Stockholm, and it included the road network, bicycle paths and footpaths. Highways were excluded from the calculations. Bicycle paths and footpaths that run parallel with roads often result in multiple intersections within one "true" intersection. Therefore, a buffering procedure was employed where two or more intersections closer to each other than 10 meters were counted as one. Street connectivity was calculated as the number of intersections per square kilometer. **Land use mix** was calculated as the evenness in distribution between five categories of land use: 1) retail/service, 2) entertainment/physical activity, 3) institutional/healthcare, 4) office/workplace, and 5) dwellings. Categories 1 to 4 were based on data delivered by Teledress, a company founded when the government-owned telecom sector was privatized. The Teledress database is updated continuously and it includes businesses and services with a registered phone number, as well as those who actively have provided information about their business. The fifth category was based on data obtained from the City Planning Administration in Stockholm. The level of land use mix was based on point data and calculated by the Herfindahl-Hirschman Index (HHI). The HHI is calculated by summing the squared proportions of each land use category ( $HHI = p_1^2 + p_2^2 + \dots + p_5^2$ ). A high HHI indicates a low level of land use mix. In this study, however, the HHI-values were reversed (multiplied by -1) to facilitate interpretation of results (making a higher HHI correspond to a higher level of land use mix). We then divided the HHI-values by 10,000. This was done in order to make the unit in the explanatory variable and the regression coefficients easier to interpret, representing a meaningful difference in the neighborhood environment. For example, one increase in the unit of residential density used in the analyses (10,000 dwellings per square kilometer), corresponded to a shift from the lowest density to a mid-range density in this sample. The ranges of the explanatory variables are shown in Table 1.

**Table 1 Descriptive statistics on the 2,178 individuals included in the study**

	Median or percent	Interquartile range	Min; max
Residential density (residential units x 10 <sup>-4</sup> /km <sup>2</sup> )	0.23	0.14; 0.43	0.06; 1.77
Street connectivity (intersections/km <sup>2</sup> )	86.4	73.4; 102.1	30.5; 155.3
Land use mix (HHI x 10 <sup>-4</sup> x (-1)) <sup>a</sup>	-0.76	-0.86; -0.36	-0.98; -0.24
Age:			
20–30	11%		
31–40	21%		
41–50	28%		
51–66	40%		
Gender ( females)	55%		
Income:			
Low	19%		
Middle	56%		
High	25%		
Marital status (married/cohabiting)	75%		
Vehicle ownership:			
0	18%		
1	48%		
≥2	34%		
Moderate to vigorous physical activity (min/day)	41.3	27.1; 57.9	0.1; 183.7
Walking for active transportation (min/week)	125	30; 300	0; 1260
Cycling for active transportation (min/week) <sup>b</sup>	0	0; 20	0; 1260

<sup>a</sup>In this study, a higher Herfindahl-Hirschman Index correspond to a higher level of land use mix.

<sup>b</sup>Observations collected between April and October (n=906).

### Time spent in moderate to vigorous physical activity

The time spent in moderate to vigorous physical activity was objectively assessed with Actigraph GT1M accelerometers (ActiGraph, Pensacola, FL, USA). Actigraph GT1M is uni-axial and registers acceleration in the vertical plane. The accelerometers were set to sum the physical activity (counts) within 60-second periods (epoch) and participants were asked to wear them during all waking hours for seven consecutive days and to only remove them when engaging in water activities. Participants were given the opportunity to choose accelerometer placement on the hip or lower back to increase compliance. A study comparing accelerometer placement on the hip or lower back under free-living conditions found no significant effect of the placement on the estimation of time spent in moderate to vigorous physical activity [17]. Four text messages were sent to participants during the seven-day period to further

increase compliance. Non-wear time was defined as ≥60 continuous minutes of zero counts. A minimum of ten hours of wear time was required to constitute a valid day and participants with six or more valid days were included in the analysis. Variance analysis of our own data was performed to determine the number of valid days required to capture habitual physical activity [18]. Time spent in MVPA was defined using Freedson's cut-off as ≥1,952 counts per minute [19].

### Walking and cycling for active transportation

The amount of walking for transportation and cycling for transportation in minutes per week was assessed by the long self-administered version of the International Physical Activity Questionnaire (IPAQ). The IPAQ has shown good reliability and fair to moderate validity when using accelerometers as the criterion [20]. The frequency and duration of walking and cycling for transport purposes during the past seven days are reported. Data were cleaned and scored according to the official IPAQ scoring protocol (sites.google.com/site/theipaq/scoring-protocol). Due to the low proportions of participants reporting cycling during November-March (7–13%), the analyses on cycling for transportation only included observations collected between April and October where 20–32% of participants reported cycling for transportation during the past seven days (n=906).

### Vehicle ownership

The numbers of vehicles in the household were based on information from the study questionnaire in which participants were asked: "How many roadworthy motor vehicles do you have in your household?" Vehicle ownership was categorized into three levels: no vehicle, one vehicle and two or more vehicles.

### Socio-demographic information

Socio-demographic data were based on self-report. Age was categorized into four levels: 20–30 years, 31–40 years, 41–50 years, and 51–66 years. Marital status was dichotomized into either married/cohabiting with a partner or living without a partner. Income was calculated by dividing the gross family income by number of people living in the household, with children/adolescents under the age of 18 being given a consumption weight of 0.5. Income was then categorized into three levels: low (<150,000 SEK/year), middle (150,000–349,999 SEK/year) and high (≥350,000 SEK/year). One SEK equals about 0.11 EUR or 0.15 USD (August 2012).

### Statistical analysis

We investigated the association between three different walkability parameters (residential density, street

connectivity and land use mix) and three different outcomes (MVPA, walking for transportation and cycling for transportation). Further, we investigated whether these associations were mediated and/or moderated by vehicle ownership. Figure 1a illustrates a potential direct effect of X on Y, while Figure 1b illustrates the mediation design where the product of a and b ( $a*b$ ) is the potentially mediating effect of M on the association between X and Y. Walking for transportation and cycling for transportation were investigated both as dichotomous variables (yes/no) and as log transformed variables (with individuals that had a value higher than 0).

Linear regression was used to investigate the associations between the walkability parameters and the physical activity outcomes. To investigate the mediating effect of vehicle ownership on these associations we used an approach described by Preacher and Hayes [21]. This approach uses bootstrapping, a nonparametric resampling procedure, to generate confidence intervals for the indirect effect. We also calculated the proportion mediated, by dividing  $a*b$  with c. To check the robustness of our results, we also performed non-parametric analyses using PROC GENMOD in SAS v. 9.2 (SAS Institute, Cary, NC, USA) with the identity link and specified the variance to be binomial as well as using ordinary logistic regression. The mediated proportions in these control results were very similar to the results shown in the tables. For all outcomes we also investigated the potential interaction between vehicle ownership and the different walkability parameters.

## Models

In all models we first investigated the association between the different walkability parameters and the physical activity outcomes. Thereafter we included the socio-demographic characteristics in the models in order to investigate if the association was confounded by individual characteristics (full model).

## Non-response analysis

A telephone-based non-response analysis of 205 persons, randomly selected from those who were reached by phone but declined participation, was performed. There was no difference in income between participants and non-participants but the proportion of females was slightly higher among participants and participants were slightly older than non-participants.

## Ethics

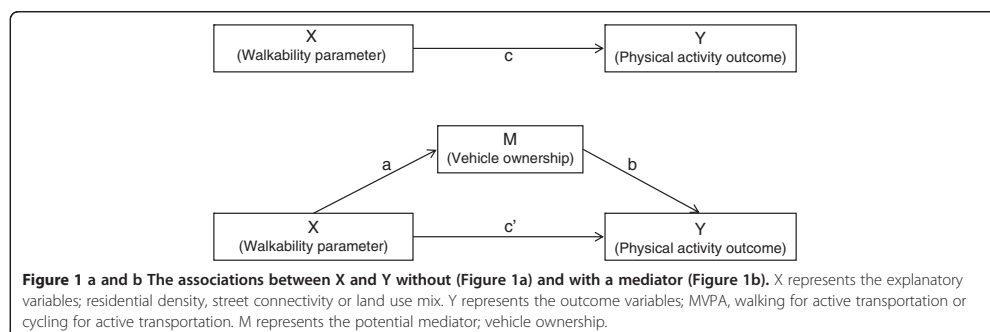
Ethical approval for this study was granted by the Ethics Committee of Karolinska Institutet, Stockholm. Written informed consent was obtained from all participants.

## Results

Participants had a median of 86.4 intersections per square kilometer (Interquartile Range, IQR=73.4-102.1; Range=30.5-155.3), 2,300 dwellings per square kilometer (IQR=1,400-4,300; Range=600-17,700) and an HHI of 7,600 (IQR 3,600-8,600; Range=2,400-9,800) within their buffer zones, as shown in Table 1. As described in the methods section, residential density was divided by 10,000 and HHI was divided by 10,000 and multiplied by -1 to facilitate interpretation of results. The study sample consisted of 55% females, 75% were married/cohabiting, 68% were over the age of 40 and 19% were in the low income group. The median value of time spent in MPVA was 41.3 minutes per day (IQR=27.1-57.9) and the median for walking for transportation was 125 minutes per week (IQR=30-300). Individuals participating in the study between April and October had a median of 0 minutes per week of cycling for transportation (IQR=0-20).

## Walkability parameters and MVPA

Table 2 shows the associations between the different walkability parameters, vehicle ownership and MVPA as well as the mediating effects of vehicle ownership. A paths illustrate the associations between walkability parameters and vehicle ownership; b paths illustrate the



**Table 2 Walkability parameters, vehicle ownership and MVPA. Numbers represent regression coefficients (95% confidence intervals)**

	a paths	b paths <sup>a</sup>	c paths	c' paths	Indirect effects (a paths*b paths)	Proportion mediated
Residential density	-0.53 (-0.60; -0.46)	-3.05 (-4.50; -1.59)	6.81 (4.35; 9.27)	5.20 (2.63; 7.77)	1.61 (0.81; 2.48)	24%
Residential density (Full model <sup>b</sup> )	-0.49 (-0.56; -0.42)	-2.95 (-4.45; -1.46)	5.86 (3.37; 8.35)	4.42 (1.84; 7.01)	1.44 (0.69; 2.31)	25%
Street connectivity	n/a	n/a	0.02 (-0.02; 0.07)	n/a	n/a	n/a
Street connectivity (Full model <sup>b</sup> )	n/a	n/a	n/a	n/a	n/a	n/a
Land use mix	-1.00 (-1.11; -0.88)	-3.07 (-4.55; -1.60)	10.30 (6.25; 14.35)	7.24 (2.95; 11.53)	3.06 (1.56; 4.67)	30%
Land use mix (Full model <sup>b</sup> )	-0.90 (-1.02; -0.78)	-3.11 (-4.62; -1.60)	8.13 (3.94; 12.32)	5.33 (0.94; 9.72)	2.80 (1.32; 4.25)	34%

a paths: Associations between walkability parameters and vehicle ownership.

b paths: Associations between vehicle ownership and MVPA (minutes/day).

c paths: Associations between walkability parameters and MVPA (minutes/day).

c' paths: c paths adjusted for vehicle ownership.

<sup>a</sup>b paths are not based on the walkability parameters.

<sup>b</sup>Adjusted for age, gender, income and marital status.

n/a: Not applicable (as no significant association was found between the walkability parameter and the physical activity outcome).

associations between vehicle ownership and MVPA (note that the walkability parameters are not included in the b paths); c paths illustrate the associations between walkability parameters and MVPA, and c' paths represent c paths adjusted for vehicle ownership.

The results of the regression analyses show that residential density and land use mix was positively associated with time spent in MVPA. An increase of residential density of 10,000 dwellings per square kilometer was associated with 6.8 (CI=4.4-9.3) more minutes per day of MVPA. This association remained significant when adjusting for age, gender, marital status and income (full model). For land use mix, an increase of the HHI by 10,000 was associated with 10.3 (CI=6.3-14.4) more minutes per day of MPVA and this association remained significant in the full model (c paths). No significant association was found between street connectivity and time spent in MVPA. There were negative associations between residential density as well as land use mix and vehicle ownership (a paths). There were also negative associations between vehicle ownership and time spent in MVPA in both models (b paths). Vehicle ownership mediated 25% of the association between residential density and time spent in MVPA in the full model and this mediating effect was statistically significant. For land use mix, the corresponding figure was 34%.

association between the walkability parameters, vehicle ownership and walking for transportation as well as the mediating effects of vehicle ownership. Residential density and land use mix were significantly and positively associated with reporting walking for transportation (yes/no) and with the amount of walking for transportation (log transformed minutes per week) in the full models. Street connectivity was significantly and positively associated with walking for transportation in the linear regression analysis (c paths). There were negative associations between vehicle ownership and walking for transportation in both the logistic and the linear regression analyses (b paths). Vehicle ownership mediated 20% of both the logistic and the linear associations between residential density and walking for transportation in the full models. For land use mix, the corresponding figures were 22% and 14% for the logistic and linear associations, respectively, and these mediating effects were statistically significant.

#### Walkability parameters and cycling for transportation (not shown in tables)

None of the walkability parameters were associated with reporting cycling for transportation (yes/no) or with the amount of cycling for transportation (log transformed minutes per week).

#### Walkability parameters and walking for transportation

Table 3 shows the logistic regression analyses and Table 4 shows the linear regression analyses of the

#### Effect modification by vehicle ownership

Table 5 shows the results from the interaction tests between the walkability parameters and vehicle

**Table 3 Walkability parameters, vehicle ownership and walking for transportation (yes/no). Numbers represent regression coefficients (95% CI)**

	a paths	b paths <sup>a</sup>	c paths	c' paths	Indirect effects (a paths*b paths)	Proportion mediated
Residential density	-0.53 (-0.60; -0.46)	-0.06 (-0.08; -0.03)	0.14 (0.10; 0.18)	0.11 (0.07; 0.15)	0.03 (0.02; 0.04)	22%
Residential density (Full model <sup>b</sup> )	-0.49 (-0.56; -0.42)	-0.05 (-0.08; -0.03)	0.13 (0.09; 0.17)	0.10 (0.06; 0.15)	0.03 (0.01; 0.04)	23%
Street connectivity	n/a	n/a	0.0003 (-0.000; 0.001)	n/a	n/a	n/a
Street connectivity (Full model <sup>b</sup> )	n/a	n/a	n/a	n/a	n/a	n/a
Land use mix	-1.00 (-1.11; -0.88)	-0.06 (-0.08; -0.03)	0.23 (0.16; 0.30)	0.18 (0.10; 0.25)	0.06 (0.03; 0.08)	26%
Land use mix (Full model <sup>b</sup> )	-0.90 (-1.02; -0.78)	-0.05 (-0.08; -0.03)	0.21 (0.14; 0.28)	0.16 (0.09; 0.24)	0.05 (0.03; 0.07)	24%

a paths: Associations between walkability parameters and vehicle ownership.

b paths: Associations between vehicle ownership and walking for active transportation (dichotomous, yes/no).

c paths: Associations between walkability parameters and walking for active transportation (dichotomous, yes/no).

c' paths: c paths adjusted for vehicle ownership.

<sup>b</sup>b paths are not based on the walkability parameters.

<sup>b</sup>Adjusted for age, gender, income and marital status.

n/a: Not applicable (as no significant association was found between the walkability parameter and the physical activity outcome).

ownership. There was no significant effect modification by vehicle ownership on any of the associations between the walkability parameters and the physical activity outcomes.

## Discussion

The aim of this study was to investigate the associations between three walkability parameters (residential density, street connectivity and land use mix) and physical

**Table 4 Walkability parameters, vehicle ownership and walking for transportation (amount\*)**

	a paths	b paths <sup>a</sup>	c paths	c' paths	Indirect effects (a paths*b paths)	Proportion mediated
Residential density	-0.49 (-0.56; -0.41)	-0.11 (-0.18; -0.03)	0.26 (0.14; 0.38)	0.21 (0.08; 0.33)	0.05 (0.02; 0.09)	19%
Residential density (Full model <sup>b</sup> )	-0.45 (-0.53; -0.37)	-0.11 (-0.18; -0.03)	0.28 (0.16; 0.40)	0.24 (0.12; 0.36)	0.05 (0.02; 0.08)	18%
Street connectivity	-0.002 (-0.004; -0.001)	-0.137 (-0.207; -0.067)	0.003 (0.000; 0.005)	0.002 (0.000; 0.004)	0.0003 (0.0001; 0.0007)	11%
Street connectivity (Full model <sup>b</sup> )	n/a	n/a	0.002 (0.000; 0.005)	0.002 (-0.000; 0.004)	n/a	n/a
Land use mix	-0.98 (-1.12; -0.86)	-0.09 (-0.16; -0.02)	0.53 (0.33; 0.74)	0.44 (0.23; 0.66)	0.09 (0.02; 0.16)	17%
Land use mix (Full model <sup>b</sup> )	-0.87 (-1.00; -0.74)	-0.09 (-0.17; -0.02)	0.58 (0.37; 0.79)	0.50 (0.27; 0.73)	0.08 (0.02; 0.15)	14%

Numbers represent regression coefficients (95% CI).

\*Only individuals that have reported some walking are included and values are log-transformed.

a paths: Associations between walkability parameters and vehicle ownership.

b paths: Associations between vehicle ownership and walking for active transportation (log-transformed min/week).

c paths: Associations between walkability parameters and walking for active transportation (log-transformed min/week).

c' paths: c paths adjusted for vehicle ownership.

<sup>b</sup>b paths are not based on the walkability parameters.

<sup>b</sup>Adjusted for age, gender, income and marital status.

n/a: Not applicable (as no significant association was found between the walkability parameter and the physical activity outcome).



**Table 5 Interaction analysis between walkability parameters and vehicle ownership**

	Residential density	Street connectivity	Land use mix
MVPA	0.806	0.112	0.589
Walking for transportation (0/1)	0.266	0.809	0.918
Walking for transportation (log)	0.889	0.575	0.953
Cycling for transportation (0/1)	0.091	0.647	0.124
Cycling for transportation (log)	0.429	0.547	0.555

Values are p-values for the interaction term.

activity and to analyze the mediating and moderating effects of vehicle ownership on these associations. The results showed that residential density and land use mix, objectively assessed within 1,000 meter network buffers around participants' residences, are positively associated with time spent in MVPA and walking for transportation. This is in line with previous research investigating objectively assessed residential density and land use mix as separate measures [22] or when incorporating these measures in indexes of overall walkability [5-7].

Street connectivity was weakly associated with the amount of walking for transportation, but it was not associated with any of the other physical activity outcomes in this study. The lack of associations between street connectivity and physical activity outcomes is in contrast to some earlier findings from other studies. For example, Frank et al. found street connectivity to be significantly associated with moderate physical activity [22]. The non-significant association between street connectivity and physical activity in this study could be explained by a relatively high level of connectivity. The median number of intersections per square kilometer was 87 in this Swedish study, compared to a mean of 37 intersections per square kilometer found by Frank and colleagues in North America [22]. The lack of association between street connectivity and physical activity found in this study is, however, in line with the conclusions of a review by Saelens and Handy on environmental correlates of walking [23]. They found that while residential density and land use mix were consistently associated with walking for transportation, the findings for street connectivity were more equivocal.

We did not find any significant associations between walkability parameters and cycling for transportation. Even though we included the cycling infrastructure in our data, walkability was developed as a measure of supportive environments for walking and not cycling. Furthermore, a 1000-meter buffer may be too small to capture the area of exposure for cyclists. A study

conducted in Stockholm investigating route distances in 110 street-recruited bicycle commuters found a mean commuting distance of 6.7 and 8.0 kilometers for women and men, respectively [24]. However, even smaller buffer zones (450m) have been used in previous research on environmental correlates of cycling for transportation [25]. Furthermore, it may be more common for cyclists to commute from residences in low walkable neighborhoods to workplaces in dense inner city areas than the opposite scenario, in order to avoid traffic congestions and parking problems. This would attenuate an association between neighborhood walkability and cycling for transportation. Future studies could explore this hypothesis using measures of walkability parameters around participants' workplaces as well as their homes.

Previous studies have found positive associations between neighborhood walkability and active transport (walking + cycling) [10,26]. Other studies have examined the association between walkability and cycling for transportation alone. For example, participants in the Belgian Environmental Physical Activity Study living in highly walkable neighborhoods (walkability assessed within administrative areas) reported 40 minutes more cycling for transportation per week compared to participants living in less walkable neighborhoods [7]. Results from a study by Winters and colleagues showed positive associations between objectively assessed population density, street connectivity and land use mix and cycling for transportation [25]. Furthermore, Titze et al. found a positive association between perceived street connectivity and cycling for transportation [27].

Vehicle ownership mediated a statistically significant proportion of all the significant associations between walkability parameters and physical activity outcomes. For example, 34% of the association between land use mix and time spent in MVPA were mediated by vehicle ownership. To our knowledge, no previous studies have investigated vehicle ownership as a mediator between objectively assessed walkability parameters and physical activity outcomes. Therefore, our results are hard to compare with the currently available knowledge base. However, our results are in line with the findings of a study by Sehatzadeh et al. in which fewer vehicles were owned by households in walkable environments and where the number of vehicles in the household was negatively associated with frequency of walking [8]. This is also supported by results from a longitudinal study by Mumford and colleagues, where participants reported more walking and less automobile use after moving to a community with a high land use mix [28].

We did not find any significant effect modification by vehicle ownership on the associations between walkability parameters and physical activity outcomes.

Participants living in dense areas with a mixed land use spent more time in MVPA and reported more walking for transportation compared to participants living in areas with lower residential density and land use mix, regardless of vehicle ownership. This is in contrast to some previous findings where vehicle ownership, or similar vehicle-related measures, moderated the relationship between the environment and physical activity. For example, driving status modified the association between convenience of bus services and physical activity in a Japanese study [12] and preference for passive transport modified the association between walkability and numbers of steps per day in a Belgian setting [13]. However, the present study and the studies by Kamada et al. and Van Dyck et al. used different explanatory as well as outcome measures. For example, preference for passive transport may have a different influence on the association between walkability parameters and physical activity compared to vehicle ownership.

This study has some limitations that should be considered. It is a cross-sectional study and therefore causality cannot be determined. Self-report measures of walking and cycling for transportation may include bias due to social desirability and difficulties to recall activities during the past seven days. Accelerometers, on the other hand, do not suffer from these biases and provide an objective measure of physical activity on a moderate to vigorous intensity level. Strengths of this study also include the large number of participants ( $n=2,178$ ) and the objective measures of walkability parameters using network buffers. The network buffers were based on detailed network data, including the road network as well as bicycle paths and footpaths. This provides a more relevant area of exposure for cyclists and pedestrians compared to network buffers based solely on the road network. Finally, participants were recruited from neighborhoods with a wide range of walkability and neighborhood-level SES, which is an additional strength.

## Conclusions

The present study showed a positive association between two out of three walkability parameters (residential density and land use mix but not street connectivity) and time spent in moderate to vigorous physical activity and walking for transportation. Significant proportions of these associations were mediated by vehicle ownership. Interaction tests suggested that residential density and land use mix are favorable for physical activity regardless of vehicle ownership status. Our findings may be useful for policy makers and city planners when designing physical activity promoting neighborhoods. We welcome future evaluations of the parameters

incorporated in environmental indices, such as the walkability index, in different countries.

## Abbreviations

SNAP: the Swedish Neighborhood and Physical Activity study; GIS: Geographic Information Systems; MVPA: moderate to vigorous physical activity.

## Competing interests

None of the authors have any conflicts of interest to declare.

## Authors' contributions

All authors contributed to the conception and design of the study. UE and KS contributed to the acquisition of data. UE and HO performed the statistical analysis. All authors contributed to interpretation of data, revision of the manuscript for important intellectual content and final approval of the manuscript.

## Acknowledgments

This study was supported by grants to Dr Kristina Sundquist from the Swedish Council for Working Life and Social Research (FAS 2006-0386) and The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (Formas 2006-1196).

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Received: 18 April 2012 Accepted: 2 October 2012

Published: 5 October 2012

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doi:10.1186/1479-5868-9-123

**Cite this article as:** Eriksson et al.: Walkability parameters, active transportation and objective physical activity: moderating and mediating effects of motor vehicle ownership in a cross-sectional study. *International Journal of Behavioral Nutrition and Physical Activity* 2012 **9**:123.

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## Study 4



RESEARCH ARTICLE

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# Availability of exercise facilities and physical activity in 2,037 adults: cross-sectional results from the Swedish neighborhood and physical activity (SNAP) study

Ulf Eriksson\*, Daniel Arvidsson and Kristina Sundquist

## Abstract

**Background:** Exercise facilities may have the potential to promote physical activity among residents, and to support an active lifestyle throughout the year. We investigated the association between objectively assessed availability of exercise facilities and objectively assessed physical activity outcomes, and whether time of year had a modifying effect on these associations.

**Methods:** A total of 2,037 adults (55% females) wore an accelerometer for seven days. Time spent in moderate to vigorous physical activity (minutes per day) and meeting the physical activity recommendations (yes/no) were used as outcome variables. Availability of exercise facilities was measured within 1,000-meter line-based road network buffers around participants' residential addresses using Geographic Information Systems. Socio-demographic variables and time of year were included as covariates in the analyses.

**Results:** Participants with  $\geq 4$  exercise facilities within their buffer zones spent 5.4 (confidence interval (CI) = 2.3-8.5) more minutes in moderate to vigorous physical activity per day, and had 69% higher odds (OR = 1.69; CI = 1.39-2.05) of meeting the physical activity recommendations, compared to those with no exercise facilities within their buffer zones. Time of year had no modifying effect on these associations.

**Conclusions:** Our results show that objective availability of exercise facilities was associated with accelerometer-assessed time spent in moderate to vigorous physical activity and the odds of meeting the recommended levels of physical activity. Neighborhoods may be a logical and potentially significant venue for policy interventions aimed at increasing physical activity in the overall population.

## Background

Although physical activity is known to influence human health [1-3], large proportions of populations worldwide do not meet recommended levels of physical activity [4,5]. According to the World Health Organization, insufficient levels of physical activity are one of the top contributors to global mortality [6]. It is therefore a highly important public health priority to increase the proportion of physically active people.

Interventions aimed at increasing levels of physical activity have, however, had varying success [7,8]. Recently,

considerable efforts have been made to implement ecological models for physical activity behavior. These ecological models often include attributes of the built neighborhood environment [9-11].

Specific attributes of the built neighborhood environment that may have the potential to promote physical activity among residents include neighborhood availability of exercise facilities. Studies examining the association between availability of exercise facilities and physical activity have, however, produced varying results. A review from 2008 found little or no evidence for an association between availability of physical activity facilities and walking for transportation or recreational walking [12]. In contrast, a study from the U.S. found an association between density of exercise facilities and

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exercise prevalence in study participants from three areas with widely varying population densities [13]. This association was modified by income and race/ethnicity, being stronger among those with low incomes and non-Hispanic Black and Hispanic participants compared to their high-income and non-Hispanic White counterparts. Income was also found to be an effect modifier in another study, which detected an association between number of gyms per square kilometer and physical activity in low-income women but not high-income women [14]. Hence, associations between exercise facilities and physical activity may be influenced by individual characteristics. If this is the case, it is possible that neighborhood characteristics aimed at increasing people's physical activity may not reach all population groups to an equal extent.

A majority of previous studies were based on self-reported physical activity and/or self-reported neighborhood availability of exercise facilities. Same-source bias may generate spurious associations if the neighborhood characteristic and the outcome are collected by self-report, as different variables collected from the same source may not be independent from each other. In addition, self-reported measures of physical activity are often biased by over-reporting, social desirability and other factors [15]. These types of biases can be avoided if physical activity is measured objectively, for example by accelerometry.

Different methods exist to objectively assess the availability of exercise facilities, and the choice of method may influence the accuracy of neighborhood assessments. A crude method of objectively measuring availability of exercise facilities is to assess neighborhood availability of exercise facilities within administrative areas, such as census tracts or provinces [14,16,17]. All residents living within these administrative areas are considered to have the same availability of exercise facilities. To obtain a more individualized measure of neighborhood availability of exercise facilities, a buffer zone may be created around each individual's residential address [13,14,18]. Circular buffer zones are easy to create but may include areas that are not accessible to participants due to, for example, rivers and other natural and unnatural barriers. Buffer zones based on the road network may provide a more accurate picture of the neighborhood facilities that are actually available to residents [19].

The present Swedish study represents a novel contribution because both the predictor variable (neighborhood availability of exercise facilities) and the outcome variable (physical activity) were measured objectively. Moreover, Sweden is particularly well suited for this kind of study due to its temperate climate. In countries with temperate climates, where the four seasons are well

defined, time of year may have an impact on people's physical activity. Previous studies have shown an association between time of year and physical activity, with lower levels of physical activity occurring during winter [20-22]. It has been hypothesized that exercise facilities could be of importance in supporting a physically active lifestyle throughout the year [23]. This suggests a stronger association between availability of indoor exercise facilities and physical activity during the winter than during the summer. To our knowledge, no previous study using objective measures of availability of exercise facilities and physical activity has explored this hypothesis.

The main aim of this study was to investigate the association between objective availability of exercise facilities, measured within line-based road network buffer zones around participants' residences, and objectively assessed physical activity outcomes. We also aimed to investigate the possible effect of socio-demographic variables and time of year on this association (effect modification).

## Methods

### Design and study sample

The data used in this cross-sectional study were collected between November 2008 and November 2009 in Stockholm, Sweden as part of the Swedish Neighborhood and Physical Activity (SNAP) study. The SNAP study was originally designed to investigate the association between neighborhood walkability and physical activity [24]. A total of 32 neighborhoods were sampled based on walkability (based on data provided by Statistics Sweden, the City Planning Administration in Stockholm and the company Teledress) and neighborhood income (based on data provided by Statistics Sweden) in order to ensure variation in neighborhood-level walkability and socio-economic status. Data were collected throughout the study period, except between 9 December 2008 and 12 January 2009 and between 16 June and 17 August 2009 (these two time periods correspond to the winter and summer holidays in Sweden, respectively).

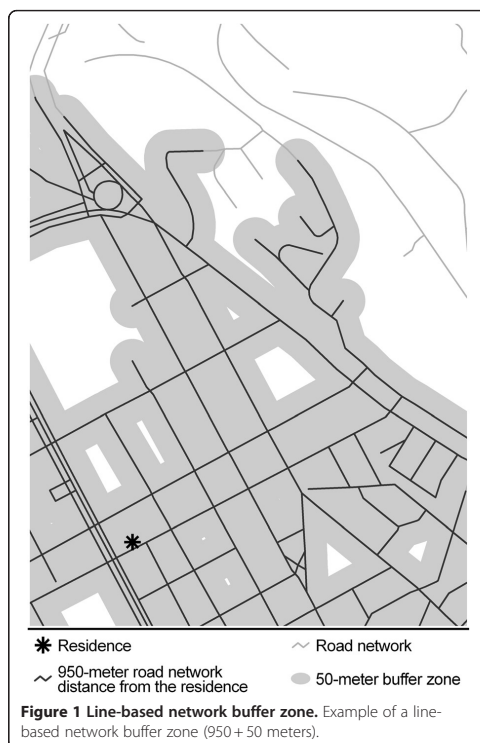
The sampling procedure has been described in detail elsewhere [24]. Briefly, neighborhood walkability and income were calculated for all 408 basic areas (neighborhoods) in the city of Stockholm. Geographic Information Systems (GIS) were used to calculate walkability as an index comprising z-scores for residential density, street connectivity and land use mix. Neighborhoods in the first to fourth walkability index deciles were considered less walkable, and those in the seventh to tenth deciles were considered highly walkable. Neighborhood income in each area was calculated as the median disposable family income, taking the number and age of family members into account. Neighborhoods in the second to fourth

neighborhood income deciles were considered to be of low income, and those in the seventh to ninth deciles of high income. Four neighborhood categories were created: high walkability/high income, high walkability/low income, low walkability/high income and low walkability/low income. A total of 32 neighborhoods (eight from each category) were sampled for the study.

The SNAP study aimed to recruit 75 participants from each of the 32 neighborhoods, i.e. 2,400 in total. Simple random sampling of 8,000 individuals aged 20 to 65 (200 from each neighborhood) was performed by the Stockholm Office of Research and Statistics. Immigrants who had arrived in Sweden after 2003 were excluded since knowledge of Swedish was an inclusion criterion (see below). A total of 6,089 individuals had a listed landline or mobile phone number and were included in the recruitment procedure. Of the 4,747 individuals who were reached, 4,369 met the three inclusion criteria: (1) being able to read and write Swedish, (2) having lived in the neighborhood for at least three months, and (3) having no serious impaired ability to walk. The final study population for analyses, after exclusion due to missing data, consisted of 2,037 individuals, which gave a response rate of 47% (2,037/4,369). Recruitment of participants was performed concurrently in all included neighborhoods by the telemarketing company Markör AB (Örebro, Sweden). Markör AB has previously been involved in the recruitment of participants for large-scale research studies. Lists of enrolled participants were delivered to us on a weekly basis and a package containing an accelerometer, an accelerometer logbook, a questionnaire and a prepaid return envelope was sent to the residential address of each participant.

#### Availability of exercise facilities

Availability of exercise facilities was objectively measured using GIS. To assess area of exposure, neighborhoods were defined by creating a buffer zone originating from the residential address of each participant using the Network Analyst extension in ArcGIS/ArcInfo 9.2 (ESRI Inc., Redlands, California, USA). Data on the road network, including cycle paths and footpaths, was obtained from the City Planning Administration in Stockholm. Line-based network buffer zones were created by following the road network in all possible directions from each residence for 950 meters, and then creating a 50-meter buffer zone in all directions from the center of the road (Figure 1). 1,000-meter buffer zones are likely to represent areas that can be reached in daily life by a large majority of the adult population and have been used to define neighborhoods in previous research [25,26]. Data from 2008 on the locations and business names of exercise facilities were provided by Teleaddress, a company created when the government-owned telecoms agency



was privatized and one of the leading providers of geocoded data on businesses and private individuals in Sweden. The data from Teleaddress included privately and publicly owned exercise facilities that have a registered telephone number and/or those that had provided information about their existence to Teleaddress. The database is updated continuously and inclusion is free of charge. The data included nine categories of exercise facilities: "gym/fitness center", "sport facility", "tennis court", "dance class center", "public ice rink", "squash court", "sports hall", "public baths" and "badminton court". Most facilities were indoor facilities; only a few in the category "tennis court" were outdoor facilities. A vast majority of the exercise facilities were charged. Exercise facilities located within buffer zones were manually screened to identify those that did not offer exercise to the adult population. These facilities, as well as those not offering any exercise opportunities on site, were excluded. We identified 341 exercise facilities; 58 of these were excluded because they did not offer exercise to the adult population on site. Individual exercise facilities offering more than one activity received a count for

each activity. For example, an exercise facility listed in both the "gym/fitness center" and "squash court" categories was counted as two facilities. The category "sport facility" was often present as a general description together with a more specific category. For example, gyms often appeared in both the "sport facility" and "gym/fitness center" categories. "Sport facility" was thus only counted when the only category present, and not when accompanied by another exercise facility category.

#### Time spent in moderate to vigorous physical activity

Actigraph GT1M accelerometers (ActiGraph, Pensacola, Florida, USA) were used to objectively measure participants' physical activity. Participants were asked to wear the accelerometer on the hip or lower back for 7 consecutive days and to remove it only when sleeping or engaging in water-based activities. A study comparing placement of accelerometers on the hip or lower back under free-living conditions found that the position of the accelerometer had no effect on the estimation of time spent in moderate to vigorous physical activity [27]. Four standardized text messages were sent to each participant's cell phone during the 7-day measurement period to improve compliance. The Actigraph GT1M measures acceleration in the vertical axis at a frequency of 30 times per second (30 Hertz). These accelerations are summed within 60-second periods (epoch) and the output is referred to as "counts". Non-wear time was defined as 30 or more consecutive minutes with zero counts, and 10 h of wear time was required to constitute a valid day. Accelerometer wear time was calculated by subtracting non-wear time from 24 h. Variance analysis of our own accelerometer data showed that 6 or 7 valid days were required for inclusion in the analysis [28]. Time spent in moderate to vigorous physical activity was determined using Freedson's cut-off point for accelerometer counts [29], which is  $\geq 1,952$  counts/min. This cut-off was applied to each minute of wear time for the valid days. The mean time per day spent in moderate to vigorous physical activity during all valid days was used as the outcome variable.

#### Meeting physical activity recommendations

According to the global physical activity recommendations of the World Health Organization, adults should engage in  $\geq 150$  min of moderate physical activity or  $\geq 75$  minutes of vigorous physical activity per week, or an equivalent combination of the two. Activities should be performed in bouts of  $\geq 10$  min [30]. In the present study, participants were considered to have met these recommendations if they accumulated  $\geq 150$  min of moderate to vigorous physical activity in bouts of  $\geq 10$  min within a week. Bouts of moderate to vigorous physical activity were identified as 10 or more

consecutive minutes with  $\geq 1,952$  counts per minute. During each bout of physical activity, the number of counts per minute was permitted to dip below this cut-off for 1-2 min. This approach, which allows for brief pauses in physical activity (for example when stopping at a red light or tying a shoelace), is recommended [31] and has been used previously [5]. Bouts of physical activity were identified during wear time on valid days as defined above. Weekly time spent in bouts of moderate to vigorous physical activity for participants with 6 valid days were extrapolated to 7 days using the mean of the six valid days (mean value for the 6 valid days multiplied by 7).

#### Time of year

The year was divided into four periods: January-March, April-June, July-September and October-December. The Swedish climate offers substantial weather variation. According to the Swedish Meteorological and Hydrological Institute ([www.smhi.se/en/services](http://www.smhi.se/en/services)), daily mean air temperature varied between  $-7^{\circ}\text{C}$  and  $+19^{\circ}\text{C}$  in the city of Stockholm during the data collection period. January-March was the coldest period with a daily mean temperature of  $-1^{\circ}\text{C}$ .

#### Socio-demographic information

Participants' socio-demographic information was based on self-report. Age was categorized as 20-30 years, 31-40 years, 41-50 years and 51-66 years. Marital status was dichotomized as married/cohabiting or single. Income was calculated by dividing the gross family income by number of people living in the household, with children under the age of 18 being given a consumption weight of 0.5. Income was then categorized as low ( $<150,000$  SEK/year), middle (150,000-349,999 SEK/year) and high ( $\geq 350,000$  SEK/year).

#### Statistical analysis

The association between availability of exercise facilities and time spent in moderate to vigorous physical activity was analyzed by linear regression. Non-parametric cluster bootstrap estimates with 1,000 replications were applied due to the skewed distribution of the physical activity data. It is a method that constructs a number of resamples of the original dataset, each obtained by random replacements of the original dataset and assuming an identically distributed population. Bootstrapping techniques have been used in previous studies of the association between environmental attributes and physical activity [24,32]. Two models were created: a crude model including only availability of exercise facilities and physical activity, and a full model also including sex, age, income, marital status and time of year. The full model was also adjusted for accelerometer wear time since it

was found to be a potential confounder (inclusion of this variable in the model resulted in a 10% change of the regression coefficients). Standard errors were corrected for clustering effects as the data were collected within 32 neighborhoods. The regression coefficients represent differences in minutes per day compared to the reference group. Interactions and multicollinearity between the explanatory variables in the full model were examined.

The association between availability of exercise facilities and whether or not participants met the physical activity recommendations (yes/no) was analyzed by logistic regression. Two models were created: a crude model including only availability of exercise facilities, and a full model also including sex, age, income, marital status and time of year. Accelerometer wear time was not a confounder and was not included in this model. Standard errors were corrected for clustering effects in the data. Interactions between explanatory variables in the full model were examined. Goodness of fit was estimated by the Hosmer-Lemeshow test [33].

All statistical analyses were performed using STATA 10.1 (StataCorp, College Station, Texas, USA) and statistical significance was determined at  $\alpha < 0.05$ .

#### Non-response analysis

Results from a telephone-based non-response analysis of 205 randomly selected non-responders showed that the proportion of females was slightly higher among participants compared to non-participants. Participants were slightly older than non-participants. There was no significant difference in income between participants and non-participants.

#### Ethics

Ethical approval for this study was granted by the Ethics Committee of Karolinska Institutet, Stockholm. Written informed consent was obtained from all participants.

### Results

#### General results

Descriptive statistics for the study participants are shown in Table 1. The overall median time spent in moderate to vigorous physical activity was 42 min per day (interquartile range = 28-58 min). The median time spent in moderate to vigorous physical activity among participants with 0, 1-3 and  $\geq 4$  exercise facilities within their buffer zones was 41, 41, and 47 min/day, respectively. The corresponding median time spent in 10-min bouts of moderate to vigorous physical activity was 14, 13 and 18 min/day, respectively. Overall, 35% of participants met the physical activity recommendation of  $\geq 150$  min of moderate to vigorous physical activity per week (31, 33 and 44% of participants with 0, 1-3, and  $\geq 4$  exercise facilities within their buffer zones, respectively).

55% of the participants were females; 77% were married/cohabiting. 57% were in the middle income group and 40% were over the age of 50.

#### Time spent in moderate to vigorous physical activity

Results from the crude linear regression model (Table 2, model A) show that participants with  $\geq 4$  exercise facilities within their buffer zones spent 5.4 more minutes per day in moderate to vigorous physical activity than those with no exercise facilities within their buffer zones (regression coefficient = 5.4, CI = 2.2-8.5). This difference remained statistically significant when sex, age, income, marital status, time of year and accelerometer wear time were included in the model (Table 2, model B). There was no significant difference in time spent in moderate to vigorous physical activity between participants with 1-3 exercise facilities within their buffer zones and those with no facilities. Single participants spent more time in moderate to vigorous physical activity than their married/cohabiting counterparts and participants aged 20-30 spent more time in moderate to vigorous physical activity than those over the age of 30. Neither time of year nor any of the other explanatory variables modified the association between availability of exercise facilities and time spent in moderate to vigorous physical activity (i.e., there was no effect modification).

#### Meeting physical activity recommendations

The crude logistic regression model shows that having  $\geq 4$  exercise facilities within the buffer zone was associated with 70% higher odds of meeting the recommendations compared to having no exercise facilities within the buffer zone (OR = 1.70, CI = 1.39-2.08) (Table 3, model A). This difference remained significant after adjustment for sex, age, income, marital status and time of year (OR = 1.69, CI = 1.39-2.05) (Table 3, model B). None of the explanatory variables modified the association between availability of exercise facilities and meeting the physical activity recommendations.

### Discussion

The main findings of this study were that participants with four or more exercise facilities within 1,000-meter road network buffer zones surrounding their residences spent more time in objectively assessed moderate to vigorous physical activity, and were more likely to meet the physical activity recommendations, compared to participants with no exercise facilities within their buffer zones. This association was independent of sex, age, income, marital status and time of year.

Our findings are in accordance with the results of a previous study, which showed a significant association between objectively assessed density of exercise facilities within circular buffer zones and self-reported frequency



**Table 1 Descriptive statistics for the 2,037 individuals included in the study**

	All	Availability of exercise facilities		
		0	1-3	≥4
		n = 964	n = 626	n = 447
	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)
Moderate to vigorous physical activity (min/day)	42 (28-58)	41 (27-57)	41 (28-58)	47 (32-63)
Accelerometer wearing time (min/day)	861 (814-902)	862 (819-903)	863 (813-906)	855 (803-893)
	n (%)	n (%)	n (%)	n (%)
<i>Physical activity recommendations met</i>				
• Yes	704 (35)	303 (31)	205 (33)	196 (44)
• No	1333 (65)	661 (69)	421 (67)	251 (56)
<i>Gender</i>				
• Male	912 (45)	457 (47)	272 (43)	183 (41)
• Female	1125 (55)	507 (53)	354 (57)	264 (59)
<i>Age (years)</i>				
• 20–30	214 (11)	87 (9)	71 (11)	56 (13)
• 31–40	415 (20)	205 (21)	130 (21)	80 (18)
• 41–50	590 (29)	270 (28)	197 (31)	123 (28)
• 51–66	818 (40)	402 (42)	228 (36)	188 (42)
<i>Income</i>				
• Low	383 (19)	174 (18)	137 (22)	72 (16)
• Middle	1159 (57)	570 (59)	351 (56)	238 (53)
• High	495 (24)	220 (23)	138 (22)	137 (31)
<i>Marital status</i>				
• Married/cohabiting	1560 (77)	765 (79)	472 (75)	323 (72)
• Single	477 (23)	199 (21)	154 (25)	124 (28)
<i>Time of year</i>				
• January–March	576 (28)	254 (26)	194 (31)	128 (29)
• April–June	597 (29)	288 (30)	177 (28)	132 (30)
• July–September	257 (13)	136 (14)	73 (12)	48 (11)
• October–December	607 (30)	286 (30)	182 (29)	139 (31)

IQR: Interquartile range.

of exercise [18]. Another study from the U.S. that investigated the association between density of exercise facilities within circular buffer zones of different sizes and a range of self-reported physical activities [13] reported similar results, although the association for the smallest buffer zones (radius 0.5 miles/805 meters) was not statistically significant. In contrast, a Spanish study found no association between numbers of exercise facilities per 10,000 inhabitants and self-reported physical activity [17]. That study measured, however, the availability of exercise facilities at the province level, and the large geographic areas used may explain the lack of association. A further study from the U.S. found no association between objectively assessed availability of exercise facilities and leisure time physical activity, as assessed using the International Physical Activity Questionnaire [34].

That study was based on relatively small circular buffer zones (radius 400 meters) and a dichotomized measure of availability of exercise facilities (yes/no).

In contrast to some previous findings [13,14], none of the socio-demographic variables included in this study (sex, age, income or marital status) modified the association between availability of exercise facilities and physical activity. In a Swedish urban setting, where differences in socioeconomic status may be less pronounced than in, for example, the U.S., individuals with different incomes seem to benefit to the same extent from exercise facilities.

Several studies have reported seasonal differences in physical activity, with higher levels of physical activity during spring and summer and a decline in activity during the colder months [20-22]. A review of the effect of

**Table 2 Linear regression analysis of predictors of moderate to vigorous physical activity**

	Model A <sup>1</sup>	Model B <sup>2</sup>
<i>Availability of exercise facilities</i>		
• 0	Reference	Reference
• 1-3	0.5 (-1.4-2.4)	0.3 (-1.5-2.1)
• ≥4	5.4* (2.2-8.5)	5.4* (2.3-8.5)
<i>Gender</i>		
• Male		Reference
• Female		-2.4 (-5.2-0.3)
<i>Age (years)</i>		
• 20-30		Reference
• 31-40		-6.0* (-10.2- -1.7)
• 41-50		-7.1* (-11.4- -2.8)
• 51-66		-8.1* (-12.7- -3.5)
<i>Income</i>		
• Low		Reference
• Middle		0.9 (-2.0-3.8)
• High		3.0 (-0.8-6.8)
<i>Marital status</i>		
• Married/cohabiting		Reference
• Single		3.5* (0.8-6.2)
<i>Time of year</i>		
• January-March		Reference
• April-June		0.1 (-2.3-2.5)
• July-September		-0.8 (-4.3-2.8)
• October-December		-1.7 (-4.5-1.0)

<sup>1</sup>Univariate linear regression.

<sup>2</sup>Multiple linear regression including all variables and adjusted for accelerometer wearing time in min/day.

\*P < 0.05.

Numbers represent regression coefficients (with 95% confidence intervals) in minutes/day, n = 2,037.

season on physical activity from 2007 concluded that availability of exercise facilities could increase the opportunities to be physically active all year round in cold and wet climates [23]. However, we found no significant interaction between time of year and availability of exercise facilities in any of our analyses, suggesting that availability of exercise facilities is of equal importance for physical activity throughout the year.

The present study has some limitations that should be considered. It is a cross-sectional study and causality cannot therefore be determined. In addition, there may be unmeasured confounders for which we did not control for in the present study (i.e., residual confounding may exist). We cannot exclude the possibility that gyms and other exercise facilities may be established in neighborhoods where physically active people live, or that people who like to exercise move to neighborhoods with

**Table 3 Logistic regression analysis of predictors of meeting physical activity recommendations**

	Model A <sup>1</sup>	Model B <sup>2</sup>
<i>Availability of exercise facilities</i>		
• 0	Reference	Reference
• 1-3	1.06 (0.86-1.31)	1.07 (0.86-1.33)
• ≥4	1.70* (1.39-2.08)	1.69* (1.39-2.05)
<i>Gender</i>		
• Male		Reference
• Female		1.04 (0.86-1.26)
<i>Age (years)</i>		
• 20-30		Reference
• 31-40		0.78 (0.56-1.07)
• 41-50		0.88 (0.66-1.18)
• 51-66		1.09 (0.83-1.43)
<i>Income</i>		
• Low		Reference
• Middle		1.18 (0.92-1.50)
• High		1.08 (0.79-1.48)
<i>Marital status</i>		
• Married/cohabiting		Reference
• Single		1.05 (0.87-1.26)
<i>Time of year</i>		
• January-March		Reference
• April-June		1.00 (0.82-1.24)
• July-September		0.90 (0.66-1.23)
• October-December		0.82 (0.65-1.03)

<sup>1</sup>Univariate logistic regression.

<sup>2</sup>Multiple logistic regression including all variables.

Goodness of fit indices for model B: Hosmer-Lemeshow = 0.27.

\*P < 0.05.

Numbers represent odds ratios (with 95% confidence intervals), n = 2,037.

good availability of exercise facilities. This, together with the fact that our sample was recruited from a large urban region, may to some extent affect the generalizability of our results. It is also important to recognize that the physical activity recommendations are based on evidence from studies of self-reported physical activity and health outcomes. It is possible that misclassification occurred when assessing by accelerometry whether the physical activity recommendations were met. Another limitation is that we only measured the availability of exercise facilities around participants' residences and not around their workplaces or their route to and from work, where they may spend a considerable amount of time [35,36]. Accelerometers may also underestimate the intensity of some physical activities performed at exercise facilities (e.g. resistance training, spinning and swimming) due to lack of mid-bodily movement and the device being non-water resistant.

Compared to another population-based Swedish sample [4], our sample spent more time in moderate to vigorous physical activity (median time 42 versus 31 min/day). The other study was conducted in 2001 and its sample also included rural participants. In contrast, our sample was exclusively urban and was recruited in the capital of Sweden. However, our non-response analysis showed small or no differences in socio-demographic factors between participants and non-participants, which means that any selection bias was most likely non-differential.

The present study also has several strengths. We were able to use detailed road network data including not only roads, but also cycle paths and footpaths. There were considerable differences when visually comparing the road network alone and the road network combined with cycle paths and footpaths. The use of these detailed network data to produce line-based buffer zones around participants' residences likely gave a good picture of the areas that are actually accessible to participants. By using objective data on availability of exercise facilities we were able to exclude the possibility of same-source bias (i.e., physically active persons reporting a higher availability of exercise facilities compared to their less active counterparts). Furthermore, accelerometers, unlike self-report, do not suffer from bias due to social desirability and recall problems [37], although it is possible that accelerometers may create some reactivity to wearing the device. However, any such bias is most likely non-differential, i.e., equal in all types of neighborhoods.

The association between availability of exercise facilities and physical activity that was identified in this study could be explained by a number of possible mechanisms. Having a large number of exercise facilities near one's home may increase the chance of finding a mode of exercise that is attractive in terms of type of activity, cost and social atmosphere. This may explain why participants with  $\geq 4$  exercise facilities within their buffer zones were more physically active compared to those with no facilities, while participants with 1-3 facilities were not. The mere presence of exercise facilities could, by putting physical activity in the minds of passers-by, also increase the overall levels of physical activity and not just exercise performed at these facilities. In agreement with this hypothesis, Sallis et al. showed that the presence of exercise facilities close to the individuals' homes did not seem to be associated with participation in the specific activities offered at those facilities, but rather with an increased overall exercise frequency [18].

## Conclusions

Our results show that objectively measured availability of exercise facilities is associated with accelerometer-assessed time spent in moderate to vigorous physical activity and the odds of meeting recommended levels of

physical activity. Time of year had no modifying effect on these associations. Neighborhoods may be a logical and potentially significant venue for policy interventions aimed at increasing physical activity in the overall population as they have the potential to affect many people over long periods of time. In future studies, we suggest researchers to improve causal inferences by performing longitudinal studies and assess the availability of exercise facilities around people's workplaces. Future studies are also encouraged to assess location-specific physical activity to discriminate physical activity performed within the neighborhood from that performed outside the neighborhood.

## Competing interests

None of the authors has any conflicts of interest to declare.

## Authors' contributions

All authors contributed to the conception and design of the study. UE and KS contributed to the acquisition of data. UE performed the statistical analysis and all authors contributed to the interpretation of data. All authors contributed to revision of the manuscript for important intellectual content and approved the final version.

## Acknowledgements

This study was supported by grants to Dr Kristina Sundquist from the Swedish Council for Working Life and Social Research (FAS; 2006-0386) and The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (Formas; 2006-1196). The authors want to thank Naomi Kawakami for her excellent handling of the GIS data used in this study.

Received: 14 November 2011 Accepted: 25 July 2012

Published: 3 August 2012

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doi:10.1186/1471-2458-12-607

**Cite this article as:** Eriksson et al.: Availability of exercise facilities and physical activity in 2,037 adults: cross-sectional results from the Swedish neighborhood and physical activity (SNAP) study. *BMC Public Health* 2012 **12**:607.

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