Assessment of active commuting behaviour – walking and bicycling in Greater Stockholm
Till min familj
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Abstract


Walking and bicycling to work, active commuting, can contribute to sustainable mobility and provide regular health-enhancing physical activity for individuals. Our knowledge of active commuting behaviours in general and in different mode and gender groups in particular is limited. Moreover, the validity and reproducibility of the methods to measure the key variables of the behaviours are uncertain. The aims of this thesis is to explore gender and mode choice differences in commuting behaviours in terms of distance, duration, velocity and trip frequency, of a group of adult commuters in Greater Stockholm, Sweden, and furthermore to develop a criterion method for distance measurements and to assess the validity of four other distance measurement methods. We used one sample of active commuters recruited by advertisements, n = 1872, and one street-recruited sample, n = 140. Participants received a questionnaire and a map to draw their commuting route on. The main findings of the thesis were, firstly, that the map-based method could function as a criterion method for active commuting distance measurements and, secondly, that four assessed distance measurement methods – straight-line distance, GIS, GPS and self-report – differed significantly from the criterion method. Therefore, we recommend the use of correction factors to compensate for the systematic over- and underestimations. We also found three distinctly different modality groups in both men and women with different behaviours in commuting distance, duration and trip frequency. These groups were commuters who exclusively walk or bicycle the whole way to work, and dual mode commuters who switch between walking and cycling. These mode groups accrued different amounts of activity time for commuting. Through active commuting per se, the median pedestrian and dual mode commuters met or were close to the recommended physical activity level of 150 minutes per week during most months of the year, whereas the single mode cyclists did so only during the summer half of the year.

Keywords: walking, cycling, commuting, validity, reproducibility, distance, duration, velocity, frequency, seasonality.

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Abstract


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List of papers

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Preface

This thesis emanates from the Research Unit for Movement, Health and Environment at the Swedish School of Sport and Health Sciences in Stockholm, Sweden. The research unit has a focus on the multidisciplinary field of physical activity, public health and sustainable development.

The thesis is part of the research project Physically Active Commuting in Greater Stockholm (PACS). It combines three research fields: behaviour, environment and physiology.

The PACS project has three overall aims: (1) to illustrate the characteristics of existing patterns of behaviour and environments related to physically active commuting in Greater Stockholm, (2) to illustrate the impact of these patterns of physical activity on physical and mental health and well-being, and, finally, (3) to illustrate the extent to which existing patterns of physically active commuting can be applied within the population of Greater Stockholm during the current and improved conditions. This thesis deals mostly with the first aim, but, to some extent, also with the second and third aim.

I have been involved in the PACS project since its start in 2004, and this thesis is the first one from that project.
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1. Introduction

Every thesis evolves in a context. This is the first thesis on active commuting in Sweden within a scientific field that emanates from gymnastics, sport and outdoor recreation. Within this broad field an interest in aspects of everyday physical activity and health has developed during the past decade and it is within that realm that this thesis appears.

An important aspect of physical activity and health is measurements of individuals' behaviours under free-living conditions. When I started with research in 2004, it soon became clear that there was a lack of validated methods for measuring the physical activity of large groups of bicycling and walking commuters.

Distance is in this respect a key variable and two of my studies deal with investigations of how to measure route distance. In the third study, the physical activity behaviour of different modes of active commuting in men and women is studied in the metropolitan area of Greater Stockholm.

During my time as a doctoral student, more and more research on active commuting has emerged, but still it is in an early phase of development. In 2008 the well-known exercise scientist Roy Shephard (2008) reviewed the 'state of the art' and proposed a number of areas that needed further research:

Much more information is needed before we can make a categorical assessment of the impact of active commuting on population health. We need a more detailed picture of the typical dose of exercise arising from such activity (the typical duration and intensity of bouts, and number of times performed per week), […] More objective information is also needed on how to persuade the general population to engage in active commuting; this should involve studies not only of counseling, but also of the built environment; how could simple and more complex modifications of the urban landscape encourage active transportation? (Shephard, 2008)

In this introduction to the thesis, I will take off from Shephard’s proposals and questions about the dose and barriers of active commuting. But I will also take the subject slightly further by introducing aspects of the view of the transport research on active commuting behaviours. Thereby, I will give a rather broad overview of the field. A reader who is not interested in these wider perspectives is recommended to move on to section 1.5, from which there is a more narrow focus on the specific research aims of the thesis.

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possible importance of the behaviour and at the same time display how this behaviour is treated in the statistics. Second, I summarize the main outcomes and the barriers and facilitators of the behaviours from both a transport and a physical activity perspective. Third, I give a brief overview of the theoretical frameworks of measurement, and conclude, from my perspective, what is most important to measure and, finally, I describe the methods used to measure these variables. The Introduction ends with the overall aim: to explore adults’ active commuting behaviours in a Nordic metropolitan setting, which is Greater Stockholm.

1.1 Walking and bicycling commuting behaviours

1.1.1 What is active commuting?
Active commuting comprise a number of different active transport modes like velomobiles, rollerblades, jogging, running, but the most common forms are most certainly walking and bicycling. In the following, the term active commuting will refer to these two modes. Moreover, there are many forms of commuting that also include an active mode for one part of the journey, but car or public transport for the remaining part. Here I chose to isolate the behaviour of interest and focus on active commuting performed with one mode per journey the whole way from home to workplace. This excludes, for example, walking and cycling as a feeder mode to public transport. The rationale for excluding multimodal trip chains was primarily scientific, as I believe that the active behaviour is best studied unaffected by the limitations imposed by other modes used in a journey.

1.1.2 Why should one study active commuting?
Active commuting is a widespread behaviour in our society. Thousands of individuals in Stockholm and elsewhere walk and cycle to work on a normal weekday. Exactly how many is not very well known due to the use of rather crude survey methods, as discussed in section 1.1.3. The active commuters, who can be assumed to be a large group, get several beneficial outcomes from their active commuting. I will describe the positive and negative outcomes of the behaviours for society and individuals in section 1.2. Many of the benefits of commuting are linked to how long distance and how often people commute, but the methods used for determining distance and frequency are often crude and their accuracy is unknown. There are many factors that determine whether people commute by active modes or passive ones and how frequently they use certain modes. However, little is known about these factors; therefore, I give a brief overview of the state of knowledge in section 1.3. Among these factors, the distance

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between home and workplace sticks out as a key variable. For instance, the potential for new active commuters in a population is often estimated from commuting distance. Thus, active commuting is an important, but understudied, behaviour and in studies of active commuting, distance is a key variable that needs to be assessed with better methods than today.

In this thesis, active commuting is walking and bicycling to a place of work or study. This makes active commuting a subset of active transport that is an even more common behaviour than commuting since it includes all walking and bicycling for transport purposes. However, there are several characteristics that make active commuting interesting to study in particular, apart from active transport in general. First, commuting is a behaviour that is repetitive and easily becomes a habit. If walking and bicycling is performed habitually, then the mode and route choices are no longer made actively as assumed in mainstream transport economic theory, but by default. Thus, previous findings regarding non-repetitive active transport behaviours are not fully applicable. Second, active commuting provides an opportunity for individuals to integrate regular physical activity into their lifestyle and thereby might be able to overcome the frequently stated ‘lack of time’ barrier to physical activity (see, e.g. Trost, Owen, Bauman, Sallis, & Brown, 2002). Third, commuting is a prevalent behaviour covering a large number of people, as described below. Fourth, since a large portion of the adult population work outside home, rush-hour commuting levels are often used for dimensioning the urban transport systems. If the commuting modal split was changed to less space-demanding transport modes, such as walking and cycling, there would be large benefits for society. Fifth, others have found that the factors that influence walking and cycling for commuting are different to those influencing leisure time walking and cycling (see, e.g. Anable & Gatersleben, 2005). All this merits a study of active commuting in particular.

1.1.3 Perspectives on walking and bicycling commuting

Bicycling might not require a definition, but it can be separated from the use of other human-powered vehicles with more than two wheels and also from electrically assisted bicycles (see Rosen, Cox, & Horton, 2007). Non-sport walking can be separated from other forms of locomotion like jogging and running mainly due to the lower velocity. There are no sharp thresholds for walking and jogging, but, according to Morris and Hardman (1997), at 7.2 km/h the walking starts to shade into jogging.

Walking and cycling have been studied from different perspectives and in different research contexts and have been labelled mostly according to the purpose, for example: as leisure, sport, transport and physical activity.
Subsequently, it is also assessed in different research fields such as transport, planning, transport geography, sport and physical activity, but with different scopes and methods. However, today and in the past the focus of these research fields has not been on walking and cycling, instead they have been looked upon as fringe modes in the transport system, or non-important, low-intensity forms of physical activity. The low interest in the behaviours is also noticeable in the survey data. In some such data, walking and cycling even form a residue category together with other small transport modes like mopeds, motorcycles and sometimes even transit, or merge walking and cycling into a single category. These categories have different labels depending on which sector collected the survey data: for example, non-motorized modes, green modes, soft modes or active modes.

In addition to commuting by one active mode on all days, there is also a possible commuting strategy where people switch between walking and cycling from day to day or from a seasonally pattern. In the following, I will refer to this commuting strategy as dual mode commuting. Since commuting easily becomes a habit, this group of commuters is interesting to study because they evidently have no mode-specific habit. Perhaps they are making their travel choices actively instead of passively continuing a habit. Dual mode commuters also have experience of two active modes, which might form their perceptions of the commute and of the urban environment, for example, in distance estimations (Mondschein, Blumenberg, & Taylor, 2010). This dual mode behaviour has not yet been captured by the survey statistics or in research. Nevertheless, in this thesis, the dual mode commuting strategy behaviour will be explored.

The main purpose of commuting is obviously to get to a place of work or study, but the purpose for the individual commuter might also encompass commuting as a source of physical activity or an opportunity to be outdoors or to feel the city pulse. Thus, there might not be one single reason for choosing a certain mode, but a multitude of reasons intertwined. Yet, in the Swedish national transport statistics, and in other statistics, journeys are labelled from a few main journey endpoints: for example, journey to work. If you leave your child at a nursery on the way to work, then the purpose of the journey is still commuting, but the journey now consists of two trips that constitute the journey, each trip with a single purpose. Moreover, if the transport mode is changed during a journey or a trip, each part performed using a certain transport mode is called a stage. In general, the mode used for the longest distance stage determines the mode category label for the whole journey. Therefore, in the statistics, if you walk or bicycle to a commuter train, the whole journey is categorized as a public transit journey. Short active commuting stages, containing lots
of physical activity, are thereby masked in the statistics. Thus, since transport statistics normally label journeys from the transport mode used for the longest part of a journey, the amount of physical activity included in commuting trips in the population is uncertain. Therefore, little is known about the exact amount of active commuting in the working population. To avoid the problems with several modes per trip, in this thesis, I will focus on the clear-cut form of active commuting with one single active mode used for the whole trip.

1.1.4 Prevalence of walking and cycling for commuting and other purposes

In the following sections I will give an overview of what is known about the levels of walking and bicycling for transport and little about walking and bicycling for all purposes since data on active commuting in particular are scarce. By prevalence of the behaviour I mean the percentage of the population that has certain behaviour. When the behaviour is active commuting the population of interest is the working and studying population whereas in walking and cycling for all purposes, it is the total population. The significance of the behaviour could be expressed dichotomously as something you do or do not do, but it could also be expressed in the number of travelled kilometres or hours in relation to all travelled kilometres or hours. Here I will refer to different types of measures given in the official data on how common the active commuting behaviours are.

I start with a retrospective view of the historic levels and then turn to the global level, Swedish national level and, finally, the levels in Stockholm, the study area.

1.1.4.1 Temporal trends

In the 20th century, walking and bicycling have played a large role in the urban transport systems and have probably also contributed to the physical activity levels in the urban populations. After the Second World War the levels of walking and bicycling have changed dramatically in most European and American cities, both in percentage of all journeys and in travelled kilometres (see, e.g. Pucher & Buehler, 2010; Shephard, 2008). In the 1970s, in connection with the oil crisis, many countries experienced a bicycling renaissance – also Sweden. In Stockholm it took the form of a new political interest in bicycling and provisions of new infrastructure for bicycling. Later, in the 1980s, the interest faded away in most cities, including Stockholm, until a new boom appeared from the late 1990s and onwards (Dufwa, 1985; Emanuel, forthcoming 2012; Traffic Office; City of Stockholm, 2008). In The Netherlands, Denmark and parts of Germany the
interest in bicycling continued to be strong. The decreases in both walking and cycling commuting in most countries have taken the form of a mode shift in favour of car commuting (see, e.g. Pooley & Turnbull, 2000).

1.1.4.2 Walking and cycling outside Sweden

Walking and cycling are probably the world’s most common forms of physical activities. I write ‘probably’ because there are almost no reliable statistics on the global level of prevalence of physical activity in general or walking and cycling in particular. Available data consist of a patchwork of different survey designs from different countries and regions emanating from both the transport and the public health sector. In addition, until lately few international institutions have shown an interest in the surveillance of active transport and commuting; consequently, there has been no standardization of survey instruments between countries. However, today there are two international surveillance systems for monitoring trends in physical activity: first, the Global Physical Activity Questionnaire (GPAQ) developed by the World Health Organization (WHO) and adapted to developing countries (Armstrong & Bull, 2006; Bull, Maslin, & Armstrong, 2009), and secondly, the similar International Physical Activity Questionnaire (IPAQ) developed to compare the physical activity prevalence in developed countries (see, e.g. Bauman et al., 2009; Craig et al., 2003). IPAQ is available in a long and short form (see www.ipaq.ki.se). The long version assesses physical activity exceeding 10 minutes per bout for each activity domain, i.e. leisure time, transportation, domestic, occupation of vigorous, moderate intensities and walking during the last seven days, while the IPAQ short version does not separate the activity domains (see, Sjöström, Oja, Hagströmer, Smith, & Bauman, 2006). The IPAQ is mostly used in its short version without specific questions about transport.

In addition to the surveillance systems, there are also single assessments of physical activity behaviours. In Europe, for example, Vaz de Almeida and co-workers reported that, on an average, in a representative European sample, 31% of the adults in EU countries reported leisure-time walking during one week. This placed walking at the top of the list of the most frequent physical activities. Cycling was number 3 on the list (Vaz de Almeida et al., 1999). The study was conducted during March and April, 1997, and comprised the last week’s physical activities (Kearney, Kearney, McElhine, & Gibney, 1999).

The levels of walking and cycling for transport in the population have also been surveyed within the transport sector, but contrary to the physical activity surveillance, there are no standardized common instruments to monitor transport and travel behaviour. There are also cross-country stud-
ies on levels of walking and bicycling transport in the population, performed by, e.g. John Pucher and co-workers, comparing rates in Australia, North America and certain European countries (see, e.g. Pucher & Buehler, 2008; Pucher & Buehler, 2010). However, these comparisons concern walking and bicycling for all purposes, and not commuting in specific, and it is also uncertain if they refer to journeys, trips or stages. Furthermore, the proportion of recreation and transport bicycling and walking might differ largely between countries, so the figures should be interpreted with caution. For instance, in car-centric cultures like the USA, walking and bicycling for recreation is the most common purpose, whereas in, e.g. Germany, people frequently walk and cycle also for transport (Buehler, 2011). A somewhat dated dataset, but interesting anyway, is the WAL-CYNG project that compiled statistics on short trips in a number of European countries, as shown in Table 1 (Solheim & Stangeby, 1997). Even though the data are uncertain, at least they give an indication of differences and similarities between countries, as shown in Figure 1.

A third source of information about active commuting levels is the time-use surveys performed in different countries (see, e.g. Adams, 2010). There are comparable time-use data for 15 countries thanks to the Eurostat project ‘Harmonized European Time Use Surveys’ (HETUS). In the HETUS database the commuting time to work is specified per transport mode, but regrettably, in the official reports the specific commuting categories are collapsed into one (Statistics Sweden, 2011).

To sum up, the three main sources of data on the levels of active commuting behaviours in the populations all have major weaknesses. The physical activity surveillance instruments are normally not specific enough to differentiate between walking and bicycling for different purposes. On the other hand, the transport surveys measure active commuting, but use non-standardized methods, sometimes merging walking and bicycling and counting only the main transport mode in a chained journey and masking. The time-use studies are standardized, but limited to the commuting time and are sometimes not divided into transport modes and time-use studies say nothing about, e.g. distance covered. Thus, better methods to cover the active commuting behaviours are needed as well as better co-operation between sectors so surveillance data compiled in one sector could have a quality that fits the requirements of the other sectors. Methods then need to be adapted to serve the purpose of surveillance in multiple fields and purposes, including physical activity, transport and time-use surveillance.
Table 1. Number of trips per person per day in ten European countries, from Solheim & Stangeby (1997).

<table>
<thead>
<tr>
<th>Country</th>
<th>Year</th>
<th>On foot</th>
<th>Bicycle</th>
<th>Car as driver</th>
<th>Car as passenger</th>
<th>Public transport</th>
<th>All trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norway</td>
<td>1991/92</td>
<td>0.66</td>
<td>0.20</td>
<td>1.70</td>
<td>0.39</td>
<td>0.26</td>
<td>3.25</td>
</tr>
<tr>
<td>Sweden</td>
<td>1994/95</td>
<td>0.48</td>
<td>0.37</td>
<td>1.25</td>
<td>0.50</td>
<td>0.33</td>
<td>2.93</td>
</tr>
<tr>
<td>Finland¹</td>
<td>1992</td>
<td>0.39</td>
<td>0.22</td>
<td>1.66</td>
<td>0.42</td>
<td>0.25</td>
<td>2.97</td>
</tr>
<tr>
<td>Denmark²</td>
<td>1992</td>
<td>0.30</td>
<td>0.50</td>
<td>1.40</td>
<td>0.30</td>
<td>0.30</td>
<td>2.90</td>
</tr>
<tr>
<td>Great Britain</td>
<td>1992/94</td>
<td>0.84</td>
<td>0.05</td>
<td>1.07</td>
<td>0.63</td>
<td>0.25</td>
<td>2.88</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>1994</td>
<td>0.67</td>
<td>1.01</td>
<td>1.28</td>
<td>0.51</td>
<td>0.19</td>
<td>3.74</td>
</tr>
<tr>
<td>Germany</td>
<td>1989</td>
<td>0.79</td>
<td>0.34</td>
<td>1.06</td>
<td>0.34</td>
<td>0.28</td>
<td>2.82</td>
</tr>
<tr>
<td>Austria (Ober)</td>
<td>1992</td>
<td>0.55</td>
<td>0.18</td>
<td>1.41³</td>
<td>-</td>
<td>0.37</td>
<td>2.59</td>
</tr>
<tr>
<td>Switzerland</td>
<td>1989</td>
<td>0.75</td>
<td>0.33</td>
<td>1.72³</td>
<td>-</td>
<td>0.46</td>
<td>3.50</td>
</tr>
<tr>
<td>France-Grenoble</td>
<td>1992</td>
<td>0.98</td>
<td>0.16</td>
<td>1.48</td>
<td>0.45</td>
<td>0.48</td>
<td>3.58</td>
</tr>
<tr>
<td>France-Lyon</td>
<td>1985</td>
<td>1.15</td>
<td>0.06</td>
<td>1.23</td>
<td>0.38</td>
<td>0.47</td>
<td>3.31</td>
</tr>
</tbody>
</table>

Notes.¹ trips longer than 200 m, ² trips longer than 300 m, ³ Trips as driver and passenger
1.1.4.3 Active commuting in Sweden

At the Swedish national level, the same three general data sources on walking and bicycling prevalence are available as at the international level. However, the Swedish health monitoring and surveillance instrument ‘Folkhälsoenkäten’, distributed by the Swedish National Institute of Public Health, contains no questions about walking and cycling or active commuting in particular, which makes it inadequate for surveillance of active commuting behaviours.

In the transportation sector more data are available on walking and cycling prevalence in general and active commuting in particular. The Swedish Survey of Living Conditions, ‘Undersökningen av levnadsförhållanden’ (ULF), collects information about the living conditions of a random sample of the Swedish adult population by face-to-face interviews at the respondent’s home. The ULF survey also collects data on active commuting. The latest data on commuting are from 1999 (Persson & Häll, 2004) and are displayed in Table 2.

Another data source is the National Travel Survey (RES) (SIKA, 2007). The latest survey was conducted for a year, with telephone interviews all days from the autumn of 2005 until the autumn of 2006. It was conducted on a daily basis to avoid a seasonality bias. RES contains data on both everyday travel and longer journeys made by Sweden’s population aged between 6 and 84 years together with questions about the individuals. Twenty-seven thousand interviews were made, corresponding to a response frequency of 68%. The trip distances stated by the respondents are displayed in Table 2. Some participants did not know their distance and these distances were calculated afterwards instead from distance tables (SIKA, 2007 Attachment: Instructions for the interviewer).

A third data source is the National Time-Use Survey that covers the time allocated to commuting in Sweden. It has been performed three times 1990/91, 2000/01, 2010/11 (forthcoming). The Swedish Time-Use Survey 2000/01 is also part of HETUS mentioned above (Statistics Sweden, 2003). The mean time-use for commuting, round trip (i.e. the journey to work and back again), on weekdays, is 51 minutes for women and 59 minutes for men. Mode type is not specified, although the transport mode is traceable in raw data (Statistics Sweden, 2003, p. 138). From the HETUS database, walking and bicycling time for all purposes are found and displayed in Table 2.
Table 2. Walking, bicycling and active commuting in Sweden.

<table>
<thead>
<tr>
<th></th>
<th>Walking</th>
<th></th>
<th>Cycling</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Men</td>
<td>Women</td>
<td>Men</td>
<td>Women</td>
</tr>
<tr>
<td>Percent of all journeys, RES 05/06¹</td>
<td>20</td>
<td>27</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Percent of journeys to work, ULF 99</td>
<td>8</td>
<td>14</td>
<td>14</td>
<td>21</td>
</tr>
<tr>
<td>Mean stage distance in km, RES 05/06</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Mean time in min. per day²</td>
<td>35</td>
<td>37</td>
<td>39</td>
<td>39</td>
</tr>
</tbody>
</table>

Notes. ¹RES 2005/06 comprise ages 6 to 84 years, i.e. including journeys to school, not including trips for part of a journey. ²walking and cycling for all purposes from HETUS 2000/01 including ages 20-74 years.

1.1.4.4 Active commuting in Stockholm

At the regional level in Stockholm there are data from a large travel survey (RVU04) distributed to 77,000 individuals in Stockholm County from 20 September to 3 October 2004; 36,081 persons responded to the survey which included questions about the individual and the household and a one-day travel diary. Analyses of the drop-out showed small differences, but respondents who had access to a car and a public transport pass to a larger extent made more trips and used car a little less than the drop-out group. The survey was performed as part of the evaluation of the Stockholm trials of congestion charging described in Allström et al. (2006). The active commuting levels are displayed in Table 3. In the travel diary, participants filled in the origin and destination addresses of each journey and the time when they started and stopped the journey. These data were used to calculate travel time and distance. The commuting times were based on the participant’s own statements, but time values that implied extreme velocities were removed. Distances were calculated from an origin and destination matrix of network distances between midpoints of traffic analysis zones in Stockholm. Short trips within one zone were instead assigned standard distance estimates based on manually calculated distances of random short trips within zones. The standard distance estimate for each transport mode was then set to a value between the median and the mean value. Evidently, this procedure made the validity of the distances estimates somewhat uncertain.
Table 3. Active commuting levels in Stockholm County from RVU04.

<table>
<thead>
<tr>
<th></th>
<th>Walking</th>
<th></th>
<th></th>
<th>Cycling</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Men</td>
<td>Women</td>
<td>Men</td>
<td>Women</td>
<td></td>
</tr>
<tr>
<td>% of journeys</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n=15 862)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance, in km</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean ± 1 SD</td>
<td>1.8 ± 2.0</td>
<td>1.6 ± 1.5</td>
<td>6.9 ± 5.3</td>
<td>4.5 ± 3.6</td>
<td></td>
</tr>
<tr>
<td>Median (Q1-Q3)</td>
<td>1.3 (0.5-2.6)</td>
<td>1.1 (0.5-2.2)</td>
<td>5.5 (3.0-9.3)</td>
<td>3.6 (2.0-6.4)</td>
<td></td>
</tr>
<tr>
<td>Time, in minutes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean ± 1 SD</td>
<td>18 ± 18</td>
<td>17 ± 13</td>
<td>22 ± 14</td>
<td>18 ± 12</td>
<td></td>
</tr>
<tr>
<td>Median (Q1-Q3)</td>
<td>15 (10-25)</td>
<td>15 (10-20)</td>
<td>20 (15-30)</td>
<td>15 (10-23)</td>
<td></td>
</tr>
</tbody>
</table>

Notes. Main mode for one-way journeys to work and school for ages >19 years, own processing of the RVU04 database.

For the municipality of Stockholm and other Swedish cities there are also annual measurements of flows of bicyclists passing certain spots (Niska et al., 2010; Traffic Office; City of Stockholm, 2008). These bicycle counts are helpful to spot trends in the number of cyclists in absolute terms, but in a city like Stockholm with a large influx of people, changes in modal split are difficult to judge from the counts. Moreover, it is impossible to separate commuting bicyclists from leisure bicyclists.

1.1.5. Potential for active commuting

Besides the prevalence rates that include individuals who already have the behaviour, there are also individuals who plan or hope to start walking or cycling to work, but have not yet started. They constitute the potentially new active commuters. This potential is interesting to measure and assess since these individuals ought to be the target group for interventions and promotion campaigns. Obviously, there are no national or international statistics on the size of this group, but it can be estimated in several different ways. One approach is to define the potential as those who have access to a bicycle and have a feasible distance (see, e.g. Nilsson, 1995). Another approach is to survey a representative sample of the population about their motivational readiness, assessed within a framework of the transtheoretical approach, also called stages of change approach (Prochaska & DiClemente, 1984). The commuters assigned to the stages contemplation and preparation constitute the potential (see, e.g. Gatersleben & Appleton, 2007; van Bekkum, Williams, & Morris, 2011). The two approaches can
also be combined, as in a study of Winters and co-workers that defined the potential bicyclists, all purposes, as those with access to a bicycle and who state that they are considering to start cycling in the future (Winters, Davidson, Kao, & Teschke, 2011). Although the potential bicyclists are interesting, in this study the focus has been on those who are already active commuters.

1.1.6 Summary of the section
Walking and cycling for all purpose seems to be common behaviours in many countries including Sweden. Active commuting by bike in particular seems to be much more common in some countries such as the Netherlands and Denmark, with Sweden neither on top nor at the bottom of the list. In addition, also the regional and local variations in each country seem to be large (Buehler, 2011). The pool of knowledge about walking and cycling to work and for other purposes appears to be meagre in terms of data that are aggregated to all types of physical activity and transport data that lack standardization, quality and specificity concerning the purpose of the walking and bicycling. In addition, many short trips are not reported or are masked because they are feeder trips to transit. In comparisons with other countries, different definitions of words like trip, journey, and travel-element exist as well as different standards of survey time periods and the age groups included. Moreover, pedestrians and bicyclists have been repeatedly shown to be largely underreported in transport surveys, especially for short trips (see, e.g. Stopher, FitzGerald, & Xu, 2007; Stopher & Greaves, 2007). A general explanation for the paucity of data on these behaviours is that walking and cycling for transport has been neglected in both a physical activity and a transport context. That might explain the lack of valid, reliable and low-cost methods to use in, e.g., travel surveys. The consequence of this paucity of high-quality data is that few conclusions can be drawn from the present statistics concerning the dose of physical activity in active transport and commuting. Moreover, the survey data of today cannot function as a solid base for policy interventions aiming to increase active commuting.

In sum, even if prevalence data are of varying quality, active commuting behaviours seem to be relatively common, have been very common in the past and have the potential to be more common also in the future. Therefore, there seems to be good reason to study these behaviours and also try to enhance the survey methods used to study them.
1.2 Outcomes of active commuting

There are several outcomes of the active commuting behaviours, although with different significances for the individual and society. They can be both positive and negative for the individual and for society. Two outcomes of active commuting that are often mentioned in policy documents are walking and bicycling to work as a source of daily physical activity and of sustainable mobility. These outcomes often constitute the rationale for measurements and assessments of active commuting and are therefore crucial in an overview of active commuting. However, the two main research areas covering active commuting, i.e. transportation and physical activity, stress the importance of different outcomes and I will therefore describe them separately. Nevertheless, the outcomes from both fields are sometimes combined, for example, in economic appraisals of infrastructure dedicated to bicycling and walking.

1.2.1 Outcomes of active commuting from a transport perspective

1.2.1.1 Mobility and Accessibility

A positive outcome of walking and bicycling of interest for the transport sector is that it offers sustainable mobility to the commuters. Mobility can be defined as the ability to move around (see Hoyle & Knowles, 1998, p. 187) and sustainable mobility is a mobility that is socially, economically and ecologically sustainable. However, in the mainstream transport field, mobility attains an economic value, not in itself, but from the stationary activity at the destination of the trip (see, e.g. Geurs & van Wee, 2004). This means that the journey has no value unless there is a destination that creates a value for the traveller. Mobility can contribute to increasing accessibility to places and facilitates the access of individuals to destinations. A definition of accessibility is:

...the extent to which the land-use and transportation systems enable (groups of) individuals to reach activities or destinations (Geurs & van Wee, 2004)

Accessibility depends on several things: how the transport system performs, land use patterns, individual characteristics, what activities and destinations exist, and the infrastructure. There are also many proposed measures of accessibility, from the simplest, including distance (see, e.g. Transportation Research Board & Institute of Medicine, 2005), time and mean velocity of the journey between home and destination, to more complicated measures such as Hägerstrand’s space-time prism (for reviews see, Geurs & van Wee, 2004; Handy & Niemeier, 1997). The most complex
measures are, however, often considered to be too difficult to operationalize and interpret for planners and policy-makers (Geurs & van Wee, 2004). Simpler measures like distance and time are therefore frequently used. Accessibility is sometimes claimed to be the rationale of the transport system because of the benefits it creates for the users. For instance, individuals who work away from home create values for themselves, for their employers and for society.

1.2.1.2 Positive environmental and social effects on a societal level
If one assumes that the need to travel to work is fixed, then the choice of active commuting before car commuting provides many benefits. For example, active commuting causes virtually no air pollution, no congestion, and no disturbing noise. Moreover, it poses no severe threats to other road users, has low space requirements for use and parking and consumes far less scarce resources and fossil energy than the motorized transport modes. Because they are affordable by virtually everyone, cycling and walking are among the most socially equitable of all transport modes. In brief, walking and cycling are quite outstanding when it comes to environmental, social and economic sustainability (see, e.g. Dora & Phillips, 2000; Woodcock, Banister, Edwards, Prentice, & Roberts, 2007).

1.2.1.3 Traffic safety
A negative outcome of active commuting is traffic accidents. Walking and bicycling have poorer traffic safety records compared to other transport modes (see, e.g. de Hartog, Boogaard, Nijland, & Hoek, 2010). However, the safety threats do not emanate from the active commuting behaviour itself, but is charged as a consequence of the mix of high and low velocity travellers in the transport system and their different vulnerabilities (Jacobsen, Racioppi, & Rutter, 2009). The most severe threat to bicyclists and pedestrians is the high-speed motor traffic; more correctly, low traffic safety of active commuters is an outcome that mainly originates from other, high-speed, road users’ behaviour. Somewhat simplified, the severity of accidents and fatalities stem from the velocity of the vehicles involved due to the higher kinetic energy involved (Lind & Wollin, 1986; Tranter, 2010).

The risks of a traffic accident differ within traffic environments, with intersections as high risk areas together with roads shared between high and low speed traffic (for a review see, Reynolds, Harris, Teschke, Cripton, & Winters, 2009). Older and younger individuals are more exposed to traffic accidents; children because they have not learned about the complexity of a traffic system not adapted to children’s behaviour, and the older individu-
als because they are more fragile and lose their balance more easily (de Hartog et al., 2010). Traffic safety is normally assessed in number of injuries, but the risk is also presented in relation to an exposure variable that can be commuting distance or time (see, e.g. Aultman-Hall & Kaltenecker, 1999; Nguyen & Williams, 2001). Based on empirical statistics, Jacobsen (2003) proposed a ‘safety in numbers’ effect. Briefly, it functions in such a way that increased numbers of bicyclists will make the motorists more observant and, thereby, the relative risk of accidents will decrease, even if the absolute numbers of fatalities might rise (Jacobsen, 2003). This hypothesis has been supported by statistics from, e.g. Belgium (Vandenbulcke et al., 2009) and Norway (Elvik, 2009). However, the concept of ‘safety in numbers’ has recently been criticized by Bhatia and Wier who claim that no causal inference can be made from past empiric non-linear statistics and that there are other plausible explanations for the safety in numbers effect (Bhatia & Wier, 2011).

In most countries the statistics on traffic accidents and incidents are incomplete because hospitals and police do not report minor accidents. Thus, the risks and inconveniences for active commuters might be largely underestimated (Aertsens et al., 2010; Niska & Thulin, 2009).

1.2.1.4 Exposure of inhaled pollutants

In urban environments, where active commuters share space with combustion engine vehicles like cars, diesel vans, lorries and buses, commuters might inhale polluted air that will affect their health negatively (see, e.g. de Hartog et al., 2010; Strak et al., 2010). The air pollution originates from several sources: exhaust fumes, tearing of tires and pavement and whirling dust from the street. The levels of both primary pollutants, for example NO₂ and CO; secondary pollutants, like NOₓ; and particular matter (PM) vary largely from street to street and from city to city due to the prevalence of, e.g. diesel driven cars and the number of catalytic emission controls in the car fleet. The exposure of bicyclists and pedestrians to air pollution is normally measured in relation to the inhaled volume of air, but the exposure can also be expressed in relation to walking and bicycling time or distance. As with the accidents, this negative outcome is not a consequence of the active commuting behaviour, but a consequence of others’ passive commuting by car or bus.

Bicyclists are generally less exposed to air pollutants from exhausts than car passengers and drivers because they are located farther away from the emission source (see, e.g. Int Panis et al., 2010; Rank, Folke, & Homann Jespersen, 2001). However, physically active commuters like bicyclists are found to have 4.3 times higher minute ventilation than car passengers (Int
Panis et al., 2010). Bicycling and walking with higher intensity will increase minute ventilation, but, on the other hand, a higher bicycling velocity will give lower exposure times. McNabola and co-workers (2007) compared several models with combinations of velocities and durations and the resulting exposure of the bicyclists to benzene and concluded that walking and cycling at higher velocity over a shorter duration result in less absorption of, at least, benzene than a lower velocity and longer duration (McNabola et al., 2007).

Besides the velocity, the commuters can adapt by walking or cycling outside rush hours or by changing their bicycle routes to streets with lower flows of motor traffic. Thus they might decrease their exposure to primary pollutants, such as NOx and CO, by 10 to 30% compared to the shortest route (Hertel, Hvidberg, Ketzel, Storm, & Stausgaard, 2008).

1.2.2 Health outcomes of physical active commuting

1.2.2.1 Definitions of physical activity and health

A major attribute of active commuting is physical activity. There are several definitions of physical activity, for example by Howley (2001), but the most frequently cited one is that of Caspersen:

Physical activity is defined as any bodily movement produced by skeletal muscles that results in energy expenditure. The energy expenditure can be measured in kilocalories. Physical activity in daily life can be categorized into occupational, sports, conditioning, household, or other activities. (Caspersen, Powell, & Christenson, 1985).

Physical activity can accordingly be regarded as a cluster of behaviours rather than a single behaviour. It could be everything from slow walking to performing extreme sports, as long as it results in energy expenditure. Therefore, physical activity is often divided into broad domains, defined from where and when the activity is performed, for example during work, at home, during leisure time, and during transport and sometimes also from the purpose and intensity of the activity, e.g. bicycle commuting, moderate intensity training or vigorous exercise.

In contrast to Caspersens rather wide definition of physical activity, Howley (2001) proposed a definition that delimits physical activity to:

“...contractions of skeletal muscle that substantially increase energy expenditure”.

Physical activity has been shown to positively affect health in several studies (Pate et al., 1995). However, health is a much discussed concept (see, e.g. Nordenfelt, 2004), that I need to define. A common definition of
health comes from the World Health Organization (WHO) which defines health as:

a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity /WHO, 1948.

That definition has later been criticized as unpractical because no one could achieve complete well-being. At the Ottawa Conference 1986 (WHO, 1986), health was defined instead as a resource to achieve other goals in life:

Health promotion is the process of enabling people to increase control over, and to improve, their health. To reach a state of complete physical, mental and social well-being, an individual or group must be able to identify and to realize aspirations, to satisfy needs, and to change or cope with the environment. Health is, therefore, seen as a resource for everyday life, not the objective of living. Health is a positive concept emphasizing social and personal resources, as well as physical capacities. Therefore, health promotion is not just the responsibility of the health sector, but goes beyond healthy life-styles to well-being (WHO, 1986).

The idea of health as a resource makes the concept difficult to operationalize; therefore, in practical and epidemiological applications, health is often quantified in disability-adjusted life years (DALY). DALY is a measure of overall disease burden, expressed as the number of years lost due to ill-health, disability or premature death. An alternative measure is quality-adjusted life years (QALY) which includes both the quality and the quantity of life lived (Schäfer Elinder & Faskunger, 2006).

1.2.2.2 Physical activity dose expressed as energy expenditure
Physical activity from walking and bicycling can improve the health of individuals depending on the dose of physical activity. The physical activity dose is commonly expressed in terms of energy expenditure due to the physical activity and measured in joules or calories and in relation to body weight. In laboratory tests, energy expenditure can be measured as heat production in a chamber, i.e. direct calorimetry or by measurements of oxygen consumption and carbon dioxide production via indirect calorimetry. In real-life situations the doubly labelled water method could be used. It is an accurate method, but costly, and is mostly used for small samples or as the gold standard for simpler and more practical field methods (Montoye, 1996). There are also portable instruments that can accurately measure oxygen consumption under free-living conditions (see, e.g. Rosdahl, Gullstrand, Salier-Eriksson, Johansson, & Schantz, 2010). Another approach is to estimate the energy expenditure from objective meas-

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urements of body motions and physical activity behaviours, e.g. from the number of steps with pedometers, the number of movement counts with an accelerometer or from heart rate variation. The physical activity dose can also be described by subjective perceptions of physical activity via self-reported activity diaries, questionnaires and interviews (Montoye, 1996).

The physical activity behaviours are usually described in four dimensions: frequency, duration, intensity and type of physical activity. Self-reports of these dimensions could also be used to estimate of the dose of physical activity. The frequency relates to how often an activity is performed over a specific time period that could be a day, a week, a month or a year. Duration denotes how long time the activity is performed, in hours and minutes. The intensity of the activity indicates how strenuous the activity is and the rate of energy expended while the activity is performed. Intensity might be described in terms of percentage of maximal aerobic capacity for the specific activity, VO$_2$ max. Another frequent measure of intensity is the metabolic equivalent (MET). MET is a classification of energy expenditure based on multiples of the resting metabolic rate and is a measure of intensity presented in absolute terms (Montoye, 1996). Often the estimations of energy expenditure are calculated with the aid of the Compendium of Physical Activity which has listed the mean energy costs of numerous daily, leisure and sport activities (Ainsworth et al., 2000).

1.2.2.3 Physical activity recommendations

Since physical activity has been shown to affect individuals’ health, health authorities have set up recommendations for the dose of physical activity. The most influential recommendation for the physical activity of adults is that of the Centers for Disease Control and Prevention (CDC) and the American College of Sports Medicine (ACSM). One part of the recommendation concerns physical activity and general health:

Every US adult should accumulate 30 minutes or more of moderate-intensity physical activity on most, preferably all, days of the week. (Pate et al., 1995).

This recommendation was later updated and clarified in 2007:

To promote and maintain health, all healthy adults aged 18 to 65 yr need moderate-intensity aerobic (endurance) physical activity for a minimum of 30 min on five days each week or vigorous-intensity aerobic physical activity for a minimum of 20 min on three days each week. (Haskell et al., 2007).

In addition, Haskell et al. also stated that:
Combinations of moderate- and vigorous intensity activity can be performed to meet this recommendation.

There are also Swedish and Nordic recommendations for physical activity that correspond to the CDC/ACSM recommendations (cf. Schäfer Elinder & Faskunger, 2006).

1.2.2.4 Health outcomes of physical activity
Being physically active can affect one’s health along different paths and with individual differences in magnitude due to heredity and fitness level, as described in the ‘Toronto model’ (see, e.g. Bouchard, Shephard, & Stephens, 1994). There are positive health effects of physical activity due both to the energy expended and as a result of the improved fitness of individuals. Health outcomes that have been shown to be inversely related to regular physical activity are cardiovascular disease, stroke, hypertension, type 2 diabetes, osteoporosis, obesity, colon cancer, breast cancer, anxiety and depression (see Haskell et al., 2007; Statens folkhälsoinstitut, 2008). Scientific evidence continues to accumulate, and there might be other health outcomes added to the list in future updates of the recommendations.

The relation between health and the volume of physical activity is often described as a dose-response curve, which is positive and curvilinear (see, e.g. figure in Pate et al., 1995, p. 404). This indicates that the greatest benefits of one unit of increased physical activity are achieved by those who are sedentary or lowly active, whereas highly active individuals have smaller benefits per increment. However, the exact form of the dose-response curve is very uncertain and most certainly the form differs with different health outcomes.

Active commuting in particular has been assessed in longitudinal studies in relation to premature mortality (see, e.g. Andersen, Schnohr, Schroll, & Hein, 2000; Besson et al., 2008; Matthews et al., 2007). The study by Andersen et al. (2000) was conducted with a cohort from Copenhagen, Denmark, that was followed for an average of 14.5 years. They analysed the bicycle commuting of 783 women and 6171 men and found a lower relative risk of all-cause mortality of 0.72 (95% CI, 0.57–0.91) of the cyclists compared to non-cyclists. The relative risk figure was adjusted for multiple confounders, e.g. leisure-time physical activity. Matthews et al. (2007) looked at cycling for transport and its association with mortality of all causes among a cohort of about 70 000 Chinese women who were followed for an average of 5.7 years. The study found that, the risk of premature death from all causes was 0.79 for cycling women who cycled up to 1
hour per day and 0.66 for women who cycled more than 1 hour per day (>3.4 MET/h/day) compared to non-cyclists. The relative risk figure was adjusted for multiple confounders, e.g. other types of physical activity. Besson et al. (2008) studied the relationship between physical activity from the transport domain and mortality. They used a population-based cohort from the United Kingdom with 14,905 men and women followed for 6-8 years. Adjusted hazard ratios for both all-cause and cardiovascular mortality were non-significant for all three cycling categories used, no cycling, cycling up to 30 min per week and cycling more than 30 min per week. The differing results of the three studies in relation to cycling might depend on the lower prevalence of cycle commuting in the UK than in Denmark and China.

There is also a meta-analysis of studies on active commuting and cardiovascular risk conducted by Hamer and Chida (2008). They included eight studies on commuting physical activity in relation to cardiovascular risk. The commuting activity was a mixture of walking and cycling. The integrated overall risk ratio for the cardiovascular outcomes was 0.89. However, walking and cycling for transport was mixed in the studies and therefore, transport mode-specific health outcomes cannot be extracted. In a response to this, Oja et al. (2011) performed a systematic review of cycling in particular. They concluded that the 18 review studies:

...were consistent in showing a positive relationship between cycling and health and functional benefits in young boys and girls and improvements in cardio-respiratory fitness and disease risk factors as well as significant risk reduction for all-cause and cancer mortality and for cardiovascular, cancer, and obesity morbidity in middle-aged and elderly men and women.

1.2.3 Putting it all together - an economic appraisal

The various positive and negative outcomes of active commuting are rarely analysed together. However, in the transport sector, infrastructure investments are often preceded by economic appraisals, such as cost benefit analyses. The idea of economic appraisals is to compare the positive and negative outcomes that follow from the investment. For example, the cost to build a segregated cycle lane is compared to the benefits of time-savings, improved health due to, e.g. physical activity and fewer accidents. The positive and negative effects are valued and translated into a monetary unit and if the costs are lower than the benefits it is considered to be a beneficiary investment. Since these appraisals are performed in a monetary unit, they can be compared to other investments in society, although with caution since translation of the different outcomes into money is a rather complex operation with large uncertainties.
Normally, these appraisals have not included health benefits from physical activity, although they might be substantial. One probable reason is the complexity of the issue. Recently, cost-benefit analyses have been applied to bicycle infrastructure and policy measures (see, e.g. Saelensminde, 2004). The results indicated that many bicycling investments are very profitable for society. However, these calculations depended on many uncertain assumptions, but other researchers were inspired and have since then continued to develop the model, with assumptions better adapted to bicycling and more health benefits incorporated (for reviews, see Cavill, Kahlmeier, Rutter, Racioppi, & Oja, 2008; Powell, Dalton, Brand, & Ogilvie, 2010).

In an attempt to transfer this research to practitioners, WHO Europe have developed a Health Economic Assessment Tool (HEAT) for cycling and walking, that allows non-health professionals to calculate the benefits in saved life-years or money from increased bicycling or walking due to an infrastructure project or policy interventions (Kahlmeier, Racioppi, Cavill, Rutter, & Oja, 2010; WHO/Europe, 2008). The tool is user-friendly and designed for transport planners without special knowledge in health matters. The basis for the calculations is, the decreased relative risk of all-cause mortality related to commuting from the Copenhagen studies by Andersen and co-workers (Andersen et al., 2000). At a minimum, the practitioners only need to enter the mean trip distance and mean number of trips per day of new and current bicyclists, and then the other parameters in the calculations are set by default to the best scientific standards, but could be changed to better local values. The tool calculates health benefits from a decreased relative risk of mortality, but not morbidity due to the larger uncertainties in morbidity data (Cavill, Kahlmeier, Rutter, Racioppi, & Oja, 2007; Rutter et al., 2008).

1.2.4 Summary of the section

Active commuting seems to have an impact on wide areas in society, but our knowledge of the size of the effect is meagre. Most data available are on accidents including bicyclists or pedestrians and a motorized vehicle and these data are frequently included in economic appraisals for road investments. The positive outcomes, such as improved health or reduced environmental impact on society, are less studied. This might result in a rather unbalanced picture of the behaviours, i.e. in economic appraisals and in the public image of the behaviours.

One reason for the scarcity of evidence on how physical activity can affect health is the lack of longitudinal studies on different health outcomes of active commuting that could contribute to the compilation of causal evidence. Also the lack of precise measurements of the dimensions of
physical activity that make up the dose of active commuting needs to be better remedied. A key variable in this respect is distance, which is also a common denominator of the exposure to air-pollution and the risk of accidents. However, distance is hardly ever measured by valid methods. Regrettably, most studies on active commuting rely on self-report methods with unclear validity and reproducibility, which makes the dose-response relationship between physical activity and health rather unclear. Also the frequent incorporation of active commuting into aggregate measures, such as 'moderate physical activity' or 'non-motorized transport', makes it difficult to discern what part of the outcomes originates from active commuting. Also the economic appraisals lack valid and reliable data due to these methodological shortcomings. Among other effects, these methodological limitations in economic appraisals might hamper an allocation of larger shares of the transport investments to walking and bicycling infrastructure.
1.3 Correlates of active commuting – factors that are barriers and facilitators

Whether a person is commuting by active modes or not and how often may depend on many different factors. These factors are called correlates if they are statistically correlated with the behaviours. Factors could also be correlated with behaviour via another factor and that is denoted as a mediator, for example a stated barrier for bicycling such as hilliness might be a mediator of the factor physical effort. Factors that might influence the magnitude of the outcome behaviour are called moderators. If the correlation is found to be causally related to the outcome behaviour, it is denoted a determinant (see Bauman, Sallis, Dzewaltowski, & Owen, 2002). Knowing the correlates of active commuting is essential in promotion and intervention campaigns and is also important in implementation and policy making regarding active commuting. In the following, I will give an overview of factors found to correlate with active commuting and active transport in different settings.

1.3.1 Correlates for active transport and commuting in different countries

Until the last decade most research on the correlates of walking and bicycling has been focused on the purpose of sport and recreation (see, e.g. Brownson et al., 2000). Today some studies have been published on walking and cycling for transport and for commuting (see, e.g. Heinen, van Wee, & Maat, 2010). An early study on commuting is however that of Vuori and co-workers (1994), who studied barriers to active commuting in Tammerfors, Finland.

The correlates of active transport are not directly transferable to active commuting since active commuting differs from other forms of active transport in that commuting is repetitive and that the behaviours often become habitual and thus are not influenced by other factors. Moreover, the origin and destination, as well as the departure time, are normally fixed and roughly also the distance and time. This carries the implication that it is impossible for the individual to adjust the distance, in relation to effort or time demands, by choosing a closer destination, the only option is to change the commuting mode or route. In addition, correlates might also differ between the walking and cycling commuting modes. Thus, the results of different studies on correlates of walking and bicycling are not always comparable.

There are several limitations in studies of active commuting correlates. First, most research of today consists of cross-sectional studies. Moreover, the studies are often conducted in car-oriented settings such as in North
America, Australia or the UK. Third, several outcome variables are also used in the studies, e.g. prevalence of the behaviour, modal split in a population, trip frequencies and attitudes to the behaviour of either active or non-active commuters. The subject of analysis also varies from individuals to the population in certain geographical areas. Many studies base their analyses on national travel survey databases with limited possibilities to adapt the questions to the study aim and population. Thus the large variety of survey methods, of uncertain psychometric quality, together with a variety of outcome variables and survey contexts, results in an unclear picture of what factors are correlated with active commuting.

Nevertheless, to get an overview of all possible correlates, I present here a number of factors found to be significant in, firstly, car-oriented countries and then less car-oriented settings. However, car-oriented settings, such as in the USA, Australia and the UK, are not uniform and studies have found large differences between different geographic localities (Butler, Orpana, & Wiens, 2007; Plaut, 2005). Reasons for this might be the natural and built environmental conditions, for example difference in climatic conditions (Baltes, 1996; Parkin, Wardman, & Page, 2008), hilliness (Parkin et al., 2008), residential density (Baltes, 1996; Cervero, 1996), mixed land use (Cervero, 1996), street connectivity (Badland, Schofield, & Garrett, 2008; Panter, Jones, van Sluijs, Griffin, & Wareham, 2011), and how many facilities there are for walking and bicycling (Dill & Carr, 2003; Nelson & Allen, 1997; Panter et al., 2011; Parkin et al., 2008; Shafizadeh & Niemeier, 1997; Shannon et al., 2006; Wardman, Tight, & Page, 2007).

Other significant correlates found in studies are short distance (Badland et al., 2008; Handy & Xing, 2011; Panter et al., 2011) and short travel time (Shannon et al., 2006).

Features of the workplace destination of the trip, for example safe bicycle parking, lockers and places to change clothes and wash up, are also pointed out in the literature as correlates or barriers to active commuting (Cleary & McClintock, 2000; Heinen, van Wee, & Maat, 2009; Kaczynski, Bopp, & Wittman, 2010).

Demographic and socio-economic factors also play a role, for example, gender (Parkin et al., 2008; Plaut, 2005), age (Butler et al., 2007; Lemieux & Godin, 2009; Shafizadeh & Niemeier, 1997), income (Butler et al., 2007; Plaut, 2005; Shafizadeh & Niemeier, 1997), car ownership (Parkin et al., 2008; Plaut, 2005), active lifestyle (Butler et al., 2007) and number of students in the town (Baltes, 1996).

Policy factors are correlates often related to how car-oriented a city or a country is. This will, for instance, influence individuals’ perceptions of whether streets are safe. A city’s car orientation will also influence whether
Individual-level correlates are also found to be important, for example, intention and habit (Lemieux & Godin, 2009; Panter et al., 2011). Whether or not active commuting has become a habit seems to be a major correlate of the daily active commute (see, e.g. Verplanken, Aarts, & van Knippenberg, 1997). However, a habit can also work in the opposite direction: if commuters have a car-commuting habit that hinders active commuting (see, e.g. Heinen, Maat, & van Wee, 2011).

Walking and bicycling prevalence differs a lot in the developed countries and the same correlates might not be valid in car-oriented countries such as the USA and Australia and less car-oriented countries in Europe. In more advanced cycling cultures, like the Netherlands or Flanders in Belgium, the barriers to active commuting are probably different to those in countries like Great Britain where cycling is less common. This difference could depend on, for instance, better infrastructure en route or on cyclist and pedestrian-friendly facilities at the workplace destinations (see, e.g. de Geus, de Bourdeaudhuij, Jannes, & Meeusen, 2008). In such environments, other correlates and barriers might be significant. The representativeness of studies conducted in sprawled low-density American cities for Swedish settings is expected to be low due to the largely different urban forms and transport cultures.

Therefore, I will look in more detail at a few studies conducted in the Netherlands and in the Flanders region of Belgium. Heinen and co-workers (2011) performed a factor analysis to find out what factors influence the attitude towards commuter cycling. The sample consisted of both cyclists and non-cyclists who were employees in several large companies or residents in four Dutch cities. They found two factors that influenced the cyclists: the awareness of the effect that their modal choice has on health and environment and direct trip-based benefits, that is, time, comfort and flexibility. The socio-demographic factors explained little of the variance, indicating that in a context where bicycle commuting is usual, considered normal, and the infrastructure is good, the socio-demographic factors might lose some of their importance as correlates. Another Dutch study reached a similar result in relation to socio-demographic factors, gender, income and age, hence, they are not as important as in less developed bicycle cultures (Engbers & Hendriksen, 2010). Also, a Belgian study by de Geus and co-workers (2008) found that socio-demographic factors were non-significant correlates when they compared cyclists and non-cyclists. However, a high level of education, often regarded as a socioeconomic factor, correlated positively with bicycling to work. They also found that ecological-
economic awareness correlated with bicycling to work. Perceived built
environment factors were generally not significant, and they concluded that
and individual factors (i.e. perceived social support, self-efficacy, perceived
benefits and barriers) outperformed the environmental factors in their
sample.

Heinen and co-workers (2011) also found that the significance of the
factors was moderated by the trip distance to work. Attitudes towards
bicycling short distance trips were more influenced by the social norm, i.e.
what people in general think is an accepted behaviour, whereas attitudes to
long distance trips were influenced by individual-based factors. A safety
factor influenced the frequency of bicycle commuting.

A number of these studies indicate that correlates for at least bicycling
are culture and context dependent, and results from, e.g. American studies,
cannot be directly transferred to other contexts. The Swedish context is
neither similar to that of the Netherlands nor to the North American con-
text, but perhaps closer to Flanders than to the UK, at least when it comes
to bicycling prevalence.

An example of how the different contexts might influence what corre-
lates are important is a Belgian study that used municipalities as the ex-
ploratory variable and looked at the spatial variation between 589 Belgian
municipalities in the use of bicycling for commuting (Vandenbulcke et al.,
2011). They found that the variation between municipalities in bicycle
commuting could be explained by environmental factors such as hilliness,
traffic volumes and cycling accidents, but they also found large regional
difference between the two Belgian regions Flanders and Wallonia which
have very different bicycling rates. The traffic volume and risk of bicycle
accidents had less impact on bicycling in Flanders, but a larger one in Wal-
lonia. Vandenbulcke et al. (2011) explain that, as an effect of the higher
visibility of cyclists in the traffic in Flanders due their greater number and
the presence of an appropriate infrastructure, the bicyclist feels safer.

Thus, in more developed cycling cultures where the bicycling environ-
ments are acceptable; other factors might become significant barriers or
facilitators than in ‘developing’ cycling cultures. In particular, socio-
demographic factors like gender and income might be less significant corre-
lates in more cycle-friendly settings.

1.3.2 Distance as a correlate and a barrier
Distance is almost always identified as a correlate of active commuting and
long distance is an often stated barrier to the behaviours (see, e.g. Handy
& Xing, 2011; Panter et al., 2011). The deterring effect of distance might
be a mediation of both the longer commuting time and the increased effort
resulting from longer distances. However, also the perception of the dis-
tance might play a part in deterring from active commuting since the per-
ceived distance can differ largely from the objective distance (Loukopoulos & Gärling, 2005). In transport planning a rough distance threshold for
walking and bicycling behaviour is often defined and used. However, these
rule-of-thumb thresholds presume that commuters are uniform and are
usually not based on empirical data, at best on mean distances of a single
study (for children, see e.g. Van Dyck, De Bourdeaudhuij, Cardon, & De-
forche, 2010). In Sweden five kilometres is often used as a feasible bicy-
cling distance in transport planning and one kilometre for walking
(Sveriges kommuner och landsting, 2007; Wallberg et al., 2010). A well-
known example from North American planning is 400 meters, a quarter of
a mile, as a presumed feasible walking distance (Untermann & Lewicki,
1984).

A more sophisticated way to describe the effect of distance on spatial in-
teractions than crude cut-off values is to relate the distances in kilometres
to the percentage of all trips. This will result in a down-sloping so-called
distance decay curve. Often, these curves have a negative exponential slope
which means fewer trips in the population at longer distances. The ration-
ale behind this measure is that the impedance, or the generalized cost, of a
trip increases as it becomes longer and, as a result, the individual’s willing-
ness to travel decreases (for an overview, see Krizek, El-Geneidy, &
Thompson, 2007). The distance decay is originally a geographical term
that has been widely used also in transport research. Distance decay curves
can be used in different ways, for example, as an estimate of the distance
barrier in a population, that is, how far each mode of transport can reach,
which is a good basis for planning of transport systems. Another field of
application is to calculate the catchment area of, for example, a workplace
with different transport modes, as a measure of accessibility. It could also
indicate the potential for a mode shift to an active mode in a certain popu-
lation. It has been widely applied to motor transport, but rarely to walking
and cycling. One exception is Iacono and co-workers (2008; 2010) who
have conducted a study in a small study area of Minneapolis to illustrate
that it is possible. They computed distance decay functions for different
combinations of transport modes and trip purposes, including commuting.

Distance decay curves are aggregate measures that encompass all single
correlates related to the traversed route distance, such as topography and
route quality. The curve will also reflect the socio-demographic characteris-
tics of the study population. Accordingly, a low-quality active transport
infrastructure in car-oriented cultures might render other distance decay
curves than high-quality systems in places with viable bicycling cultures.
Also the purpose and the mode of the trip will render different curves. For instance, Thomas and co-workers (2003) found that work trips are less sensitive to distance than other trip purposes and, expectedly, walking is more sensitive to distance than cycling and both are more sensitive than passive modes of transport. Yasmin and co-workers (2010) found similar results, i.e. that pedestrian and bicycling work trips show a more gradually decreasing curve than trips for other purpose, meaning that people are generally willing to walk or cycle greater distances to work. The negative exponential slope of some distance decay curves makes accurate distance measurements important since even short distances could be translated to relatively large decreases in commuting in the study population. An accurate method for measuring walking and cycling distance is therefore essential in such analyzes.

1.3.3 Walkability, bikeability and other aggregated constructs

The environmental correlates of active commuting and active transport are sometimes merged into indexes or constructs. Two popular constructs are bikeability and walkability. The definitions of the two constructs are not standardized, but they can be briefly defined as the extent to which an environment is walking or cycling-friendly. The constructs are normally used to characterize the transport context in relation to active transport behaviours. Walkability and bikeability cover environmental aspects on a macro-environmental scale such as retail and population density, land use mix and street connectivity (Saelens, Sallis, Black, & Chen, 2003). These macro-scale environmental aspects of walkability are all closely connected to trip distance since both density, diversity and connectivity affect the distance between origins and potential destinations. Also, aspects on a micro-environmental scale, such as a certain route and more detailed design aspects of the route infrastructure and environments are sometimes included, such as quality of pavements and bicycle lane surface (Saelens, Sallis, Black et al., 2003).

The measurements are usually calculated for areas, such as census tracts or neighbourhoods around a person’s home address (see, e.g. Frank et al., 2010). They can also be used to characterize larger areas like cities or smaller areas like street blocks. Recently, the bikeability construct has been applied to behaviour-specified areas, such as the stated commuting routes (Titze, Strømøger, Janschitz, & Oja, 2007; Wahlgren & Schantz, 2011; Wahlgren, Stigell, & Schantz, 2010) or the calculated shortest commuting routes (Winters, Brauer, Setton, & Teschke, 2010). However, the constructs are context-dependent and the same constructs might not be valid everywhere and in all transport cultures. What is considered walkable in a...
car-centric planned city and a transit-planned development might be different. Different walkability constructs have been shown to correlate with active transport in general (see, e.g. Owen et al., 2010), but there are as yet not many studies of correlation between active commuting and bikeability.

1.3.4 Summary of the section

Even if few studies have been conducted on correlates of active commuting, many factors are found to influence the behaviours. However, the results come from studies with mostly cross-sectional designs, with different outcome variables, such as prevalence or attitude to the behaviours. Moreover, data are gathered by different survey methods. There are also geographical and cultural differences that might influence what factors become significant in the studies. For example, socio-demographic, environment and individual psychological factors seem to be important in different settings. Today, most studies are conducted in car-centric countries and hence the result cannot be transferred to a Swedish context. As a result, it is difficult to draw up a clear and valid picture of the overall significant correlates. There is one recent study of the correlates of walking in a Swedish urban context by Sundquist et al. (2011), but more studies are needed, preferably conducted with quasi-experimental or longitudinal designs that could help to find out what correlations are causal. The designs of studies also need to be structured according to a framework like the social-ecological model that incorporate factors from different levels and research fields.

Much research on correlates to active commuting is done with commuting route choice as an outcome variable and little is done with commuting frequency as an outcome, although it could be of great interest from a physical activity and health point of view. For instance, Heinen (2010) found few examples of studies that looked at correlates for frequency of bicycle commuting. Also the correlates of commuting distance and time need to be studied to get a clearer picture of what factors influence the dose of physical activity from active commuting. For example, what factors influences the distance decay curves. To assess the correlates of the physical activity dose, studies need to be conducted in places where walking and bicycle commuting are prevalent and with study designs that make causal inference possible. Large study groups are needed which also include different socio-demographic groups, for example, both men and women and different mode choice strategies.

In all sorts of contexts, distance seems to be a crucial variable for mode choice and prevalence outcomes, either directly or mediated through macro-environmental variables such as residential density, street connec-
tivity and mixed land use in constructs such as walkability and bikeability. However, first of all, methods to assess distance need to be in place. A first step would then be to assess the validity, reliability and costs of different methods to see whether they are feasible for such studies.
1.4 Crucial aspects of measurements

Decisions about measurements of active commuting include several aspects: for instance, if the scope of the instrument is specific or broad, the type of scoring of the instrument and the reliability and the validity of the measurements (Bowling, 2005). The measurements should also be practical for the researcher and the participants. What measurement scale level the study requires, nominal, ordinal, interval or ratio-scale, is also important to decide. Of these criteria, validity is the most essential, but in most cases it must also be weighed against other aspects of measurements (Bowling, 2005).

1.4.1 Validity

Validity is a way of describing whether an indicator or measure actually does measure what was intended to be measured (Kerlinger & Lee, 1999). Validity or accuracy is a key issue in assessments, if measurements have low validity a study loses much of its value. Bowling (2005) describes different forms of validity: first, content and face validity which covers representativeness and that a measure measures what was intended; second, criterion validity, concurrent validity and predictive validity which cover the measures relation to an external variable that is studied by comparing the measure to a criterion variable and third, construct validity which is intended to confirm that an instrument is measuring the underlying concept that the construct is intended to measure. All types of validity cover the same basic function of a measure, but in different ways.

The form of validity that should be used is determined by the specific behaviours or attributes of interest in the assessment. In the case of metric measures, often criterion validity is assessed. The actual measure is then compared to an external criterion measure, or a gold standard, to assess the correlation between them. The criterion method should have face validity, be known to measure the variable correctly and should be the best method and provide a better measurement of the underlying phenomenon than non-criterion methods. Often, criterion methods are more costly and burdensome for researchers and participants and are therefore not always feasible for larger groups.

Different criterion methods are used in assessment of active commuting depending on what variables are in focus. For energy expenditure, doubly labelled water and the Douglas bag method are regarded as gold standards, but in measurements of the three dimensions of physical activity, frequency, duration and intensity, there are no gold standards that cover all dimensions. For the distance of an active commute, there has been no criterion method up to now (Schantz & Stigell, 2009). For other crucial vari-
ables like active commuting frequency over the year, a criterion method is lacking. However, new techniques like GPS and motion sensors are increasing continuously in storing and battery capacity and decreasing in size and cost and might offer new opportunities as criterion methods for assessing dimensions of active commuting by themselves or in combination with other techniques (see, e.g. Duncan, Badland, & Schofield, 2009; Duncan, Badland, Duncan, & Oliver, 2009; Stopher, FitzGerald, & Zhang, 2008).

1.4.2 Reliability and reproducibility

According to Kerlinger and Lee (1999), the definition of reliability can be understood from three approaches: first, it denotes the predictability or stability of a measurement, i.e., getting the same answer to a question two or more times, secondly, lack of distortion, which is how well the measurement agrees with itself, as in the precision of an instrument. Finally, reliability can mean the relative absence of error of measurements, i.e. a subset of random error (Kerlinger & Lee, 1999).

Correspondingly, there are also different approaches to testing reliability, but a frequently used method is to test whether the same results occur at two or three administrations of, for instance, a questionnaire, to the same sample. This procedure is called test-retest reproducibility or repeatability. However, since the first administration might affect the second, it is important to let enough time pass from the first to the second administration. The time periods between administration should be long enough for participants not to remember what they answered last time, but not so long that the behaviour could have changed substantially (Bowling, 2005).

The consequences of low reproducibility is that the method will produce small real differences or correlations, and thus makes the results hard to interpret (see, e.g. Baranowski, Måsse, Ragan, & Welk, 2008).

1.4.3 Other features of measurements

If the research is done on large groups and under free-living conditions there are additional demands for the method since research budgets are limited. In addition to the validity and reproducibility of a measurement, it should also be practical and affordable to administer for the researchers and also acceptable to the participants. Moreover, a measurement should not be affected by the measuring situation or the measuring tool, i.e. the measure should be non-reactive (Bowling, 2005). Furthermore measurements should be sensitive to detecting change if that is the purpose of the study.
In real life, all these demands on a measurement are rarely met, and the validity and reproducibility of a method must therefore be balanced against the practical aspects; hence, the most valid method is not always used. This balancing is done differently in scientific experiments where samples are small and the cost per participant is not as crucial as in large epidemiological or surveillance studies where total costs grow large because of the sample size. Finally, to some extent, certain methods and designs are also associated with certain research fields, partly due to theoretical frameworks, but also due to tradition.

1.4.4 Measurement is influenced by theoretical considerations

The decisions about what to measure in a study and how, are more or less influenced by theoretical frameworks or models. In the assessment of active commuting, different theoretical backgrounds are used, but physical activity behaviours are often assessed within the social-ecological models. Social-ecological models may be used to formulate and assess interventions aimed at to increasing physical activity behaviours and providing flexible frameworks for understanding various behaviours and interpreting physiological outcomes. The social-ecological models display the determinant of a behaviour on multiple levels, i.e. the individual, social and environmental and policy levels of a behaviour (see, e.g. Sallis & Owen, 2002). Ecological models are macro models, which might include psychological theories such as Theory of Planned Behaviour (Ajzen, 1991) and Habit Theory (see, e.g. Verplanken et al., 1997). A social-ecological model for active transport behaviours has been proposed by Saelens et al. (2003), including both recreation and transport walking and cycling. That model has later been developed further by Ogilvie et al. (2011). The Ogilvie model includes the contribution of a variety of correlates: individual; interpersonal; social and physical environment; perceived and objective built environment and policy factors affecting individual commuters. The correlates may be estimated in relation to physical activity outcomes such as commuting distance or duration, but also the extent to which the individual meets the physical activity recommendations.

In the transport field most theories and models build on a microeconomic framework. It assumes that utility is maximized, costs are minimized and commuters make rational, informed choices from a number of alternatives. The most famous transport model is probably the four-step model for transport planning. The first step of that model is to decide the number of trips generated by an area, often a region, based on socio-economic variables such as household size, income and car ownership. The second step is to feed in data from step one into a model that distributes the trips
between Traffic Analysis Zones of different sizes, simplified as centroids of the area. The third step is to predict the transport mode choice based on previous transport surveys and, finally, the route choice is modelled from the least cost route, which is normally the fastest route. The four-step model was originally a model used for high-way planning, but its use has been extended beyond that, and it has also been challenged by other models (see, e.g. Cervero, 2006).

1.5. My choice of variables to measure

The study of active commuting is, in my opinion, motivated both by the fact that it includes so many persons per day over the year and that it is a potential source of physical activity for even more people. Also, the positive outcomes for society and individuals in the form of daily physical activity and sustainable mobility prompt a study of walking and bicycle commuting.

There are several variables crucial to the understanding of the active commuting behaviours. In my choice of important variables to study, I have been guided by the social-ecological model that proposes different types of factors that might correlate with the behaviour and several potential outcomes of the behaviour. In this thesis I have used the social-ecological model as an inspiration for how to study active commuting behaviour. For instance, the social-ecological models influenced the design of the studies in a way that different analyses have been stratified by the gender and mode variables. The choice of the individual as the smallest study subject was also inspired by the social-ecological model in contrast to the transport field where groups of individuals are a common choice in assessments based on transport economic theory. Also, the choice of variables was guided by the ecological models on active transport as have been presented by Saelens (2003) and later also by Ogilvie (2011). The studies in the thesis were not planned to grasp the entirety of the behaviour, but parts of the behaviours, and therefore I used the ecological model mostly as a guiding tool and an inspiration for the design. At the same time, I have chosen not to use a transport economic framework for the design and analyses of the studies.

The social-ecological models are built on several clusters of factors that might influence the active commuting behaviour. The socio-demographic characteristics of the active transport have been shown to be important, as well as the quality of the environment where individuals commute, their psychological factors, and policy factors. In this thesis I have chosen not to include psychological factors such as attitude, intention, habit, social norm, and social support. They should be further investigated, especially in studies of groups that do not bicycle or walk to work today. However, I do study a group of commuters who are already active commuters and who probably have developed some sort of habit. Some aspects are inflexible and of less interest and therefore will not be studied. The environmental factors have been shown to be significant correlates in previous studies. However, today the methods used to assess the objective measures of environmental correlates along the route rely on rather uncertain data because the commuting route estimations are based on the shortest route calcula-
1.5. My choice of variables to measure

The study of active commuting is, in my opinion, motivated both by the fact that it includes so many persons per day over the year and that it is a potential source of physical activity for even more people. Also, the positive outcomes for society and individuals in the form of daily physical activity and sustainable mobility prompt a study of walking and bicycle commuting.

There are several variables crucial to the understanding of the active commuting behaviours. In my choice of important variables to study, I have been guided by the social-ecological model that proposes different types of factors that might correlate with the behaviour and several potential outcomes of the behaviour. In this thesis I have used the social-ecological model as an inspiration for how to study active commuting behaviour. For instance, the social-ecological models influenced the design of the studies in a way that different analyses have been stratified by the gender and mode variables. The choice of the individual as the smallest study subject was also inspired by the social-ecological model in contrast to the transport field where groups of individuals are a common choice in assessments based on transport economic theory. Also, the choice of variables was guided by the ecological models on active transport as have been presented by Saelens (2003) and later also by Ogilvie (2011). The studies in the thesis were not planned to grasp the entirety of the behaviour, but parts of the behaviours, and therefore I used the ecological model mostly as a guiding tool and an inspiration for the design. At the same time, I have chosen not to use a transport economic framework for the design and analyses of the studies.

The social-ecological models are built on several clusters of factors that might influence the active commuting behaviour. The socio-demographic characteristics of the active transport have been shown to be important, as well as the quality of the environment where individuals commute, their psychological factors, and policy factors. In this thesis I have chosen not to include psychological factors such as attitude, intention, habit, social norm, and social support. They should be further investigated, especially in studies of groups that do not bicycle or walk to work today. However, I do study a group of commuters who are already active commuters and who probably have developed some sort of habit. Some aspects are inflexible and of less interest and therefore will not be studied. The environmental factors have been shown to be significant correlates in previous studies. However, today the methods used to assess the objective measures of environmental correlates along the route rely on rather uncertain data because the commuting route estimations are based on the shortest route calcula-
tions and not actual routes (see, e.g. Badland et al., 2008). Therefore, objective measurements of route choice need to be established first and then the objective correlates of the routes could be assessed. Moreover, comfort and safety perspectives of bicyclists and pedestrians are rather well studied and infrastructure and policy could already be radically improved in many countries with the current state of knowledge. Perhaps the greatest problem in this area might not be one of a shortage in accumulated knowledge, but one of a non-supportive policy and lack of implementation of bicycling-friendly policies. Therefore, environmental and policy factors will not be studied.

The correlates of the behaviour I find most interesting are the socio-demographic factors, such as gender, but also mode choice. Gender has been shown to be an important correlate of physical activity behaviours (Trost et al., 2002), but differing with the type of activity and setting. Moreover, the outcomes of active commuting might also be moderated by socio-demographic factors. For example, gender and age might influence the frequency of active commuting over the year. Women are also known to make shorter commutes due to household responsibilities, i.e. the much studied household responsibility hypothesis, or that female-dominated workplaces are spatially more evenly distributed (see, e.g. Turner & Niemeier, 1997). Whether this hypothesis is also valid for commuting with active modes is uncertain. Consequently, I have included gender as a study variable. Demographic and socio-economic factors such as age, education, income and car-availability are included as being descriptive of the study population.

The mode choice could be seen both as an outcome and a correlate of the active commuting behaviour, but since the study group already has a commuting behaviour, I chose to see it as a correlate that influence physical activity outcomes, such as duration, intensity and feasible distance. Furthermore, it could also be important to distinguish between people who use one commuting mode and those switching between two or more active modes. This mode choice pattern has not been studied before and therefore explorative studies on the possible influence of it on active commuting outcomes need to be conducted.

The outcomes of importance from my perspective of ’sports’ are measures of the physical activity aspect of the commuting behaviour. However, some physical activity measurements could also be of great interest for transport professionals: for instance, measurements of correlates and outcomes of active commuting. Thus, measurements done in one field could be used by the other. For example, surveillance and promotion of active commuting are common interests and if contemporary measurement pro-
tocols are enhanced and adapted, they can be used by both the transport and physical activity professionals.

To me, the most important outcome variable is the trip distance and it has also been recognized as a major correlate in a social-ecological model proposed by Ogilvie et al. (2011). It is a key variable for outcomes such as mobility and accessibility, but it is also a denominator of the exposure regarding traffic safety and air pollution as described in section 1.2. Moreover, it is a barrier to and facilitator of commuting activity and is essential in calculations of the velocity of the commute and is probably the best indicator of active commuting duration as it is unaffected by stops during the commute. Many of the built environment correlates on a macro level, such as connectivity, density and mixed use, have a common influence on trip distance. The validity and reliability of methods to measure distance therefore need to be tested in order to base future research on solid ground.

The most neglected area, with the largest needs for measurements, appears to be the physical activity dimensions of active commuting: intensity, duration and frequency. Walking and bicycle commuting are two specific forms of physical activity and should therefore have measuring methods adapted to their specific prerequisites.

Measuring the intensity of specific forms of physical activity, such as active commuting, in large groups is not straightforward. For example, motion sensors such as accelerometers cannot provide both the type and intensity of an activity without supporting surveys or inspections. Therefore, the trip velocity is often used as a proxy in walking and cycling activities. The mean trip velocity gives a picture of the absolute intensity of the commute that can be converted into METs by the use of the Compendium of Physical Activity (Ainsworth et al., 2000). The mean values do not take into account that there might be large intra-individual differences in the energy cost of different activities in relation to e.g. gender, age, skill and body mass. The alternative is to ask for perceived intensity by using semantic Likert scales. There are also scales, like the Borg scale, that are related in physiological variables such as the heart rate. In addition, questions about sweating and breathlessness have also been used to estimate the perceived intensity, but they have limited precision and sweating is also affected by the environmental temperature. Thus, relative intensity is difficult to estimate if the VO$_2$ max is not known (Shephard & Vuillemin, 2003). Velocity is a variable that is easy to calculate from distance and time and, therefore, reliable measures of velocity are preferred as an approximation of intensity. Commuting time is an important variable both as an estimation of activity duration and as the denominator in velocity and of exposure to air pollution and as a correlate of active commuting. The frequency
of active commuting per year is a crucial dimension of physical activity, but also an important exposure variable of air pollution and accident risks and is important for economic appraisals of walking and bicycling infrastructure.

Several variables deserve to be recognized in assessments of active commuting, but in the next section I will focus on four crucial variables: distance, commuting time, velocity and frequency and the methods used to measure them.

1.6 Methods of Assessing key variables in active commuting

The four crucial variables pointed out in section 1.5, distance, commuting time, velocity and frequency, are today measured by different methods, easy or complicated, cheap or costly and with different validity and reproducibility. In the next section I will give an overview of the methods found in the literature that are used to measure these crucial variables. I will also present some of the advantages and disadvantages of these methods.

1.6.1 Assessment of commuting distance

An extensive survey of the literature that I made at the beginning of the PACS project failed to show any appropriate studies on the validity and reproducibility of any of the methods for measuring active commuting distances. Methods used to assess commuting distance include various forms of self-estimated distance as well as more objective methods, such as straight-line distance or shortest network distance between home and workplace. Other methods use routes drawn on maps, GPS tracks or motion sensors such as bicycle distance recorders, pedometers and accelerometers. Here I will discuss the most common methods available for both walking and bicycle commuting. Therefore, I will briefly describe such methods as pedometer, accelerometer and bicycle distance recorders since they are feasible for only one of the two active modes assessed.

1.6.1.1 Distance measurements from routes drawn on maps

At the start of the PACS study there was no obvious criterion method for measuring route distance in active commuting. However, a map-based distance measuring method using drawn routes was used by Aultman-Hall and co-workers (1997), who transferred and measured the drawn routes within a GIS software.

1.6.1.2 Perceived distance

Commuting distance is sometimes estimated through self-reported surveys, e.g. questionnaires, activity diaries or interviews. There are several advantages in using such methods: for example, low cost and non-obtrusiveness (Stopher, 2004). This makes the self-report methods feasible in surveys distributed to large samples. In self-report surveys people simply recall their distance and report it. However, there are recall biases primarily due to time passed since the route was cycled or walked, but also depending on how often the route has been traversed. The ability to recall past events also differs between individuals in relation to certain socio-demographic factors, such as age (Shephard & Vuillemin, 2003).
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Assessments of commuting distance in travel surveys often presume that the commuters are motorized and can use the car trip meters to report distances accurately, while in active commuting, the corresponding measuring tools are rare. Instead, active commuters have to estimate their route distances from their mental/cognitive maps, i.e. representations of their spatial knowledge acquired through experience of the environment. From the mental maps, they can retrieve information about distances between places, often referred to as cognitive distances (see Golledge & Gärling, 2004; Gärling & Loukopoulos, 2007).

Cognitive distances are based on actual distances, but they can be distorted by several things. Montello (1997; 2009) list three classes of factors that affect the distance estimate of travel through environments. The first class is the number of environmental features that the traveller sees or senses. There are several hypotheses, not necessarily excluding each other, about what environmental features influence distance estimates and what mental functions are used in the estimation. I will describe them briefly. One hypothesis says that features en route, such as intersections, subdivide a route into smaller pieces and these distances are then perceived as longer than an undivided distance; therefore, routes with many subdividing elements like intersections are perceived as being longer. Another hypothesis is that, e.g. intersections, number of turns and landmarks along the route, provide information to the traveller which, in some way, requires a cognitive capacity. This cognitive load distorts the estimation, making the route appear longer than in reality. There is also the scaling hypothesis that states that longer physical distances are perceived as relatively shorter than shorter physical distances. If a route is divided into many small segments, the sum of the specific segment distances, put together mentally, will be perceived as being longer than the same route without intersections or other segmenting environmental features (Montello, 1997).

The second class is that people use the travel time to estimate distance. Time and distance are rather well correlated and people might use memorized relations of distance and time in their distance estimations.

The third class concerns the travel effort or the expended energy, e.g. via the travel velocity. The effort hypothesis implies that whether or not the transport mode is motorized or human-powered may also affect the estimations due to a larger required physical effort. The same function is valid if a load is carried or a hill needs to be mounted; then, the distance will be perceived as being longer (Stefanucci, Proffitt, Banton, & Epstein, 2005; Witt, Proffitt, & Epstein, 2004).

Most of this literature concerns distances travelled in general and not for specific transport modes or purposes, such as walking or bicycle commut-
ing. However, active commuting is special since the distance is travelled many times and the commuter becomes familiar with the route, and consequently the perceived complexity and cognitive demand decrease and the distance estimate will then increase in accuracy (Montello, 1997, 2009). Montello (1997) also distinguishes between active and passive navigation, e.g. between driver and passenger, and between physically active and passive transportation where active travellers can sense the distance with their body in some way. Also, many of the studies in the area are experiments in which potential cues are controlled and few studies are conducted under free living conditions and this limits the conclusions that can be transferred to real-life situations.

1.6.1.3 GPS distance
Commuting distance can also be estimated by using logged traces from a Global Navigation Satellite System (GNSS). The most common GNSS is the NAVSTAR global positioning system (GPS). The GPS provides geospatial positioning and allows small electronic receivers to determine their location (longitude, latitude and altitude) within a few meters, using time signals transmitted along a line-of-sight by radio from satellites (for an overview, see Maddison & Ni Mhurchu, 2009). The GPS receivers then calculate the precise time as well as position. The positions can be collected with different intervals, but usually 1 Hz is used due to limitations in the storage capacity of the GPS under free-living conditions.

GPS positioning is based on triangulation with satellites, and if there are more than four satellites, positions in three dimensions can be achieved. Commuting distance is derived from positions logged by the receiver and therefore errors in positioning will spill over to distance calculations. From the GPS positions, a commuting route choice can also be derived, which is helpful in studies of environmental effects on active commuting behaviour and can be used as a criterion method for bicyclists’ route choice (see, e.g. Dill, 2009; Menghini, Carrasco, Schüssler, & Axhausen, 2010). GPS has also been used to validate travel surveys (Stopher et al., 2007) and to calculate bicycling and walking velocity (see, e.g. Parkin & Rotheram, 2010; Townshend, Worringham, & Stewart, 2008). The receivers’ measure of time is more or less exact, but distance estimations can be faulty in settings where the line of sight is blocked: for example, in urban environments. As a consequence, the trip velocity may be uncertain in such settings.

An advantage of GPS in distance estimations is the good validity shown, at least in test settings, and the easiness of carrying the receiver on the body (for a review see Duncan, Badland, & Mummery, 2009), and the fact that there are no indications of reactivity of the behaviour from carrying a GPS
receiver. The disadvantages are the costs of the receivers which make population studies unfeasible and the problems of GPS signal loss in certain urban settings. The storage and battery capacity are also limitations in studies over several days. The development of the GPS technique is continuous and more advanced and higher-capacity GPS receivers are continuously becoming affordable.

The accuracy and reliability of a GPS device in measuring distances outdoors has been tested in a study by Duncan et al. (2007), who found it an accurate tool for positioning and route tracking under good open-air test conditions. However, another study (Duncan & Mummery, 2007) indicated that GPS applied in real-life urban settings, with high buildings on both sides of a street forming an urban canyon, can cause problems with signal loss or distortion of the radio signals from the satellites. The reason for that can also be features of the natural environments: for example, street trees. If too few satellite signals are received, there cannot be any triangulation and no positioning. In addition, there might be problems with signal noise, especially in static positions, and in ‘cold starts’ when the receiver has no actual positions to start the calculations of positions from. Signal noise gives too many GPS positions, leading to a false prolongation of the route distance (Stopher et al., 2008). Exactly how signal noise affects the distance calculations depends on the routing algorithm in the receiver and such software algorithms are generally not public. Signal noise can be cleaned to enhance the distance estimation, but it is time-demanding work (Le Faucheur et al., 2007). Another method to enhance the distance calculations of a GPS trace is to insert the route into a GIS network and fill in shorter episodes of signal loss and clean small deviations in relation to the GIS street network and, finally, perform the distance calculation using the GIS distance calculation function. The validity and reliability of distance estimations of a GPS device are also affected by the non-linearity of the route and the velocity of the transport (Gray, Jenkins, Andrews, Taaffe, & Glover, 2010). The magnitude of the different signal-transferring problems appears to vary with context, and which problems dominate in a mixture of environmental settings is not known. Thus, GPS measurements seem to have a potential for both under- and overestimations of distance measurements; for reviews see e.g. Duncan et al. (2009) and Stopher et al. (2008).

1.6.1.4 Straight-line distance

Another method to approximate route distance is to calculate the straight-line distance between the origin and destination. This is also called Euclidean distance, crow-flies distance or airline distance. A very similar expression is the great circle distance that also accounts for the curvature of the

1.6.1.5 GIS network distance

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1.6.1.13 GIS network distance

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1.6.1.14 GIS street network distance

Another method to approximate route distance is to calculate the straight-line distance between the origin and destination. This is also called Euclidean distance, crow-flies distance or airline distance. A very similar expression is the great circle distance that also accounts for the curvature of the
earth surface. Straight-line distance is a rather straightforward method that only requires the addresses or the co-ordinates of origin and destination in GIS, or alternately, an accurate and detailed paper map together with a ruler.

There are several advantages of the straight-line distance method: for example, low cost and easiness to use, and therefore its use is feasible in assessments of large samples. When it is used in a commuting context, the address of the workplace is rather easy to find out, compared to other more occasional destinations. On the other hand, the home address cannot always be retrieved due to the integrity of the participants. Therefore, many surveys are unable to use exact addresses and use instead midpoints in, for example, a zip code area with corresponding lower accuracy as a result. These zones can also cause problems if they are too large, because then, short trips that have both an origin and destination inside the zones cannot be given a distance value.

To sum up, the method has a low inherited validity which gives an underestimation of distance. Therefore a correction factor is sometimes used to adjust the mean underestimation (see, e.g. Chalasani, 2005; Chalasani, Denstadli, Engebretsen, & Axhausen, 2005; Lau, 1999). The size of the correction factors depends on the difference between the chosen route and the straight-line distance. In settings with large natural barriers like mountains and rivers, the error can be rather large and even small gradients can cause detours. In active transport, also the built environment, such as motorways and railways with few underpasses, can form barriers. Moreover, the level of underestimation using straight-line distances seems to vary in relation to the transport mode (see, e.g. Witlox, 2007) and might depend on the connectivity of the road network and different routing behaviours for example, due to comfort or safety perceptions in different socio-demographic groups. The correction factors can only be calculated for groups of bicyclists and pedestrians in a certain geographic area and cannot correct the individual values. Thus, correction factors need to be further studied in different contexts and for different active transport purposes and modes, not least because they enhance the validity of simple methods at the population level.

1.6.1.5 GIS network distance
A more refined method than straight-line distance is to calculate the shortest distance between the origin and destination through a designated road network with a route determined by some kind of algorithm. This is called the network distance or the shortest route distance. As with the straight-line distance, it is important to enter valid addresses to the origin and des-
destination. In commuting, usually the addresses of origin and destination of a trip are known by the participant; on the other hand, an exact address coordinate might reveal the identity of the participant. A second prerequisite for the method is a street network that is comprehensive and includes all possible bicycling and walking routes. This is not always easy to achieve, since pedestrians and bicyclists use a fine-meshed network and also informal paths and short-cuts. Sometimes the available route net needs to be enhanced manually, which is a time-consuming process (cf. Aultman-Hall et al., 1997). Next, an algorithm suitable for the purpose needs to be chosen, and normally there are shortest-path functions included in the GIS programme packages, as well as in the open-access route planners on the Internet (see, e.g. Bere, van der Horst, Oenema, Prins, & Brug, 2008; Titze, Strønegger, Janschitz, & Oja, 2008). The routing algorithms are commercial and secret, but they are roughly based on the shortest distance route including features of time or cost minimization. In the Handbook of Transport Geography and Spatial Systems, Golledge and Gärling (2004) present an extensive list of route selection criteria that has been referred to in the literature. Surely, an algorithm based on solely the shortest distance route is a simplification of a complex route choice behaviour.

The shortest distance route might not be the route people perceive as the shortest, as discussed in the section on perceived distance above. Moreover, the routing algorithms are normally set up for only two dimensions, not taking hilliness into account, neither as a prolongation of the distance nor as a factor that might impact route choice behaviour. Routing algorithms can of course be enhanced and made to work more like human active commuting behaviour, with weights and rules applied to links and nodes in the network, but this is not yet the case. At least, one-way restrictions and motorways where bicycling is prohibited should be included in the algorithms in some way. Little is known about actual commuters routing behaviour and hence the shortest route usually functions as a proxy for the real behaviour.

The cost of calculating the network distance depends a lot on whether a network database is available and what precision is required. If open-access route planners are used, the cost is mainly the time used to insert the origin and destination, but the precision is then rather uncertain. On the other hand, to construct or update a complete network database might be very expensive.

1.6.2 Assessment of commuting time

Usually commuting time is reported via a travel or activity diary, interviews or questionnaires. Since most people have access to watches, either
separate or integrated in other devices like mobile telephones, measurements of trip duration are simple and low-cost. Reported times also have the potential to be accurate since commuters do not have to perceive journey time, but can clock their trip and report it. However, if the active commuting time is assessed in a survey with the expressed purpose of assessing physical activity, respondents might overestimate durations because they feel that longer durations are socially desired.

Many people round off the reported times, however, to the nearest multiple of 5 or 10 at least in durations exceeding 10 minutes (see, e.g. Rietveld, 2002; Rietveld, Zwart, van Wee, & van den Hoorn, 1999). The effect of rounding off is lower validity, but at the group level the roundings up and down might cancel out. Another source of error in self-report surveys is uncertainties about when people start and stop counting travel time. Is it when they leave home or when they start bicycling? In addition, there is also considerable day-to-day variation in individuals’ reported travel behaviour (Hanson & Huff, 1988); however, it is less in commuting than in other travel. As a consequence, travel behaviours might need to be measured over several days.

If the trip duration is used to measure physical activity duration, new methodological problems arise because a commuting tour often encompasses stops, for example, at red-lights and at busy intersections. How large an impact these stops have on the difference between commuting time and physical activity time is uncertain, but a bicyclist’s stop time at a red-light in Stockholm is, on average, about 20–30 seconds based on inspections of the GPS tracks of 19 participants used in Paper 2 (data not shown). On the other hand, some people do not bother to stop at red-lights when there is no traffic. Anyway, the duration of physically active time and the trip duration are in principle two different things.

1.6.3 Assessment of trip frequency
The frequency of active commuting can be measured in relation to many different time periods: for example, frequency per day, week, month or year. There is no obvious criterion method for determining active commuting frequency; instead, it is normally assessed in travel diaries, as in the Swedish National Travel Survey or in activity diaries or questionnaires. The diaries often comprise one or two weeks, but rarely longer time periods, but sometimes it is presumed that the measured behaviour represents an all-year habit. The IPAQ questionnaire on the other hand was developed to survey the last seven days active transport frequency and could therefore not be used to survey active commuting habits over the year unless it is distributed during several seasons. This is important since large
seasonal variations in active commuting have been reported in previous studies (see, e.g. Bere & Bjorkelund, 2009; Bergström & Magnusson, 2003; Stinson & Bhat, 2004).

There are other methods that anticipate seasonal variation. The Swedish National Travel Survey is distributed equally over the year and thereby overcomes seasonal variation, at least on a population level (SIKA, 2007). Other studies have performed several distributions of questionnaires, one per season (see, e.g. McCormack, Friedenreich, Shiel, Giles-Corti, & Doyle-Baker, 2010), but, on the other hand, such procedures might increase the participant burden. Surveyors can also ask the respondents about their usual behaviour, leaving it to the respondent to calculate the mean frequency of the year. Self-report measurements are also inclined to have problems of recall of the behaviour if a long time has passed since the behaviour. Moreover, there is also a risk of overestimation of the behaviour due to social desirability. Alternative methods for measuring yearly commuting frequencies are bicycle flow measurements, but they can only encompass changes at an aggregated level. Alternatively, motion sensors or GPS devices worn for longer time periods can be used, but often the charging time and storing capacity of these devices limit their feasibility in long-term assessments. A possible method not yet studied could be to put anonymized radiofrequency identification tags (RFID) on bicycles of commuters from one workplace and receivers at a place where bicyclists pass, e.g. the bicycle entrance at that workplace (see, e.g. Freedson et al., 2008). Thus, methods for assessment of commuting frequency need to be designed to include effects of seasonal variation and made feasible for long-term studies.

1.6.4 Assessment of velocity

Velocity is a derived variable from measurements of distance and time and is therefore sensitive to low validity of the built-in variables. For example, problems with rounding off of time and distance also affect velocity calculations. Some methods used to measure velocity, for example, laser and GPS, measure time and distance simultaneously, others measure them consecutively as in transport diaries. Moreover, measurements might comprise the whole trip or sections of a trip that are then extrapolated to represent mean trip velocity (Murtagh, Boreham, & Murphy, 2002; Reneland, 2002). The distance and time might also be derived from questionnaires, but there are numerous potential biases to consider when working with self-report questionnaires. Other methods are to use GPS, but, as discussed above, the GPS distance measurements may be severely disrupted by signal loss. Some studies (de Geus, de Smet, Nijs, & Meeusen, 2007; Hendriksen,
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There are other methods that anticipate seasonal variation. The Swedish National Travel Survey is distributed equally over the year and thereby overcomes seasonal variation, at least on a population level (SIKA, 2007). Other studies have performed several distributions of questionnaires, one per season (see, e.g. McCormack, Friedenreich, Shiell, Giles-Corti, & Doyle-Baker, 2010), but, on the other hand, such procedures might increase the participant burden. Surveyors can also ask the respondents about their usual behaviour, leaving it to the respondent to calculate the mean frequency of the year. Self-report measurements are also inclined to have problems of recall of the behaviour if a long time has passed since the behaviour. Moreover, there is also a risk of overestimation of the behaviour due to social desirability. Alternative methods for measuring yearly commuting frequencies are bicycle flow measurements, but they can only encompass changes at an aggregated level. Alternatively, motion sensors or GPS devices worn for longer time periods can be used, but often the charging time and storing capacity of these devices limit their feasibility in long-term assessments. A possible method not yet studied could be to put anonymized radiofrequency identification tags (RFID) on bicycles of commuters from one workplace and receivers at a place where bicyclists pass, e.g. the bicycle entrance at that workplace (see, e.g. Freedson et al., 2008). Thus, methods for assessment of commuting frequency need to be designed to include effects of seasonal variation and made feasible for long-term studies.

1.6.4 Assessment of velocity

Velocity is a derived variable from measurements of distance and time and is therefore sensitive to low validity of the built-in variables. For example, problems with rounding of time and distance also affect velocity calculations. Some methods used to measure velocity, for example, laser and GPS, measure time and distance simultaneously, others measure them consecutively as in transport diaries. Moreover, measurements might comprise the whole trip or sections of a trip that are then extrapolated to represent mean trip velocity (Murtagh, Boreham, & Murphy, 2002; Reneland, 2002). The distance and time might also be derived from questionnaires, but there are numerous potential biases to consider when working with self-report questionnaires. Other methods are to use GPS, but, as discussed above, the GPS distance measurements may be severely disrupted by signal loss. Some studies (de Geus, de Smet, Nijs, & Meeusen, 2007; Hendriksen, Zuiderveld, Kemper, & Bezemer, 2000) have used distance recorders on bicycles to measure velocity and these devices have a potential to record time accurately, but the distance measurement, via the wheel circumference, needs to be thoroughly calibrated in relation to the air pressure in the tube and the weight of the bicyclist. For walking, pedometers can provide reasonably valid distance measurements at a normal walking velocity, but they underestimate distance at a fast velocity and overestimate it in slow velocities if stride length is entered into the device (Bassett, Mahar, Rowe, & Morrow, 2008). This error is then transmitted to the velocity calculations. However, if velocities are used as proxies for physical activity intensity, derived velocities should be interpreted with caution since there are many possible errors in transformations and calculations. Thus, there are several valid methods to measure velocity for short distances, for example, laser and manual inspections, but the methods to measure mean trip velocity are rather undeveloped because they depend on separate measurements of time and distance. Since time is rather easy to measure with clocks and watches, the valid measurement of distance is the crux of the matter. Thus valid and reproducible methods for measuring distance are needed.
2. Aims

The overall aim of this thesis was to explore active commuting behaviours of adults who were walking or bicycling to work in a Nordic metropolitan setting.

The specific aims were to:

• develop and assess validity and reproducibility of a potential criterion method for assessment of route distance in walking and cycling commuting (Papers 1 & 2)
• assess the reproducibility of four distance estimation methods, reported duration, weekly trip frequency per month over the year, red-light stops and derived velocity (Papers 1, 2 & 3)
• assess the validity of four distance estimation methods (Paper 2)
• investigate whether the three active commuting mode groups: pedestrians, bicyclists and dual mode commuters, have different behaviours with regard to distance, duration, red-light stops, velocity and weekly trip frequency per month over the year (Paper 3)
• explore gender differences in commuting behaviours within the three modal groups (Paper 3)
• compare the extent to which the different modal choice and gender groups contribute to meeting the recommendations of moderate physical activity of 150 minutes per week (Paper 3)
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3. Methods and Materials

3.1 Study area
The study area is the County of Stockholm, Sweden, a metropolitan area of approximately 1.9 million inhabitants. It includes commuting routes in the inner urban area of Stockholm and the suburbs and in rural areas surrounding it. The inner road systems consist mostly of grid-patterned streets, while in the suburbs, roads are less structured and often affected by the natural topography.

Figure 2. Map of central Stockholm with red dots at the places of recruitment of Sample II, see below. The yellow circle represents women's median bicycle commuting distance and the blue one is the corresponding distance for men, originating from the yellow dot in the middle; see Paper 3.

3.2 Procedures and participants

3.2.1 Recruitment of participants
The participants comprised two samples. Sample I was recruited by advertisements (for the advertisement, see appendix) published on weekdays three times each in two daily newspapers, Svenska Dagbladet and Dagens Nyheter, in May 2004. The advertisement included a response coupon that
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participants could send in without cost, by post, fax or e-mail. They could also leave their response as a voice message.

Sample II was recruited among bicyclists and pedestrians *en route*. We contacted them as they slowed down at one of four bridges or stopped at a traffic-light on one arterial road; see Figure 2. We made all the contacts in central Stockholm between 7 and 9 a.m. in mid-November 2005. In total, 589 invitations were distributed.

The respondents from both samples sent in response-coupons with their written addresses to their home and work or study place. We then posted a questionnaire to them together with instructions on how to fill in the questionnaire and how to draw their commuting routes on an enclosed map (for questionnaire and instructions, see appendix).

The inclusion criteria for both samples were that participants should be of a minimum age of 20 years, live in the County of Stockholm, excluding the municipality of Norrtälje, and walk or cycle the whole way to work or place of study at least once a year. The information to the commuters stressed that people with very short commuting distances were also welcome to participate in the study.

The Ethics Committee of the Karolinska Institute approved the study, and the participants gave their written informed consent.

### 3.2.2 Participants

The response rate in Sample I was 93.8 percent after two postal reminders and one e-mail reminder to those who had reported an e-mail address (Figure 3). In Sample II the response rate was 85.1%, calculated from the first distribution of the Physical Active Commuting in Greater Stockholm Questionnaire 1, (PACS Q1), n = 114, in the test-retest assessment (Figure 4).

The characteristics of the two samples are described in Table 4. Sixty-eight percent in Sample I were women compared to 39% in Sample II.
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We divided the participants into three categories based on their reported choice of commuting mode, bicycling or walking, and for those who used both modes alternately we formed a separate category, the dual-mode group. The basis of the categorization was whether they reported on walking or cycling commuting time or both. This categorization was then checked with their answers to the mode-separated questions about ‘commuting frequency’ and ‘stated distance’ and how they marked the routes on maps and, in uncertain cases, also from their further comments in the questionnaire. Fifty-eight percent of the participants in Sample I were categorized as bicyclists, 15% as pedestrians, and 27% as dual-mode commuters. The corresponding mode distribution in Sample II was: 68% bicyclists, 14% pedestrians and 18% dual-mode commuters.
3.2.2.1 Subgroups of participants used in Papers 1–3
In Paper 1 we used participants from Sample II and in Papers 2 and 3 we used participants from both Samples I and II. Sample II was used to test the reproducibility of map drawings and two questionnaires, PACS Q1 and PACS Q2; see below. In Paper 3 we used 70 participants from Sample II who completed PACS Q1 on both test and retest occasions. Sixty-two of
Table 4. Participant characteristics of Samples I and II.

<table>
<thead>
<tr>
<th></th>
<th>Sample I (n=1872)</th>
<th></th>
<th>Sample II (n=140)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Men</td>
<td>Women</td>
<td>Men</td>
<td>Women</td>
</tr>
<tr>
<td></td>
<td>Walk</td>
<td>DM</td>
<td>Cycle</td>
<td>Walk</td>
</tr>
<tr>
<td>Max. numbers:</td>
<td>63</td>
<td>83</td>
<td>464</td>
<td>214</td>
</tr>
<tr>
<td>Age in years, mean ± SD</td>
<td>49±10</td>
<td>47±12</td>
<td>47±11</td>
<td>49±10</td>
</tr>
<tr>
<td>Gainful employment, %</td>
<td>95</td>
<td>92</td>
<td>94</td>
<td>97</td>
</tr>
<tr>
<td>Educated, university level, %</td>
<td>75</td>
<td>76</td>
<td>70</td>
<td>72</td>
</tr>
<tr>
<td>Income +25,000 SEK, %</td>
<td>56</td>
<td>64</td>
<td>66</td>
<td>51</td>
</tr>
<tr>
<td>Participant &amp; both parents born in Sweden, %</td>
<td>86</td>
<td>80</td>
<td>82</td>
<td>86</td>
</tr>
<tr>
<td>Having a driver’s licence, %</td>
<td>94</td>
<td>92</td>
<td>94</td>
<td>92</td>
</tr>
<tr>
<td>Usually access to a car, %</td>
<td>65</td>
<td>71</td>
<td>79</td>
<td>57</td>
</tr>
<tr>
<td>Live in inner urban area, %</td>
<td>57</td>
<td>48</td>
<td>20</td>
<td>65</td>
</tr>
<tr>
<td>Work in inner urban area, %</td>
<td>70</td>
<td>58</td>
<td>54</td>
<td>68</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Notes. Values are based on self-reports in PACS Q1 and PACS Q2. No one lived or worked in rural areas, DM = dual mode.

3.2.2.1 Subgroups of participants used in Papers 1–3
In Paper 1 we used participants from Sample II and in Papers 2 and 3 we used participants from both Samples I and II. Sample II was used to test the reproducibility of map drawings and two questionnaires, PACS Q1 and PACS Q2; see below. In Paper 3 we used 70 participants from Sample II who completed PACS Q1 on both test and retest occasions. Sixty-two of
them reported on cycling and 22 on walking, including 16 participants who reported on both walking and cycling. Sixty-seven of the 70 that also returned two maps were used in Paper 2 for test-retest assessments of distance. After the reproducibility procedure, we sent the respective questionnaire, once, and in a cross-over fashion, to the participants who had not previously completed it; see Figure 4. Accordingly, 52 participants who had responded to PACS Q2 twice thereafter completed PACS Q1 once; 34 of them were single-mode bicyclists who were added to the study population of street-recruited single-mode bicyclists. This increased the group to 140 participants, of which 93 bicyclists were used in Paper 3.

In the assessment of validity of the criterion method in Paper 2 we also used 13 participants selected from single-mode bicyclists in Sample I. The selection criteria were: commuters with no medical disorders and with reported values for both age and route distances close to the median values for bicyclists. These 13 participants were also used in the assessment of GPS distance validity together with 17 bicyclists used in the validation of the criterion method in Paper 1; see Figures 3 and 4. These 17 were recruited on the basis of their good reproducibility in routes drawn on maps.

In the GPS distance validity assessments, the author of this thesis also participated and performed 56 tours.

**3.2.3 Development and assessment of the criterion method for distance measurements**

The main idea when attempting to develop a criterion method was to measure the distance of commuters’ self-drawn routes on maps and then convert the map distances to real distances using the map scale. We chose a wide-ranging map from the telephone directory which we thought would be recognized by most participants.

To be able to measure the distance on maps, we needed a valid and reliable map-measuring tool. We therefore tested the reproducibility of several different distance-measuring tools and found great differences. The tool with the best result, a digital curvimetric distance measurer (Run Mate Club; CST/Berger, Watseka, IL, USA), was tested for validity and reproducibility by using a straight 250-mm-long line that was measured 20 times and by measuring a right-angled triangle five rounds. We also tested two different techniques to measure the angles: by lifting the distance measurer and rotating it in the air when arriving at an angle and by turning it while still on the map. Each technique was assessed ten times, each time consisting of five rounds along the triangle. The turning technique was then chosen for all measurements. We also tested map measuring in a mimicked commuting route setting. A line with a total length of 319 mm and consist...
ing of four right angles, two flat angles of 120° and 135° and one sharp angle of 35° was tested 10 times before and 10 times after 2.5 h of map measurements. The results of the tests of the curvimetric distance measuring tool are displayed in Paper 1 and the good results convinced us to use the tool further.

The map and the distance measurer form the criterion method and to ensure that every part of this procedure was valid, we performed several tests. First, to create each individual map, the original map had to be copied in two steps. We therefore checked the scale of 30 randomly chosen map copies by comparing the distance between two coordinates on maps with the corresponding distance on the map from the Swedish Mapping and Land Registration Authority. Second, we checked the validity and reproducibility of participants’ starting and destination points marked on the maps by comparing them with their stated home and workplace addresses displayed on three address-geocoding systems (Google Earth [version 4.0], www.eniro.se, and www.hitta.se). Third, we tested if the route drawings were reproducible, by comparing route drawings from the participants’ first map with the second. Fourth, we tested the validity of map-drawn routes in two separate tests with a GPS track as criterion measure. Routes drawn were validated first with a subgroup of 19 participants from Sample II and then with 13 from Sample I. This was done with a GPS receiver, (SPI10; GPSports Systems Inc., Canberra, Australia), which was placed in a harness on the upper back of the participants to enable a good satellite reception. The walking or bicycling trip started when the GPS had contact with at least four satellites. Next, GPS tracks were transferred to mapping software (OziExplorer version 3.9; Ozi-Explorer, Inc, Brisbane, Australia) equipped with a Stockholm County map (“Gröna kartan,” scale 1:50 000; Lantmäteriverket, Gävle, Sweden, 1999). These maps were printed out in the same scale as the paper maps and were compared with the drawn routes. If lateral deviations of more than 3 mm between the drawn routes and the GPS tracks were found, the longitudinal length of the deviating parts was measured. The GPS was not used for any distance measurements. Instead, all distances were measured on the paper maps (scale 1:25 000) with the digital curvimetric distance measurer.

3.2.4 Assessment of test-retest reproducibility
We assessed the reproducibility of the maps and two different questionnaires in November and December 2005. We divided the Sample II respondents (n = 214) into two subgroups. We then posted maps and some questions in common and two different questionnaires (PACS Q1 and Q2)
to the participants. About half (n = 114) of the group received PACS Q1 and the rest PACS Q2 (see Figure 4).

A second letter with the same material and tasks as in the first letter, was sent to the participants two weeks, with a few exceptions, after they had returned the first questionnaire and map. The median time between the participants’ return of the first and second maps and questionnaire was 21 days, with a range of 12 to 59 days.

In order not to influence the results, the participants were neither at the point of recruitment nor at the first distribution of maps and questionnaires informed about the objectives of the study. At the second distribution of the same material, the participants were informed that the reason for duplicating the procedure was to evaluate how certain the data were.

We tested the reproducibility of the two GIS-based open-access route planners by comparing the results of the first input with the same input a week later. A corresponding test of the licensed GIS software used was considered unnecessary as there was no variation either in the route network or in the routing algorithm.

The reproducibility of the GPS was tested by the author of this thesis. I cycled 14 different pre-determined routes with a total distance of 43 km; seven routes in predominantly urban environments with higher buildings and seven in predominantly low-density suburban environments with lower buildings and more green areas. A few days later, I repeated the procedure to check reproducibility. The weather conditions on the two occasions were similar, with cloudy skies. We checked these GPS recordings for signal loss of more than 20 s, but found no such losses. The recordings were not cleaned for signal noise since the time between switching the GPS device on and off and the actual start/end of the trip was very short. In all assessments of reproducibility we checked how the test-retest difference varied over long and short distances by plotting the distance from the first test against the test-retest difference.
3.3 Measurements

3.3.1 Questionnaires
The questionnaire used in most of the studies, PACS Q1, is self-administered, in Swedish, and contains 35 items; see appendix. A small convenience sample of academic staff members pre-tested the questionnaire. The questionnaire was developed by the author of this thesis and Dr Peter Schantz. It is constructed partly based on a review, performed in an early phase of the PACS-project, of existing questionnaires with physical activity or transport scopes. These questionnaires were scrutinized and some of the questions were used word for word for comparability reasons, but most were enhanced to better serve our purpose and context. Some questions were also developed based on our long-standing experience as bicyclist commuters.

In this thesis, only a few of the items are used, namely those about gender, year of birth, height, weight, employment status, commuting frequency per week each month over the year, commuting time, number of red-light stops and commuting distance. In the questionnaire, participants wrote down their commuting time and distance to work separately for walking and cycling. They marked their normal commuting frequency by foot and by bike separately on a scheme of pre-specified numbers representing mean commuting days per week for each month. The response options were whole numbers from 0 to 14, an option ‘less than one’ and a free response option.

Some of the participant characteristics as well as the departure times from home and workplace were taken from a subsequent questionnaire (PACS Q2) distributed to the same group. This questionnaire is further described in Wahlgren et al. (2010).

3.3.2 Maps
In most case the maps used were copied from the telephone directory for the County of Stockholm (scale 1:25 000) and, in 25 cases, copies of a standard outdoor map (scale 1:50 000). The outdoor map was used to cover areas not covered by the map from the telephone directory. The map copies were individually adjusted to the participants’ home and work or study place addresses stated in the response-coupons. On the maps, the participants marked their most usual commuting routes with different markings for bicycle and pedestrian routes and for travel to and from the workplace (for instructions, see appendix). Participants with two or more workplaces were asked to pick the one they spent the most time at and, in the case of equal time spent, to choose one of them. They were then asked
to walk or cycle their route once, noting their route choice and the street names, before filling them in on the map. Finally, the respondents were asked to carefully mark their routes in places outside the printed street grid network, such as tunnels and parkways.

3.3.3 Measurement of criterion distance
The routes on maps were used as criterion distance measures. The distances of the map-drawn commuting routes from home to work were measured twice by a technical assistant. If the two measurements differed, she performed a third measurement. In Sample I, a third measurement was undertaken if differences between the first two values were, on the average, greater than 5.8 ± 3.3 mm (n = 151). The corresponding average for Sample II measurements was 4.7 ± 2.3 mm (n = 23), i.e. 1.7% of the first measured value. We then used the mean distance value of the two closest values of the three.

3.3.4 Measurement of route distances from GIS tools
The accuracy of distance estimations of two open-access route-planning systems, Eniro (www.eniro.se) and Hitta (www.hitta.se), and one licensed GIS software (MapPoint 2009, Microsoft Corporation, Redmond, USA, 2009) was tested by entering the addresses, from response coupons, of 133 participants’ home and workplaces into the GIS software. The two route planners examined were both accessible on the Internet, and used a routing database from the Tele Atlas Company (‘s-Hertogenbosch, the Netherlands, 2009). The licensed GIS software used a routing database from NAVTEQ Corp. (Chicago, USA, 2007). In the licensed software, we chose the shortest-route distance algorithm in the programme menu. Motorways, where cycling is prohibited, were eligible routes, however, in the shortest-route calculation due to a setting in the software that did not permit an exclusion of them. Furthermore, separate cycle and walking paths were not included in the route network database and were therefore not eligible in the route calculations. All three routing instruments used secret routing algorithms.

3.3.5 Measurement of GPS distance and route choice
We tested the accuracy of distance estimations of a GPS device without differential correction. The participants carried the device in a harness on their upper back to permit good satellite reception. We set the sampling frequency to 1 Hz and started the logging when the GPS had contact with at least four satellites. When the participants had reached their workplace or home we turned off the logging function. To measure the distance, we
transferred the logged tracks from the GPS receiver to the manufacturer’s analysis software (GPSports Analysis 6.6, GPSports Systems Inc., Canberra, Australia). Occasionally, at the beginning and end of the assessed trips, time passed from the moment we switched on and off the device to the actual starting and stopping of the trip. During this time, the GPS device logged positions and consequently accumulated distance, although there was no movement. Therefore, we erased the data from distance recordings logged before and after the actual trip movement. To check for signal loss, we transferred the logged tracks to the mapping software (OziExplorer). The software indicates segments of signal loss of more than 20 s with a red line, in contrast to the normal black dots. Seven routes with signal loss were found: four had losses on a major part of the route, and they were therefore discarded. The remaining three routes were used since their indications of signal loss were on straight roads or tunnels, and consequently did not deviate laterally and thereby shorten the logged route in relation to the actual route. Signal losses shorter than 20 s also occurred, but they were not assessed systematically in terms of route distance effects. Their most likely effect is a slight shortening of the measured distance.

Figure 5. An example of bicycle route markings from the instructions to the participants. The black and white colour of the maps represents the types of maps that were sent to the respondents.
3.4 Statistical analysis

In the studies we used a statistical level of $p \leq 0.05$ as significant. In all statistical analyses, we used IBM SPSS Statistics, version 15.0 to 17.0 (SPSS Inc., Chicago, Illinois, USA). The statistical procedures and data treatments are described in detail in each paper. An overview of the statistical methods used is given in Table 5.

Table 5. An overview of the statistical methods used in the thesis.

<table>
<thead>
<tr>
<th>Statistical method</th>
<th>Paper 1</th>
<th>Paper 2</th>
<th>Paper 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-way Intraclass Correlation (ICC)</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Typical Error of the Method (TEM)</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Student’s paired t-test</td>
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<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Two-way ANOVA for independent samples</td>
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<td>X</td>
<td></td>
</tr>
<tr>
<td>Linear regression</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Mann-Whitney test</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Kruskal-Wallis test</td>
<td></td>
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<td>X</td>
</tr>
<tr>
<td>One-way repeated measures ANOVA</td>
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<td></td>
<td>X</td>
</tr>
<tr>
<td>Kolmogorov-Smirnov test</td>
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<td>X</td>
</tr>
<tr>
<td>Levene’s test</td>
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<td>X</td>
</tr>
<tr>
<td>Wilcoxon signed-rank test</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Friedman’s ANOVA</td>
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<td></td>
<td>X</td>
</tr>
<tr>
<td>Pearson’s Chi-square analysis</td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

*Note. ANOVA = analysis of variance*
4. Results

4.1 Assessment of the criterion method for assessment of route distance in active commuting

4.1.1 Validity of map-drawn route distance measurements (Paper 1–2)

The first step in the validity check was to compare the routes drawn on the maps with the tracks recorded by the GPS device. Thirteen of the 19 participants had identical or almost identical GPS tracks (≤3 mm lateral deviation) compared to the map-drawn routes. For six participants, there were lateral deviations of more than 3 mm. The lengths of the deviating sections of the routes varied between 1% and 12% (7.0 ± 4.6%) of the total lengths of drawn routes. The main characteristic of the deviations was that GPS tracks were located on streets parallel to those drawn on maps. The effect of these route deviations on the total distance measured on the route-drawn maps was 1.21 ± 1.60% (n.s.) in the six cases with deviations. In relation to the whole group, the difference decreased to 0.38 ± 1.02% (n.s.), with a 95% confidence interval of -0.18% to 0.94% of the whole route-drawn distance.

In Paper 2 we repeated the validity check. There, eight of the 13 drawn commuting routes displayed lateral deviations of more than 3 mm compared to the GPS tracks. The lengths of the deviating sections of the routes varied between 2.7% and 17% (mean 7.4 ± 5.1%) of the total lengths of the drawn routes. The effect of these route deviations on the total distance was 0.12 ± 1.49% (n.s.) in the eight cases with deviations. In relation to the whole group, the effect was 0.08 ± 1.14% (n.s.), with a 95% confidence interval of -0.54 to 0.70% of the whole route-drawn distance.

4.1.2 Reproducibility of map-drawn route distance (Paper 1)

The result of the reproducibility assessments is presented in Table 6. There were no significant order effects between test and retest occasions. The differences for each group did not differ significantly between the groups. The test-retest differences were in absolute terms of the same order of magnitude throughout the studied range of distances.
Figure 6. Test and retest values of map-drawn route distance measurements in relation to the line of identity (n = 133).

Table 6. Test–retest reproducibility of map-drawn route distance measurements.

<table>
<thead>
<tr>
<th></th>
<th>Pedestrians</th>
<th>Bicyclists</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Women (n = 15)</td>
<td>Men (n = 8)</td>
<td>Women (n = 41)</td>
</tr>
<tr>
<td>Map 1 (m)</td>
<td>3190 ± 1330</td>
<td>2920 ± 1150</td>
<td>6650 ± 3810</td>
</tr>
<tr>
<td>Map1-map 2 (m)</td>
<td>-78 ± 181</td>
<td>12 ± 113</td>
<td>61 ± 276</td>
</tr>
<tr>
<td>Typical error (m)</td>
<td>128</td>
<td>80</td>
<td>195</td>
</tr>
<tr>
<td>ICC</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. Means ± 1 standard deviation, SD

4.1.3 Reproducibility and validity of origin and destination markings (Paper 1)

Ninety-six percent of the participants map markings of home agreed within 3 mm with the stated addresses. This applied to all three address-geocoding systems used to localize the addresses stated by the participants. The corre-
sponding figure was 95% for the destination points. The mean values of
the deviations divided between all 133 individuals were 0.21 mm for the
origin points and 0.62 mm for the destination points, which correspond to
less than 0.1% and 0.3%, respectively, of the total measured average route
distance length.

Ninety-six percent of the origin markings were reproduced within 3 mm
from each other. The corresponding value for the destination points was
88%. The mean values of the deviations divided between all 133 individu-
als were 0.20 mm for the points of origin and 1.37 mm for the destination
points, corresponding to less than 0.1% and 0.6%, respectively, of the
total measured average route distance length.

4.2 Assessment of reproducibility

4.2.1 Reproducibility of distance estimation methods (Paper 2)
The test–retest intraclass correlation coefficients, ICC, ranged from 0.757
to complete concordance as displayed in Table 7. There was no significant
order effect between test and retest in any of the methods. The range of the
typical errors was from 0 to 2780 metres. The test–retest differences were
in absolute terms of the same order of magnitude throughout the range of
distances studied.

Table 7. Test–retest reproducibility of self-estimated distance (SED), straight-
line distance (SLD) GPS and GIS distances in metres.

<table>
<thead>
<tr>
<th></th>
<th>Test 1</th>
<th>Test 1 - Test 2</th>
<th>Typical error</th>
<th>ICC</th>
<th>Order effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>SED, n = 67</td>
<td>7770 ± 5850</td>
<td>119 ± 3940</td>
<td>2780</td>
<td>0.757</td>
<td>No</td>
</tr>
<tr>
<td>SLD, n = 133</td>
<td>5370 ± 3210</td>
<td>14 ± 178</td>
<td>130</td>
<td>0.998</td>
<td>No</td>
</tr>
<tr>
<td>GPS, n = 14</td>
<td>3070 ± 1090</td>
<td>19 ± 64</td>
<td>50</td>
<td>0.998</td>
<td>No</td>
</tr>
<tr>
<td>GIS-H, n = 133</td>
<td>7367 ± 3824</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>No</td>
</tr>
<tr>
<td>GIS-E, n = 133</td>
<td>7835 ± 4134</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>No</td>
</tr>
</tbody>
</table>

Note. All GIS algorithms showed complete concordance. GIS-H = hitta.se, GIS-E = Eniro.se

4.2.2 Reproducibility of methods for determining reported time and
frequency and derived velocity (Paper 3)
The results of the reproducibility assessment for walking and bicycling
variables are shown in Table 8. Order effects were seen in bicycle commut-
ing time and velocity, but with a negligible magnitude. The range of the
ICCs was ‘moderate’ (0.48) to ‘almost perfect’ (0.99) using the wordings of Landis and Koch (1977).
Table 8. Test-retest reproducibility of participants stated walking and bicycling commuting time, red-light stops, trip frequency per week, and derived velocity.

<table>
<thead>
<tr>
<th>Item</th>
<th>Test</th>
<th>Retest</th>
<th>Test-retest difference</th>
<th>t-test3</th>
<th>TEM</th>
<th>ICC1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking (n=22)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time to work, min.</td>
<td>42.7 ± 19.1</td>
<td>42.7 ± 19.2</td>
<td>0.0 ± 1.5</td>
<td>1.00</td>
<td>1.1</td>
<td>0.99</td>
</tr>
<tr>
<td>Red-light stops²</td>
<td>2.5 ± 2.4</td>
<td>2.7 ± 2.9</td>
<td>-0.1 ± 0.8</td>
<td>0.45</td>
<td>1.0</td>
<td>0.95</td>
</tr>
<tr>
<td>trips per week in:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>January</td>
<td>5.9 ± 4.2</td>
<td>6.3 ± 4.5</td>
<td>-0.6 ± 2.1</td>
<td>0.17</td>
<td>1.5</td>
<td>0.88</td>
</tr>
<tr>
<td>February</td>
<td>5.8 ± 4.3</td>
<td>6.4 ± 4.5</td>
<td>-0.6 ± 2.1</td>
<td>0.16</td>
<td>1.5</td>
<td>0.89</td>
</tr>
<tr>
<td>March</td>
<td>5.4 ± 4.7</td>
<td>5.5 ± 4.9</td>
<td>0.0 ± 1.3</td>
<td>0.94</td>
<td>0.9</td>
<td>0.96</td>
</tr>
<tr>
<td>April</td>
<td>4.3 ± 4.7</td>
<td>4.3 ± 4.7</td>
<td>0.0 ± 1.3</td>
<td>0.87</td>
<td>1.9</td>
<td>0.97</td>
</tr>
<tr>
<td>May</td>
<td>3.5 ± 4.5</td>
<td>3.2 ± 4.4</td>
<td>0.3 ± 0.8</td>
<td>0.11</td>
<td>0.6</td>
<td>0.98</td>
</tr>
<tr>
<td>June</td>
<td>3.5 ± 4.5</td>
<td>3.3 ± 4.4</td>
<td>0.2 ± 0.9</td>
<td>0.38</td>
<td>0.6</td>
<td>0.98</td>
</tr>
<tr>
<td>July</td>
<td>2.2 ± 3.7</td>
<td>2.3 ± 3.9</td>
<td>-0.1 ± 1.5</td>
<td>0.77</td>
<td>1.1</td>
<td>0.93</td>
</tr>
<tr>
<td>August</td>
<td>3.0 ± 4.0</td>
<td>2.5 ± 3.8</td>
<td>0.5 ± 2.6</td>
<td>0.42</td>
<td>1.8</td>
<td>0.78</td>
</tr>
<tr>
<td>September</td>
<td>3.6 ± 4.5</td>
<td>3.4 ± 4.5</td>
<td>0.2 ± 1.3</td>
<td>0.47</td>
<td>0.9</td>
<td>0.96</td>
</tr>
<tr>
<td>October</td>
<td>4.2 ± 4.6</td>
<td>4.4 ± 4.6</td>
<td>-0.2 ± 3.6</td>
<td>0.75</td>
<td>2.5</td>
<td>0.70</td>
</tr>
<tr>
<td>November</td>
<td>5.2 ± 4.6</td>
<td>5.2 ± 4.6</td>
<td>0.1 ± 1.9</td>
<td>0.87</td>
<td>1.3</td>
<td>0.91</td>
</tr>
<tr>
<td>December</td>
<td>6.0 ± 4.5</td>
<td>5.8 ± 4.3</td>
<td>0.2 ± 1.5</td>
<td>0.58</td>
<td>1.1</td>
<td>0.94</td>
</tr>
<tr>
<td>Velocity, km/h</td>
<td>5.3 ± 0.5</td>
<td>5.2 ± 0.6</td>
<td>0.0 ± 0.2</td>
<td>0.90</td>
<td>0.1</td>
<td>0.91</td>
</tr>
<tr>
<td>Bicycling (n=62)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time to work, min.</td>
<td>27.2 ± 12.6</td>
<td>27.9 ± 12.6</td>
<td>-0.7 ± 2.6</td>
<td>0.05</td>
<td>1.8</td>
<td>0.98</td>
</tr>
<tr>
<td>Red-light stops</td>
<td>4.4 ± 2.8</td>
<td>4.3 ± 3.1</td>
<td>0.1 ± 1.4</td>
<td>0.65</td>
<td>0.6</td>
<td>0.89</td>
</tr>
<tr>
<td>trips per week in:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>January</td>
<td>4.5 ± 4.1</td>
<td>4.2 ± 4.1</td>
<td>0.2 ± 1.3</td>
<td>0.34</td>
<td>0.9</td>
<td>0.95</td>
</tr>
<tr>
<td>February</td>
<td>4.5 ± 4.2</td>
<td>4.3 ± 4.2</td>
<td>0.2 ± 1.3</td>
<td>0.28</td>
<td>0.9</td>
<td>0.95</td>
</tr>
<tr>
<td>March</td>
<td>5.9 ± 4.3</td>
<td>5.8 ± 4.1</td>
<td>0.1 ± 1.7</td>
<td>0.55</td>
<td>1.2</td>
<td>0.92</td>
</tr>
<tr>
<td>April</td>
<td>7.6 ± 3.3</td>
<td>7.9 ± 3.4</td>
<td>-0.4 ± 2.9</td>
<td>0.34</td>
<td>2.1</td>
<td>0.62</td>
</tr>
<tr>
<td>May</td>
<td>8.6 ± 2.5</td>
<td>8.8 ± 3.1</td>
<td>-0.2 ± 2.4</td>
<td>0.54</td>
<td>1.7</td>
<td>0.65</td>
</tr>
<tr>
<td>June</td>
<td>8.1 ± 2.7</td>
<td>8.4 ± 3.3</td>
<td>-0.3 ± 2.7</td>
<td>0.45</td>
<td>1.9</td>
<td>0.61</td>
</tr>
<tr>
<td>July</td>
<td>3.0 ± 4.3</td>
<td>3.3 ± 4.1</td>
<td>-0.3 ± 3.6</td>
<td>0.52</td>
<td>2.5</td>
<td>0.63</td>
</tr>
<tr>
<td>August</td>
<td>7.2 ± 3.8</td>
<td>7.5 ± 3.2</td>
<td>-0.2 ± 3.0</td>
<td>0.56</td>
<td>2.1</td>
<td>0.62</td>
</tr>
<tr>
<td>September</td>
<td>8.9 ± 2.0</td>
<td>9.1 ± 2.6</td>
<td>-0.2 ± 2.4</td>
<td>0.46</td>
<td>1.7</td>
<td>0.48</td>
</tr>
<tr>
<td>October</td>
<td>8.5 ± 2.6</td>
<td>8.3 ± 3.3</td>
<td>0.1 ± 2.8</td>
<td>0.69</td>
<td>2.0</td>
<td>0.55</td>
</tr>
<tr>
<td>November</td>
<td>6.7 ± 3.8</td>
<td>7.1 ± 3.5</td>
<td>-0.3 ± 2.6</td>
<td>0.30</td>
<td>1.8</td>
<td>0.74</td>
</tr>
<tr>
<td>December</td>
<td>4.8 ± 4.0</td>
<td>4.9 ± 3.8</td>
<td>-0.2 ± 1.8</td>
<td>0.48</td>
<td>1.3</td>
<td>0.90</td>
</tr>
<tr>
<td>Velocity, km/h</td>
<td>15.9 ± 3.4</td>
<td>15.4 ± 3.8</td>
<td>0.5 ± 1.7</td>
<td>0.03</td>
<td>1.2</td>
<td>0.87</td>
</tr>
</tbody>
</table>

Notes. ¹Intraclass correlation coefficient, ²n = 21, ³P-value of t-test.
4.3 Validity of four distance estimation methods (Paper 2)

The average percentages of the four distance estimation methods in relation to the criterion distance are displayed in Table 9 and Figure 8. In Paper 2, Table 3, we also display the median values. The average percentage of each method differed significantly from the criterion distance, but did not differ significantly among groups of gender and mode. An exception was GIS distance estimations where pedestrians and bicyclists differed significantly. Pedestrians had 7–12% larger deviations from the criterion distance than the bicyclists.

With varying criterion distances, the relative level of overestimation appeared to vary in the subjective estimation, see Figure 7, in the GIS distance and slightly in straight-line distance, whereas the GPS distance estimations appeared to be rather constant over short and long criterion distances.

![Figure 7. Self-estimated distance in relation to criterion method and line of identity (n = 117).](image)

Table 9. Self-estimated distance (SED), straight-line distance (SLD) and three different GIS route-network distances and GPS distance in relation to criterion distance (CD).

<table>
<thead>
<tr>
<th></th>
<th>Women</th>
<th>Men</th>
<th>Women</th>
<th>Men</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n = 12</td>
<td>n = 7</td>
<td>n = 35</td>
<td>n = 63</td>
</tr>
<tr>
<td>CD</td>
<td>3310±1450</td>
<td>3110±1110</td>
<td>6800±3810</td>
<td>8120±3670</td>
</tr>
<tr>
<td>(SED/CD)x100</td>
<td>104±39</td>
<td>109±20</td>
<td>115±101</td>
<td>117±40</td>
</tr>
<tr>
<td>(SLD/CD)x100</td>
<td>83.9±8.1</td>
<td>76.2±13.8</td>
<td>75.9±12.6</td>
<td>80.3±8.7</td>
</tr>
<tr>
<td>(GIS-M/CD)x100</td>
<td>117 ± 17</td>
<td>124 ± 26</td>
<td>111 ± 21</td>
<td>110 ± 16</td>
</tr>
<tr>
<td>(GIS-E/CD)x100</td>
<td>133 ± 24</td>
<td>131 ± 33</td>
<td>117 ± 21</td>
<td>120 ± 20</td>
</tr>
<tr>
<td>(GIS-H/CD)x100</td>
<td>123 ± 21</td>
<td>124 ± 28</td>
<td>113 ± 19</td>
<td>112 ± 19</td>
</tr>
<tr>
<td>(GPS/CD)x100</td>
<td>104 ± 4</td>
<td>105 ± 3</td>
<td>105 ± 3</td>
<td>105 ± 4</td>
</tr>
</tbody>
</table>

Note: GIS-M = Map Point, GIS-E = Eniro.se, GIS-H = hitta.se
The average percentages of the four distance estimation methods in relation to the criterion distance are displayed in Table 9 and Figure 8. In Paper 2, Table 3, we also display the median values. The average percentage of each method differed significantly from the criterion distance, but did not differ significantly among groups of gender and mode. An exception was GIS distance estimations where pedestrians and bicyclists differed significantly. Pedestrians had 7–12% larger deviations from the criterion distance than the bicyclists.

With varying criterion distances, the relative level of overestimation appeared to vary in the subjective estimation, see Figure 7, in the GIS distance and slightly in straight-line distance, whereas the GPS distance estimations appeared to be rather constant over short and long criterion distances.

**Table 9. Self-estimated distance (SED), straight-line distance (SLD) and three different GIS route-network distances and GPS distance in relation to criterion distance (CD).**

<table>
<thead>
<tr>
<th></th>
<th>Pedestrians</th>
<th>Bicyclists</th>
<th>All participants</th>
<th>Corr. factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Women</td>
<td>Men</td>
<td>Women</td>
<td>Men</td>
</tr>
<tr>
<td>n = 12</td>
<td>n = 7</td>
<td>n = 35</td>
<td>n = 63</td>
<td>n = 117</td>
</tr>
<tr>
<td>CD</td>
<td>3310±1450</td>
<td>3110±1110</td>
<td>6800±3810</td>
<td>8120±3670</td>
</tr>
<tr>
<td>(SED/CD)x100</td>
<td>104±39</td>
<td>109±20</td>
<td>115±101</td>
<td>117±40</td>
</tr>
<tr>
<td></td>
<td>n = 15</td>
<td>n = 8</td>
<td>n = 41</td>
<td>n = 69</td>
</tr>
<tr>
<td>CD</td>
<td>3190±1330</td>
<td>2920±1150</td>
<td>6650±3810</td>
<td>7960±3580</td>
</tr>
<tr>
<td>(SLD/CD)x100</td>
<td>83.9±8.1</td>
<td>76.2±13.8</td>
<td>75.9±12.6</td>
<td>80.3±8.7</td>
</tr>
<tr>
<td>(GIS-M/CD)x100</td>
<td>117 ± 17</td>
<td>124 ± 26</td>
<td>111 ± 21</td>
<td>110 ± 16</td>
</tr>
<tr>
<td>(GIS-E/CD)x100</td>
<td>133 ± 24</td>
<td>131 ± 33</td>
<td>117 ± 21</td>
<td>120 ± 20</td>
</tr>
<tr>
<td>(GIS-H/CD)x100</td>
<td>123 ± 21</td>
<td>124 ± 28</td>
<td>113 ± 19</td>
<td>112 ± 19</td>
</tr>
<tr>
<td>Urban</td>
<td>n = 14</td>
<td>n = 14</td>
<td>n = 58</td>
<td>n = 86</td>
</tr>
<tr>
<td>(GPS/CD)x100</td>
<td>104 ± 4</td>
<td>105 ± 3</td>
<td>105 ± 3</td>
<td>105 ± 4</td>
</tr>
</tbody>
</table>

Note. GIS-M = Map Point, GIS-E = Eniro.se, GIS-H = hitta.se
4.4. Gender and transport mode differences (Paper 3)

In Paper 3 we noted that there are three different categories of active commuters and we therefore use these mode groups in comparisons.

Both male and female single mode cyclists had higher values for distance (f, 123%; m, 210%) than dual-mode commuters. The same was true for time (f, 80%; m, 114%), velocity (f, 16%; m, 30%) and number of red-light stops, 50%, whereas the mean number of bicycling trips did not differ between the groups (Table 10 and Paper 3). In walking, the female dual-mode commuters had higher values for distance, 26%, and duration, 35%, but lower numbers of red-light stops, 50%, and walking trips per year, 78%, compared to the single-mode pedestrians (Table 10 and Paper 3).

Pedestrian males had 4% higher velocities than females. Male cyclists had higher values in bicycling distance, 34%, calculated velocity, 26%, and the stated number of trips per year, 13%, than females. Males show 12% higher cycling velocities than females in both the group of single-mode cyclists in Sample II and in the dual-mode group.

Both male and female single-mode pedestrians had a higher frequency of walking trips per week than the dual-mode commuters during every month of the year; see Figure 9. In Paper 3, Table 8, we display the medians and means stratified for gender and mode group. The only differences in the frequency of cycling trips per week over the year noted between single and dual-mode commuters were that the female dual-mode bicyclists had higher trip frequencies in April and October. In the dual-mode group, men
showed a slightly higher frequency of walking trips per week than women from May to September; see Figure 9. Men in both the single and dual-mode groups had higher cycling frequencies than women in the Nordic wintertime (November-March), although there were no differences in the median value in January and February due to many zero scores.
Table 10. Participants measured distance, stated commuting time, derived velocity, one-way to work and commuting trips per year, median values (first–third quartile) and mean values ± 1 SD.

<table>
<thead>
<tr>
<th></th>
<th>Walking</th>
<th>Cycling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single mode, Sample I</td>
<td>Dual mode, Sample I</td>
</tr>
<tr>
<td></td>
<td>Men</td>
<td>Women</td>
</tr>
<tr>
<td></td>
<td>n=63</td>
<td>n=214</td>
</tr>
<tr>
<td><strong>Distance (km)</strong></td>
<td>2.3</td>
<td>2.3&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Median (Q1-Q3)</td>
<td>(1.7-3.9)</td>
<td>(1.4-3.4)</td>
</tr>
<tr>
<td>Mean ± 1 SD</td>
<td>3.0±2.0</td>
<td>2.5±1.3</td>
</tr>
<tr>
<td><strong>Time (minutes)</strong></td>
<td>25</td>
<td>26&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mean ± 1 SD</td>
<td>32.8±19.6</td>
<td>28.8±14.3</td>
</tr>
<tr>
<td><strong>Velocity (km/h)</strong></td>
<td>5.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.2</td>
</tr>
<tr>
<td>Median (Q1-Q3)</td>
<td>(4.8-5.9)</td>
<td>(4.6-5.6)</td>
</tr>
<tr>
<td>Mean ± 1 SD</td>
<td>5.4±0.8</td>
<td>5.1±0.9</td>
</tr>
<tr>
<td><strong>Trips per year</strong></td>
<td>37.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>389&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mean ± 1 SD</td>
<td>341±142</td>
<td>358±155</td>
</tr>
</tbody>
</table>

Notes. a = Significant gender difference within a mode group, b = Significant mode group difference within a cycling or walking gender group, respectively, c = significant difference between single-mode cycling men and women in Samples I and II.
Figure 9. Median active commuting frequencies per week for different months and transport modes.
4.5 Seasonal variation in active commuting time per week for genders and transport modes

When we combine the trip frequencies and the duration we get data on the active commuting time per week for each month over the year. This time can be compared to the physical activity recommendations of 150 minutes per week; see section 1.2.2. For single mode pedestrians of both genders, the median total walking commuting time was higher for each month than for the dual mode commuters. During the 'cycling season', single-mode cyclists of both genders had higher total commuting times than the dual-mode commuters.

With change of season, the dual-mode group replaces one mode of transport with another or combines the two. The effect of this is illustrated in Figure 10.

The commuting time accumulated from walking was slightly higher during the summer period for the men than for the women in the dual-mode group. The equivalent was true for the male single and dual mode bicyclists during primarily the Nordic winter season.
4.5 Seasonal variation in active commuting time per week for genders and transport modes

When we combine the trip frequencies and the duration we get data on the active commuting time per week for each month over the year. This time can be compared to the physical activity recommendations of 150 minutes per week; see section 1.2. For single mode pedestrians of both genders, the median total walking commuting time was higher for each month than for the dual mode commuters. During the 'cycling season', single-mode cyclists of both genders had higher total commuting times than the dual-mode commuters.

With change of season, the dual-mode group replaces one mode of transport with another or combines the two. The effect of this is illustrated in Figure 10.

The commuting time accumulated from walking was slightly higher during the summer period for the men than for the women in the dual-mode group. The equivalent was true for the male single and dual-mode bicyclists during primarily the Nordic winter season.

Figure 10. Total active commuting time per week for different months.
5 Discussion and Concluding Remarks

5.1 Discussion of the results from Paper 1
Distance is a key variable in assessments of walking and cycling both as a type of physical activity and a type of transport. For instance, in a Dutch study the physical activity from transport was found to be one of few factors that contributed significantly to the physical activity level of the participants (Bonomi, Plasqui, Goris, & Westerterp, in press). Moreover, the duration of the active transport is highly dependent on the trip distance and, in the case of commuting, the distance is often repeated two times a day, several times a week.

In Paper 1 we found that the method of letting active commuters draw their commuting routes on a map and measure the distance with a curvimeter distance measurer has both high validity and reproducibility. We have thereby established a criterion method that is useful by itself and as a basis for future studies in the expanding field of active transport research. In Paper 2 we reassessed the validity of the map-drawn route choice, but with a differently recruited sample of active commuters, and got a similar result. This strengthens the validity of the criterion method.

Before we could state that our proposed method is a criterion method, several criteria have to be met. Therefore, we first checked that the scale of the original map was valid and that it was preserved in the copying procedure. This was checked in Papers 1 and 2 with good results. Next, we checked our distance measuring system and found that it was valid and reproducible. After that, we checked the markings of origin and destination on the maps and found them both valid and reproducible. Finally, we checked the route drawings and found that they sometimes differed slightly between the first map and the second one and also between the first map and the GPS tracks for the same route. However, we then found that these lateral deviations played a negligible role for the route distance measurements. In general, the participants draw their route on parallel streets and that made no differences to the distance measurement. The deviations in GPS tracks in relation to route drawings mirrored the deviations between test and retest in route drawing. Given that these deviations were of the same magnitude, we think it is reasonable to assume that this reflects the size of deviations in potentially existing differences between both drawn routes and the actual routes taken in the whole group of participants. Explanations of the lateral deviations might be existing small day-to-day differences in route choice with commuters switching between parallel streets or incorrectly drawn routes. Thus, taking all the mentioned...
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points into consideration, we became confident that routes drawn on a map are both a valid and highly reproducible basis for route distance measurements in physically active commuting and that they also give an approximate representation of active commuters’ route choice.

We tested the validity of the criterion method on a specific group of commuters in a specific geographic area and these facts might influence the results. However, we do not believe that the good results are due to a specific selection of respondents with competence in map route drawing. In the recruitment of the Sample II participants, 36% of those who received an invitation to participate in the study sent in the response coupon. This is not an unusual response rate after a first distribution of a mail survey and since we did not know who the non-respondents were, we could not send any reminder letter or check whether they were eligible or not. In addition, some pedestrians and bicyclists probably realized that they did not meet the inclusion criteria: for example, if they were walking to an underground station and did not send in the response coupon for that reason. Anyway, to make sure that there was no such selection effect, we reassessed the validity of the route markings in relation to GPS in Paper 2, but this time with commuters recruited by advertisements. The results agreed with those of Paper 1, thus supporting the validity of the method itself and extending its external validity.

A large majority of our participants were educated at a university level. Perhaps, the method is unintentionally adapted to people with a university education? This is rather unlikely since few university courses include the map reading skills, which are a key dimension in the criterion method. Therefore, to have participants with a university education should not be a necessary condition for a successful application of the criterion method.

The participants’ ability to read and understand maps is an important element in the criterion method. Swedes are trained in the early school years to read maps through orienteering during physical education in school and, for some males, also during military training. The good result could partly be explained by this. On the other hand, this fact might also cast doubts on whether the method would work in countries were map-reading is not a common skill in the population as well as in young age groups. Therefore, the validity and reproducibility of this method in other cultural and geographical settings deserve specific studies.

We tested the method on active commuters that walk or cycle their routes regularly and probably even habitually. This fact might increase the validity and reproducibility of the route distance method since recall of the route is an important element of the method. This also underlines the need to test whether the method is applicable and valid also in active transport...
not carried out habitually. The criterion method has recently been validated in a group of children from New Zealand and the result of that study indicated that the criterion method was not fully transferable to assessments of children (Badland, Oliver, Duncan, & Schantz, 2011).

Until now, no criterion method has been established for active commuting route distance measurements. Nevertheless, Chalasani et al. (2005) have suggested a gold standard of distance measurement as ‘an uninterrupted trace of GPS points matched to a complete and geometrically correct network model in GIS.’ However, this gold standard is more or less theoretical since the stated prerequisites are rarely satisfied. For instance, short episodes of signal loss are ubiquitous in most GPS applications, at least in urban settings where satellite reception is often distorted. Moreover, available GIS network models normally lack paths used for walking and bicycling.

Several varieties of Chalasani’s proposed gold standard have been tested. For instance, Oliver et al. (2010) assessed the combined use of GPS, GIS and accelerometer in active commuting and found several methodological problems with the GPS, including short battery time, ‘cold start’ problems and signal loss. Considerable signal loss in some participants’ tracks might lead to exclusion of them from a study. In addition, these problems cause extra burdens and costs for the researcher that might also spill over and bother the participants and cause study drop-out. Nevertheless, some of these problems could be reduced by data cleaning and supplementing procedures within a GIS system as proposed by Stopher et al. (2008), but still, it is a burden for researchers to do all the data cleaning. Furthermore, the participants’ burdens still remain in Chalasani’s method: for example, waiting time for the GPS to switch to a start mode and to establish contact with enough satellites. In addition, when the survey period includes several days participants might also be instructed to turn on and off the receiver, and even charge it with increased participant burden as a result.

Conversely, our criterion method appears to involve less participant burden than Chalasani’s gold standard since it can be executed at home, but perhaps a larger researcher burden. We prepared and copied maps and distributed them to the participants and, finally, a technical assistant measured them manually during a period of several months. However, the researchers’ burden as well as time and labour costs could be lessened in several ways. For instance, maps could be printed out directly from map software instead of preparing and copying maps from an original paper map as we did. Moreover, the map measuring procedure could be enhanced, for example, by digital scanning of the routes on maps and then exporting and matching them to a GIS network database. An advantage
could then be quicker measurements of large numbers of maps in GIS and involve fewer human-induced measurement errors than with a hand-held curvimeter. Also, the participant burden of our method could be lessened to some extent by a more detailed colour map with higher resolution including markings of bicycle tracks and landmarks such as churches, schools and large retail shops.

Another possible enhancement of the method would be to change the paper maps into digital maps on-line to save distribution costs. However, this could also introduce new problems for the participants: for example, technical stress and problems with limited access to the Internet and the web-based map software. At present, the paper map is a familiar object and it also allows people to stop drawing the map if they are hesitant, put it aside, and continued later without the trouble of a new Internet log in.

There are many fields of application for the criterion method. One application is validation of other distance measuring methods that are more feasible and easy to use, as we did in Paper 2. The map method could also be used in intervention studies where the need for valid methods is high and in research designs where other distance measuring methods are less suitable. For instance, in studies where both the route distance and the route choice are of interest it is more feasible to use the criterion method since it gives both a good approximation of the route choice and a valid route distance. However, when the map method is used to assess route choice, one needs to remember it is not a criterion method, but a second-best method. Nevertheless, in relation to the calculated shortest network route described in section 1.6.1.5 which is often used in studies of environmental correlates of active transport, the criterion method sometimes gives a more valid route estimation (cf. Panter, Jones, Van Sluijs, & Griffin, 2010).

5.2 Discussion of results from Paper 2

In Paper 2 we found the reproducibility to be perfect, or almost perfect, in GIS, straight-line distances and GPS methods and substantial in the self-estimated distance method. In addition, we found no order effects, indicating no systematic variation due to time passing between tests. Good test-retest reproducibility is a necessary criterion for high validity of a method.

In assessments of the validity of the methods, we found a significant systematic underestimation of the straight-line distance and significant overestimations of the other three methods, in relation to the criterion method. Nonetheless, at the level of mean or median values the systematic over- or underestimations can be adjusted for with correction factors. The remaining errors are then due to the spreading of individual data and cannot be corrected for. Therefore, when correction factors are used, the spread around the mean ratio is crucial for the validity of individual data. If the spreading is large the correction factor will be less effective in correcting the individual values. The spreading varied greatly between the methods. The ratio of self-estimated distance to criterion distance had a high standard deviation, 55%, of the mean. The corresponding values were 13% for the straight-line distance, 16–18% for GIS distances and 4% for the GPS distance. However, the regression equations for each distance estimation method, in relation to the criterion method, indicated possible variation in the size of the deviations in relation to the criterion distance. Hence, depending on the methods used and distance values obtained with different groups, different correction factors may be needed, and these can be calculated on the basis of the regression equations presented in Paper 2, Table 4.

The variations in correction factors in relation to distance might be an effect of distance itself, but it could also be an effect of gender or transport mode, since men and bicyclists average longer distances than women and pedestrians. However, this is not likely to be a general explanation, as we found no gender differences in any of the methods, and no differences between transport modes, except for the GIS methods. On the other hand, given the relatively small samples in, primarily, the pedestrian groups, we cannot fully rule out these alternative explanations. It would therefore be of value to analyse these issues in larger samples.

5.2.1 Self-estimated distance

The participants’ overestimation of self-estimated distances could be explained by people’s generally poor ability to estimate distances described in the Introduction. Individuals often overestimate distance. This could be explained by features in the route environment that make up a cognitive load that distorts the estimation. These features could be signs, junctions,
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and built landmarks in the route environment. This effect becomes smaller as the route becomes more familiar as in the case of a commuting route and with lower cognitive loads, distance perception will become more accurate (Gärling & Loukopoulos, 2007). Correspondingly, a study of the validity of distance estimations by visitors to a new town showed much larger overestimations than by our commuting group (Crompton & Brown, 2006). Smaller overestimations were found in two other studies on commuting (Agrawal, Schlossberg, & Irvin, 2008; Nguyen & Williams, 2001). They both compared self-estimated route distances and map-drawn route distances and both found similar numbers of over- and underestimations of the commuting distance. Nguyen and Williams reported a mean size of the absolute discrepancies of 2.1 km, i.e., 46% of a mean value of 4.6 km. In fact, on comparing their results with ours for the same distance range, their study is in general concordance with ours.

The validity of self-estimated distances is influenced by how many times the route has been travelled. Therefore, if the self-estimated distance is used on bicycling or walking with non-repetitive purposes, the validity is assumed to be lower. The commuters in Sample II were recruited in November and commuted more days per year than those in Sample I and should then make better estimations. On the other hand, increasing trip frequency might involve a saturation effect in the active commuters’ ability to estimate distance. In such a case, the differences between the average active commuters and the present respondents might be small, if any. Finally, also active commuters who have recently started to commute a certain route are anticipated to have lower validity in their estimations. In our study, we did not know for how long time they have been commuters and used their present route.

It is difficult to compare individual studies since differences in study design might interfere. For instance, in our study we distributed a map and a questionnaire at the same time and some participants might have used the map to measure or estimate distance instead of reporting distance estimations based on their mental maps. It is also possible that some bicyclists used a distance recorder on their bikes and reported a measured distance instead of a perceived one. However, the generally consistent overestimations of self-reported values noted in the bicyclist group did not support such an interpretation of the general trend of the data.

The large standard deviations around the mean value could partially be explained by rounding off of self-estimated distances to multiples of 1 or 0.5 km, which we found in our data. The same phenomenon has been reported by, e.g., Witlox (2007), in a study including active commuters. Another partial explanation might be the design of the questionnaire response...
options. We used a pre-printed decimal point and in the data we found several possible cases where digits could have been misplaced in relation to the decimal point and consequently created outliers.

5.2.2 Straight-line and GIS distance
The underestimation of the straight-line distance is more or less inherited in the method since few people can walk or cycle in a straight line between home and workplace. No previous studies found have compared the straight-line distance with a criterion distance and the few studies that actually assessed walking and bicycling distances have used GIS network distance as a comparison method (see, e.g. Chalasani et al., 2005; Witlox, 2007). The sizes of the underestimation in straight-line distance depend mainly on how much the actual route distance diverges from a theoretical straight-line distance route; this relation is called a detour factor.

In a city with a fine-meshed street network, the underestimations are generally small, but they become larger if the city comprises natural environmental barriers such as rivers, lakes and mountains. Therefore, the connectivity of the urban street network is important, but also the journey distances since the effect of a barrier seems to be smaller in long distances. The effect of distance will probably also affect gender and mode groups differently since they have different distance ranges. In addition to the effects of the built environment, there could also be differences due to different route choice behaviours in groups of active commuters. However, little is known about such differences between genders, transport modes and experienced and inexperienced active commuters.

Also the three studied GIS distance calculation methods overestimated the distance. It is contra-intuitive that the shortest route is longer than the actual route, but it could be explained by the fact that the route networks used in route choice calculations do not include all paths designated for walking and bicycling. Especially paths for walking are omitted, which might explain why bicyclists’ route distance estimations are less overestimated than the pedestrians’ routes estimations. A limitation in the understanding of how the method works is also the fact that the three routing algorithms are secret, but at least the open-access route planners seem to make use of the shortest-time route for cars instead of the absolute shortest-distance route. This could explain the lengthened route distances resulting from theses routing algorithms.

However, even if the route network is perfectly comprehensive, the shortest route algorithm is an estimate and a simplification of the complex routing behaviours of commuters. Three available studies that have supplemented the standard GIS-route networks with bicycling paths suggest
that this also renders non-valid distance estimations. First, Aultman-Hall et al. (1997) found an underestimation of about 11% in the shortest network distance compared to the map-drawn distance. These authors also found that the mean overlap between the shortest-distance route and the map-drawn route in terms of route choice was 55% in a group of bicycle commuters. A similar overlap was found by Howard and Burns (2001) in bicycle commuters. In that study, too, the calculated shortest-route distance was about 10% shorter than the actual route. Finally, Winters et al. (2010) compared the distances of map-drawn routes with shortest-route estimations with an accurate route network and found that, in 75% of the bicyclists, the underestimations were within 10% of the map-drawn route. Thus, it appears that existing route algorithms are rather poor in predicting distance as well as route choice, and that this is also valid where the road network available for GIS is optimized for bicycling transport.

In general, both straight-line distance and GIS network distance rely on simplified assumptions of the commuters’ route choice behaviours. The main idea behind the GIS algorithms is that people prefer the shortest route before other routes. This idea originates from the economic theory that dominates thinking in the transport field about how humans behave. Transport researchers normally consider distance as a cost that should be minimized. This is not necessarily the whole truth as some commuters might find the trip to be a purpose of its own instead of a simple transport demand derived from their need to reach an activity in another place, for example, work, as transport professionals often assume. Conversely, commuters might choose scenic, calm or intense routes before the shortest route and even take considerable detours just for the joy of cycling or walking. To what extent different groups of active commuters choose to take the shortest route or to take detours and the reasons for their route choice have been sparsely studied (see, e.g. Menghini et al., 2010). Thus, better algorithms that mimic the routing behaviours of walking and bicycling for different purposes are needed. Moreover, in order for the distance estimations to perform better, the routing databases also need to be supplemented to include all routes possible to use by active commuters. Finally, the two methods also depend on accurate data on trip origin and destination. In our study, the reproducibility and validity of the origin and the destination were good, but it is not sure that this is true also for more infrequent destinations to which it is more difficult to recall the address (see, e.g. Denstadli & Hjorthol, 2003).
5.2.3 GPS distance

The overestimation of the GPS distance that we found could be explained mainly as an effect of signal noise that creates positioning errors that accumulate into a false prolongation of distance. Signal noise occurs on mainly three occasions: at the beginning of the trip, e.g. at cold starts, during stops throughout the trip, for example, at traffic lights, and signal noise produced continuously during a route. The signal noise is caused by poor signal reception conditions of the GPS receiver or by the inaccuracy of the GPS receiver, or by combinations of both. In addition, the trip velocity and the linearity of the route might affect the amount of signal noise (Gray et al., 2010).

The problem with low satellite reception is more common in dense urban environments due to high buildings and narrow streets that form so-called urban canyons. Our regression equation for the GPS distance measurements in relation to the criterion distance also indicates an effect of distance. Signal noise could, however, be cleaned away. For instance, we cleaned signal noise accumulated prior to trip start and after trip end. Also, Duncan et al. (2007) cleaned their GPS data and then found that their overestimations shrank from 5–8% in raw data to 0.32–1.97% in cleaned data. A proposed way to partly overcome the problem with signal noise is to use better antennas which increase the signal reception of the GPS receivers (see, e.g. Stopher et al., 2008). However, it is important that the antennas do not affect the commuters’ walking and cycling in a negative way.

When too few satellites are connected to the GPS receiver, for example, due to poor signal reception, no positioning is possible during that time period. This problem of signal loss can arise in longer and shorter sections of a route. Thus, such losses must be checked for in every measurement, which is time-consuming, but, luckily much mapping software, like the one we used, replaces long sections of signal loss with straight-line distances. Certainly, this shortens the route. We did not check for the exact effect, but a small shortening effect can be anticipated. This could also mask some of the lengthening effect of the signal noise.

Another source of error in GPS measurements is the accuracy of the GPS receiver and the routing algorithm used to calculate distance from GPS positions. They could increase or decrease the size of the reception problem. The GPS receiver we used (SPI 10) has been tested for validity in two other studies with a similar absolute magnitude in the misestimation (Coutts & Duffield, 2010; Edgecomb & Norton, 2006), but Coutts and Duffield also showed that GPS models from the same company, tested for the same activities and distances, can produce different results.
The environmental specificity in signal loss shows that GPS devices must be checked prior to use in the specific physical activity and environment to be studied. However, the high reproducibility and accuracy demonstrated in our study is a good indication of the attainable strength of this method for distance measurements of active transport in both suburban and urban environments.

5.2.4 Fields of application of results from Papers 1 and 2
As described in the Introduction, monitoring and surveillance procedures for walking and bicycling performed by, e.g. the Swedish National Institute of Public Health, Transport Analysis and Statistics Sweden are deficient, probably due to a lack of interest in active commuting and to shortages in methodology. Surveillance studies require simple and low-cost methods to be feasible in the large study populations. Today, surveillance studies asking about walking and cycling distance normally make use of self-reported distances measurements, without applying correction factors. Interestingly, this method was the least reproducible in our study. A possible enhancement could therefore be to use straight-line distance measurements together with correction factors and thereby benefit from the better reproducibility of that method and avoid problems with large overestimations of self-report distance in surveys. This could be possible today since the geocodes of home and several destinations are already collected in the Swedish National Travel Survey (SIKA, 2007). However, correction factors differ in relation to how dense and connected a street network is and that will differ between urban and rural areas and also in relation to natural barriers in different settings. Therefore, reassessments of our correction factors in other settings are needed before implementation in active commuting surveillances.

Interventions and promotion campaigns aimed at increasing walking and bicycling are often initiated by professionals in health promotion and transport, e.g. from the Swedish Transport Administration, the Swedish National Institute of Public Health or local and regional authorities or even health campaigners at workplaces. These professionals could enhance their evaluation methods for campaigns and interventions by using more valid and reproducible measures of distance. If the aim in the campaign is to give some individual feedback, and the geographic area and the group size are rather small, the criterion method, enhanced as proposed above, or the GPS distance or the straight-line distance together with correction factors are the methods we recommend. The excellent reproducibility of these methods also supports this choice.

Epidemiologists and other researchers interested in the relation between transport physical activity and health might find validity and reliability findings concerning the distance variable useful. They might consider distance as a more robust estimation of active commuting work than the time duration. Distance could also be a better denominator, instead of time, of negative outcomes such as air pollution and might be used more frequently in descriptions of the risks and exposure of active commuting. The trip time from home to work might be a less good estimation of physical activity duration since trip time includes an indefinite amount of non-active time, whereas a distance covered is a stable variable, not affected by how often commuters’ stop.
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5.3 Discussion of the results from Paper 3

How often people commute, for how long time and how fast they walk and cycle are important characteristics of active commuting behaviour. For instance, these variables can be used to estimate the dose of physical activity that comes from commuting. The dose of physical activity has been shown to differ between genders and in relation to the type of activity (see, e.g. Trost et al., 2002) therefore, it is also important to study whether the active commuting behaviours differ between men and women. In Paper 3 we found that the travel behaviour in terms of the distance, duration, frequency and velocity of active commuters also differed between transport mode choices. Moreover, seasons, with different climate and hours of daylight, were found to have a large effect on active commuting behaviours, but the effect was different for pedestrians, cyclists and dual-mode commuters of different genders.

5.3.1 Mode choice differences

An important finding in Paper 3 was that active commuting behaviours in a metropolitan setting can be divided into three different modal choice groups among both men and women. The groups are pedestrians and bicyclists, and dual-mode commuters and they represent distinctly different behaviours. The mode group differences that we found in median distance and duration could be expected, since cycling trips in survey data usually are longer than walking trips. Moreover, we also found that dual-mode bicyclists have significantly lower velocities than single-mode cyclists. This finding is new since no studies have looked at single and dual-modes separately and, consequently, this finding is hard to evaluate. However, we might speculate that, assuming equal time budgets, due to longer distances of the single-mode compared to the dual-mode cyclists, the former will be motivated to cycle faster. In line with this, El-Geneidy et al. (2007) have reported that longer distances in cycling as a mode of transport were associated with higher velocities. They reported that an increase in total cycling distance of 1.6 km, i.e. 1 mile, results in a 0.38 km/h higher velocity. Another explanation might be that since many workplaces are situated in the inner city, short commuting trips might be made more often in dense urban environments which have more street crossings and traffic lights, the pace in both walking and cycling will be slowed down. However, in our dual-mode group about half of the group started or ended their trip in the inner city, so that is not a sufficient explanation. A third possibility is that the single-mode cyclists represent a subgroup with higher aerobic power than the dual-mode group, and thus that selection factors play a role here.
5.3.2 Gender differences

Another finding was that male single-mode bicyclists cover longer distances than females. In terms of commuting time, this gender difference is neutralized due to men’s higher mean velocity. There are several different possible explanations for this. Shorter all-mode commuting distances for women have been reported in Sweden (Gil Solá, 2009; Sandow, 2008; SIKA, 2007) and for bicycle commuting in other countries (Dickinson, Kingham, Copsey, & Hougie, 2003; Howard & Burns, 2001). They explain the differences in distance by the household responsibility hypothesis. The rationale of the household responsibility hypothesis is that women choose workplaces near their home or choose to live near their workplace, so as to minimize travel time in order to have time for the household chores that have traditionally been women’s responsibility (for reviews, see Law, 1999; Turner & Niemeier, 1997). Another explanation is the observation that female-dominated workplaces, such as child and health care centres, have a more even spatial distribution in the urban area (Law, 1999; Turner & Niemeier, 1997). Since these workplaces are more evenly distributed in the urban areas, they give rise to potentially shorter commuting distances.

Surprisingly, we did not find any other significant gender differences in commuting distance, neither in walking nor in bicycling in the dual-mode group. There are some potential explanations for this. First, the gender hypotheses presented above might not be valid in analyses of groups comprising exclusively short-distance modes like walking and the dual mode since the longest commuting distances in the population are not included due to the mode restriction. Moreover, our study group is a well-educated subgroup and has blue collar jobs to a lesser extent than the general population. This fact might mask an existing general gender bias in workplace location in the population.

We also found a higher calculated cycling velocity for men than for women, although with a small magnitude of the difference. The same direction of the difference appears in all three assessed bicycling groups: single mode from Samples I and II and the dual-mode group. An explanation of the difference might be different social norms regarding the velocity of cycling between the genders. This can partly be due to higher demands of traffic safety among women and that men are less risk aware of the consequences of higher velocities (Emond, Tang, & Handy, 2009; Krizek, Johnson, & Tilahun, 2005). Moreover, the results in our study, viz. that men show higher cycling velocities, are in line with the physiological expectations. Whereas the leg muscular force capacity for walking and cycling appear to create equal conditions for both sexes (Schantz, Randall-Fox, Hutchison, Tydén, & Åstrand, 1983), the aerobic capacity relative to body
mass has been shown to differ between genders, by 15–20%, in a fashion that can explain to a great extent the differences in cycling velocity noted between men and women (Åstrand & Rodahl, 1986). Finally, we note in Paper 3 that men generally have bicycles with a greater number of gears; see Paper 3, Table 4. Whatever the reason, the higher cycling velocities for men than for women in both Samples I and II and in the dual-mode group are in conformity with the results of other studies on bicycle commuting (see, e.g. de Geus et al., 2007; Hendriksen et al., 2000; Parkin & Rotheram, 2010).

5.3.3 Seasonal variation in trip frequency
To the best of my knowledge, Paper 3 in this thesis is the first to assess differences in self-reported walking and cycling frequencies between single and dual-mode active commuters of both genders. The reason for this is that single-and dual-mode commuters are usually assessed jointly, and that commuters are categorized from their mode at the time of assessment (SIKA, 2007), thus hiding a possible mode choice variability. Furthermore, imprecise measuring methods have sometimes been used in reporting frequency variation over the year. For example, activity diaries normally cover the last days’ or weeks’ travel, or population-based travel surveys and bicycle flow measurements that only encompass data or changes at an aggregated level are reported. As a result, very little is known about how the behaviour of individual active commuters varies over the year.

We found three striking characteristics in the trip frequency patterns. First of all, there was the high and stable trip frequency over the year noted among both male and female single-mode pedestrians. This stability is only interrupted during the month of July, and the cause for that is that July is the primary summer holiday month in Sweden. Second, this stability is contrasted by the high variability in cycling frequency for both genders among the single and dual-mode cyclists. Third, the variations in cycling frequency in the dual-mode group are replaced by compensations in walking frequency. Therefore, it is necessary to include questions about several commuting modes, or at least walking and bicycling, in travel and physical activity surveys. Otherwise, the total active commuting frequency might be underestimated.

Previous research has found seasonal variation in young adults’ total physical activity (see, e.g. Plasqui & Westerterp, 2004) and in leisure-time physical activity (see, e.g. Pivarnik, Reeves, & Rafferty, 2003) with lower levels in the wintertime than in other seasons. In line with this, we note a rather dramatic seasonality in bicycle commuting, among both single and dual-mode commuters. The decrease in bicycle commuting between No-
vember and March is similar to the variations in flows of bicyclists in the bicycle counts of arterial streets leading to the inner urban areas of Stockholm, as well as within the inner urban area itself (Stockholm Office of Research and Statistics, 2000; Traffic Office; City of Stockholm, 2008). These counts are, however, rather rough measurements that cannot fully distinguish between mopeds, prams and bicycles and neither between cyclists with different purposes, but, on the other hand, measuring spots are located in places with few prams and many commuting bicyclists. Nonetheless, the variation we found is in line with findings from other cities in Sweden (Bergström & Magnusson, 2003). What is new in this study is that we note the same overall pattern of seasonality in both genders, and that it is seen to the same extent in single-mode cyclists with long distances as in dual-mode cyclists with shorter distances. This is an indication that cycling behaviour is very sensitive to the changes in the external environment between the summer and winter half of the Nordic year. And this is strikingly different compared to the stability in the walking commuting behaviour among single-mode pedestrians, which appears to change very little during the year. To our knowledge, this has not been reported previously. McCormack et al. (2010) assessed the seasonal variation in walking for transport in Calgary in Canada. In contrast to the present study, they found a decrease in the wintertime. However, they assessed walking for transport in general, and not walking to work specifically. As in the present study, they noted that the seasonal variation differs between different types of physical activity.

What can explain the overall variations in cycling trip frequency compared to the stable frequency pattern of the pedestrians? When winter is coming to Stockholm, many environmental changes occur in parallel: it gets darker, colder and snow and ice may appear on the roads and streets. It is therefore difficult to judge the effect of each individual factor.

Interestingly, the seasonal change seems to affect men and women slightly differently. Men continue to cycle for a longer period in the autumn and to a greater extent during the winter and those who stop cycling during the winter seem to start earlier in spring than their female counterparts. Thus, there is a gender difference that stands out in a more detailed analysis of the seasonal variability. Possible reasons for this gender difference in the present study might be perceptions of more unsafe bicycling conditions and less comfort during the winter. Women appear to value the importance of personal and traffic safety higher than men (see, e.g. Emond et al., 2009; Krizek et al., 2005) and they also appear to value bicycling comfort more highly than men (see Emond et al., 2009). Interestingly, in walking we found no gender difference in commuting frequencies, so the
explanation for the difference must include something specific for the cycling mode. Unlike walking, bicycling includes keeping a vehicle in balance in order not to fall, and bicyclists are therefore more exposed to poor road conditions. In line with this, Winters et al. (2011) found that regular cyclists in Vancouver, Canada, perceived icy and snowy routes as major deterrents. However, also the interaction with other traffic might be a critical factor. The risk of not being seen by car-drivers when cycling in darkness, and not seeing motorized vehicles, might be critical for the perception of safety.

5.3.4 Total active commuting time in relation to physical activity recommendations

The minimum level of physical activity time per week to gain important health effects is 150 minutes of moderate intensity or 60 minutes of vigorous intensity (Haskell et al., 2007). Among the modal choice groups studied, adherence to the levels largely mirrors the variations in total trip frequency per week and month. The majority in the pedestrian group meet the recommendation exclusively with commuting physical activity, except for in July, which is the predominant summer holiday month; see Figure 10. The median levels of physical activity accumulated in the dual-mode group from cycling do not meet the physical activity guidelines. However, if walking and cycling times are added together, the dual-mode group has median values which, for most of the year, are only slightly lower than the physical activity recommendations. Thus, the walking component is important for this outcome. With only the cycling component, the dual-mode group does not come close to the physical activity recommendations. The median single-mode bicyclists meet the 150 minutes recommendation solely in the summer. Thus, to meet the recommendations all-year round, the bicyclists need to complement with other forms of physical activity in the wintertime. That is also true for the dual-mode group during most parts of the year, but to a rather modest extent. The dual-mode strategy therefore has clear advantages, and it is interesting to note that this seems to be a strategy that functions up to distances of about 4–5 kilometres, as judged from the 3rd distance quartiles of men and women; see Table 10.

Duration is one aspect of the physical activity recommendations, intensity is another. The calculated median velocities in the present study ranged from 5.2 to 5.4 km/h in walking and from 12.8 to 18.6 km/h in cycling. Are they intense enough to meet the recommendations? This is hard to tell, since the velocities are based on valid distance values, but also on duration values that include time for red-light stops. Furthermore, due to rounding off in the majority of the cases, the duration values involve errors on the
individual level, which, however, might cancel out at the group level. Never-
theless, with these limitations in mind, the median walking velocity in
Paper 3 is included in the proposed range of brisk walking in the recom-
mandation which is 3–4 mph or 4.8–6.4 km/h (Pate et al., 1995). The
lower limit in the recommendation corresponds to the first quartile of
walking velocity in the present study, an indication that the velocity is, in
general, brisk and of moderate intensity even if it also encompasses stops at
red lights and junctions.

No velocity limits are set for bicycling in the physical activity recom-
mandation. However, moderate intensity correspond to 3–6 METs and in
the Compendium of Physical Activity, 4 METs correspond to 16 km/h
(Ainsworth et al., 2000); hence, it is one MET higher than the minimal
recommendation with an indication that the median bicycling velocities in
the present study are of moderate intensity. Whether normal bicycling
commuting velocities meet the recommendations have been tested by de
Geus et al. (2007) who found a high mean intensity of 6.8 METs in field
tests. Correspondingly, Haskell et al. (2007) suggest that both walking and
cycling, with a transport purpose, should be recognized as being of mod-
erate intensity.

The recommended amounts of physical activity are rather roughly ex-
pressed in the guidelines as thresholds for the three dimensions: duration,
intensity and frequency. However, a high intensity for a shorter duration
might expend an equal amount of energy as a longer duration with a lower
intensity. If the recommendation is expressed as thresholds of the dimen-
sions instead of an energy expenditure of 750 kcal per week, this may give
an underestimation of the energy expenditure since the surplus duration
and intensity is not taken into account. Alternatively, the total volume of
physical activity and the recommendation could be expressed in MET-
minutes obtained by multiplying the number of minutes a physical activity
is performed by the energy cost of that activity expressed in METs. Then,
the active commuting exceeding the thresholds of 30 minutes and moderate
intensity is also included: for example, bicycling a long time at a faster
velocity. However, the smallest bout of physical activity to count in the
recommendation is set to 10 minutes, thus shorter bouts of physical activ-
ity should not be included at present although they evidently imply energy
expenditure.

Finally, some comments on the single-mode cycling strategy in relation
to possible effects on health. If there is no substitution during the winter
for the physical activity gained from cycling during the summer, a detrain-
ing effect will most probably take over rather quickly, leading to a lowered
metabolic capacity as indicated by decreases in capillarization, levels of
oxidative enzymes and the capacity for mitochondrial ATP production in skeletal muscle (Schantz, Henriksson, & Jansson, 1983; Wibom et al., 1992) and secondary effects such as a lowered glucose tolerance (Rogers, King, Hagberg, Ehsani, & Holloszy, 1990). Interestingly, there is also a study on the effect of seasonal versus all-year-round levels of physical activity on premature mortality, showing the beneficial effect of all-year-round physical activity (Magnus, Matroos, & Strackee, 1979). Indeed, this is another and important reason to try to stimulate, and enhance the conditions for all-year-round cycling.

5.3.5 Fields of application of results from Paper 3

The findings concerning different commuting behaviours between gender and mode groups could be used to tailor promotion campaigns aimed at increasing levels of active commuting. Campaigns should promote both walking and bicycling modes. In the wintertime, campaigns should focus on keeping bicyclists cycling by providing information on clothing and components for bicycling in the winter, such as studded tyres. If cyclists are hesitant to cycle in the wintertime, they should be informed about the benefits of walking to work instead. This information could be distributed to commuters with distances up to 4–5 km. The message to commuters could be to walk, at least a few days per week or one-way to work. Possible users of this knowledge are national transport and health promotion professionals, but also local campaigners at workplaces.

To get a fair picture of the contribution of active commuting to total physical activity, epidemiologists and other researchers in physical activity should consider seasonality and mode and gender group differences in the collection of data.

Policy and planning professionals from both the transport and the physical activity fields might use the findings of reliability and validity of distance and the other crucial variables helpful for enhancing the quality of input variables in economic appraisals. For instance, cost-benefit analyses or tools like HEAT for cycling and walking (WHO/Europe, 2008, 2011) could get better input data if more reliable methods are used. Better appraisals of active commuting can, in turn, result in a more efficient allocation of public infrastructure funding, to the betterment of all society. Policy-makers responsible for bicycle route maintenance should consider how the quality of the maintenance could be improved in order to give males and females similar opportunities to use walking and bicycling infrastructure.
5.4 Limitations and strengths of study design and method

The studies included in this thesis have several limitations. A limitation in common for all the studies is that we used non-random samples of participants. One reason for not using random population sampling was that the prevalence of the behaviours was assumed to be rather low, about 10–20% of the work trips are by foot or bike the whole way and, consequently, it is costly to randomly recruit an adequate number of active commuters to be able to stratify analyses from several demographic factors. We also wanted to recruit a large group, preferably with geographic and demographic heterogeneity, in order to analyse differences between genders and transport mode groups. Sample I was therefore recruited by advertisements. However, to use advertisement recruitment introduces a risk of selection bias. For example, people with high socio-economic status might subscribe to morning newspapers to a larger extent and might also be more inclined to answer questionnaires than people with low socio-economic status. On the other hand, according to the results from the randomly recruited regional travel survey for Stockholm (RVU04), active commuting seems to be an activity that largely attracts people with high socio-economic status; see Table 11. Also, Börjesson and Eliasson noted high socio-economic status in a study of bicyclist commuters in Stockholm (Börjesson & Eliasson, 2010).

Another potential selection bias is that people who feel that they are performing a socially desirable activity, such as walking and bicycling many times a year and over long distances, might reply to a larger extent than others. Since GIH was the addressee in the advertisement, this might also have triggered well-trained and fit people to reply. However, since we were well aware of this potential effect, we stressed in the advertisement that also people walking and riding short distance were welcome in the study. The potential selection bias in the recruitment of Sample I also led us to recruit Sample II differently.

Alternative recruitment strategies could have been to contact walking and bicycling clubs or organizations in Stockholm, but they mostly organize sport or recreation bicyclists and pedestrians and not active commuters and this will also imply a selection bias. Thus, there were no reasonable alternative to the existing recruitment method.

However, when Samples I and II are compared with the above-mentioned regional travel survey RVU04 using the same inclusion criteria, there were rather small socio-economic differences in the variables that were available in both studies, as displayed in Tables 4 and 11. On the other hand, the mean commuting time and distance in both Samples I and II were of a higher magnitude than in the regional sample, as displayed in Tables 3 and 10. This could be an indication that advertisement sampling,
as well as the street sampling at the entrances to the inner city, might lead
to oversampling of people commuting long distances and times. This dif-
ference is most noticeable in bicycling distances. However, these differences
might possibly be explained by different recruitment periods: our Sample I
in May, Sample II in November and RVU04 in September of the same
year. However, this is an unlikely explanation since both months display
equally high bicycling levels both in our studies and in the bicycle counts
performed by the traffic office of Stockholm. The size of the dual-mode
group in the RVU04 and our samples might possibly influence the different
mean bicycling distances. Another explanation of the difference is the
rather crude methods for estimating commuting distance used in the
RVU04 sample; see section 1.1 and Allström et al. (2006). However, the
possibility of a selection bias cannot be ruled out.

A consequence of a possible selection bias would be that the results
should be interpreted with caution and the results could not be extrap-
olated to population levels. However, as long as we are aware of these pos-
sible limitations of the sample, we can use it in methodological studies and
in comparisons within the samples.

Table 11. Characteristic of pedestrians and bicycling commuters from RVU04.

<table>
<thead>
<tr>
<th></th>
<th>Bicycling</th>
<th>Walking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Men</td>
<td>Women</td>
</tr>
<tr>
<td>Range, number of replies:</td>
<td>413-452</td>
<td>475-552</td>
</tr>
<tr>
<td>Age in years, mean ± SD</td>
<td>41.1±11.5</td>
<td>41.9±12.0</td>
</tr>
<tr>
<td>Gainful employment, %</td>
<td>91.4</td>
<td>86.2</td>
</tr>
<tr>
<td>Income &gt;25000 SEK/m, %</td>
<td>79.5</td>
<td>68.3</td>
</tr>
<tr>
<td>Have a driver’s licence, %</td>
<td>90.7</td>
<td>79.5</td>
</tr>
<tr>
<td>Usual access to a car, %</td>
<td>67.0</td>
<td>65.4</td>
</tr>
</tbody>
</table>

Note. Values are based on self-reports, main mode for journeys to work and school for ages >19 years, own processing of the RVU04 database.

Another limitation of the study design is the choice to study the active
commuting behaviour of a group consisting of already active commuters.
With the present design, we cannot study the correlates of active commu-
ting prevalence and identify significant perceived barriers to and facilitators
of walking and bicycle commuting, but that was neither the aim of the
studies. On the other hand, the revealed behaviour of the already active
commuting people might be more interesting since some of the perceived
barriers to active commuting will disappear when a person has actually tried to bicycle or walk to work (cf. van Bekkum et al., 2011). The use of already active commuters could therefore be regarded as a strength of the study.

In the same way, the use of clear-cut behaviours could be seen both as a limitation and a strength of the study. Other studies use aggregations of several active behaviours, such as moderate physical activity or leisure-time activity. This gives an uncertain picture of the exact contribution of walking and cycling commuting to the findings. From an implementation perspective, there is, however, a clear positive value for policy professionals to know the contribution of more specific behaviours to positive and negative outcomes. The actions and interventions proposed by the policy professionals could then be tailored and more efficient. On the other hand, studying one or two active behaviours at the time might mask the effect of activity domain substitution and we miss finding that a decrease in physical activity might be compensated for in another activity domain. A high specificity in studied active behaviours might also seize effects of possible domain substitution that are masked if larger constructs of physical activity such as leisure-time physical activity are used.

Moreover, the idea of substitution of physical activity between domains implies an idea of an individual budget of physical activity time or effort so that the same level of physical activity would be upheld over time. If there are such budgets, they seem to consist in more of an upper time allocation limit than a certain energy expenditure budget since many studies have shown large seasonal variation in physical activity levels. Interestingly, in the transport sector, a parallel idea of a travel-time budget for transport exists, but it seems to work solely on highly aggregate population levels, such as countries (for a review, see Mokhtarian & Chen, 2004).

The cross-sectional study design is also a limitation in that we cannot study changes over time in relation to different correlates.

To define active commuting as solely the walking and cycling modes is a limitation; also to require the journey to be made with a single mode the whole way is a limitation. It excludes other, potentially successful, active commuting strategies, such as walking long distances from public transport or combining public transport with cycling at the access or the egress part (cf. Martens, 2007). Also commuting with electrically assisted bikes might be a feasible commuting strategy (cf. Gojanovic, Welker, Iglesias, Daucourt, & Gremion, in press; Simons, Van Es, & Hendriksen, 2009). On the other hand, studying the clear-cut walking and cycling behaviours will result in clear-cut analyses without the limitations introduced by other
modes. Nevertheless, the present assessment of two clear-cut forms of active commuting behaviours could be considered as a first step.

The methods used in these studies are thoroughly tested for reproducibility and, in the case of distance, also validity, and this strengthen the studies. The use of maps to encompass the commuting routes is hardly ever implemented, but it has shown to be a successful method for assessing commuting distance and, to a lesser extent, also commuting routes choice.

A limitation of the self-report method, such as the questionnaire in this thesis, is the risk of recall bias and the risk of under- or overestimation due to social desirability. For example, it might be too difficult to remember the commuting habits in every month, at least in bicycling where the frequencies change markedly over the year. Moreover, questionnaires could also constitute large cognitive burdens for the participant due to complicated wordings, and temporal burdens due to the number of questions. We tried to ease these burdens by performing pre-tests of the questionnaire on several active commuters in and outside the department and also to split the questions into two questionnaires PACS Q1 and Q2. Still, there are weaknesses in the questionnaire design in the question of stated distance. A number of participants seem not to have noticed the pre-printed decimal point and might have put the figures down wrong. This caused problems with evidently extreme over- and underestimations. Moreover, some questions were not included, for example, about the participants’ record of active commuting in the past and if they have been commuters for years or decades and if they have used the previous route for a long time. This could have been interesting in relation to, for instance, their perceptions of distance.

At first glance, commuting time seems like a straightforward variable but, in a physical activity context, it might include several stops and non-active periods, and this aspect is not fully encompassed by our questionnaire. We do ask about stops at red lights, but there might be other stops as well, for example, in downhill cycling. The importance of non-active times during a trip needs to be considered in relation to activity duration. We have therefore chosen to use distance as a complementary estimate of physical activity duration in commuting.

In the assessment of distance estimations, the dominant input came from bicyclists. To be certain whether there are differences between bicyclists and pedestrians, larger samples and further studies are needed. An inherent weakness of the GPS method is that satellite signals may be obstructed, for example, by high buildings. Since we are interested in commuting in an urban environment and under free living conditions, this problem could not be avoided. Therefore, we checked all GPS tracks for signal loss.
The GIS method was limited by the fact that we could not control the routing algorithms and the GIS routing databases used were not completely comprehensive. Here, one of the ideas with the choice of an open access route-planner was to test methods that could be feasible also for studies with low budgets.

In the test of reproducibility, in some cases there was snow was falling between the two test occasions. In such cases, we instructed the participants to recall the conditions of the first test occasion regarding the items that could have changed due to the snow and to report them also on the retest occasion.
5.5 Future perspectives

Active commuting provides important outcomes for individuals in terms of daily physical activity and sustainable mobility and accessibility. In line with this policymakers such as those associated with WHO and the Swedish National Institute of Public Health (Folkhälsoinstitutet) have proposed active commuting as a means to tackle the problems that originates from too little physical activity in populations. Moreover, if active commuting replaces passive car commuting there are additional health benefits in terms of lower levels of pollution and noise exposure for individuals. Besides the potential health effects, there are also monetary gains for society if commuting is done in a less harmful way for society. Thus there are several good reasons to promote active commuting.

Promotion of behaviour in large populations is, however, costly and should therefore be tailored to be both effective and cost-efficient. Furthermore, policymakers from the public health, planning, and transport sectors need to co-operate in order to promote walking and cycling of all purposes both in Sweden and elsewhere. Such promotion efforts imply changes in many parts of society and are best guided by social-ecological models for behaviour change. These models suggest that the factors that influence behaviours originate from several levels: individual, psychosocial and environmental and policymaking.

An overview of some of the correlates of active commuting is given in section 1.3. There I also conclude that, still, little is known about what factors are the most important barriers and facilitators in walking and bicycle commuting. More research on the correlates and determinants of active commuting in different socio-economic groups and different cultural and infrastructural settings is needed to better prioritize policy actions and other types of promotion. Research design also needs to be adapted to specific conditions of various settings, in terms of transport cultures, social norms, available infrastructure, land use patterns and urban density. However, researchers also need to search for correlates and determinants that might be common to all settings, for example the effect of distance.

Correlates for walking and bicycling commuting cannot be seen in isolation from the dominant car-commuting mode that influences the behavioural setting, e.g. through the social norms for how different modes are looked upon, but also by influencing the comfort and safety perceptions of other road-users. In addition, car commuting and active commuting interests often compete on the scarce street space in the urban cores and also for the limited public infrastructure investments and how maintenance and reinvestment resources should be allocated. Future research therefore needs to look at how car commuting is promoted, indirectly and directly by, for
instance, parking subsides and urban planning and how that promotion affects active commuting in terms of lower transport route quality and lower perceived safety and comfort among both present and potential active commuters.

The scope of future studies on active commuting need to be widened to also include walking and bicycling integrated with public transport systems and other forms of active commuting such as, for instance, electrically assisted bicycles. If these forms of commuting are to be promoted by society, their determinants need to be identified. For example, what journey distances are feasible for active commuting to a train station? And what distances are feasible with an electrically assisted bicycle? Also, the outcomes of these behaviours in terms of physical activity, mobility and effects on the environment should be studied. Future studies should also investigate the potential of bicycles and other forms of human-powered vehicles in the transport of lighter goods, e.g. deliveries in order to increase physical activity in the work domain. More human-powered deliveries in the urban areas could also contribute to safer, cleaner and friendlier urban environments for all.

Promoting bicycling and walking to school is often put forward in policy documents as a means to increase the use of walking and bicycling today and in the future. The proposed positive outcomes of active commuting to school are many in number; for example, that it might form lifelong physical activity habits, imply less chauffeuring of children and correspondingly result in fewer cars around the schools and a safer environment. There are also possible psychological gains in giving children the opportunity to walk or cycle independently of their parents. Studies have already been conducted on this, but the role of parents’ modal choice should be better investigated as they are role models for their children and those who make the decision to chauffer their children, perhaps due to their own commuting habits.

Some outcomes of active commuting are described in section 1.2 and one conclusion from the section was the there is a need for better methods to measure the positive and negative outcomes from both physical activity and transport perspectives. Better measurements of the size of the contribution of physical activity from active commuting could help to provide better correlations of physical activity and health outcomes in large study populations. A crucial methodological advancement should be to find better measurements of active commuting frequency and the correlates of the frequency variation. How important are, for example, the weather, daylight, climate and road conditions for the decision to commute actively or not over the year? What can be done to mitigate the effects of season and
weather on commuting frequency? To learn more about this requires better methods to measure active commuting frequency. Existing self-report methods often are not tested for validity and there are doubts about the feasibility of objective methods, such as GPS due to its limitations in storage capacity and battery time. Therefore, the passive RFID technique, described in section 1.6, is a method that needs to be better investigated and developed. Another dimension of physical activity that needs to be better investigated is the active commuting intensity. The mean trip velocity interpreted by the Compendium of Physical Activity is a rather crude measure of the absolute intensity and say nothing about the intensity in relation to e.g. people's aerobic capacity. Methods need to be developed to assess both absolute and relative intensity under free-living conditions. Also, the effect of the intermittent work needs to be better investigated, for example, when a journey includes several short stops.

Future studies should also assess active commuters’ route choice behaviours since they form an important methodological basis for studies on what environmental correlates are important for different groups of commuters. Today many researchers use the shortest route as a proxy for the actual route, both for distance estimations and for route characteristics. A better knowledge of commuters’ route choice could also be implemented in daily use in route navigators for bicyclists. However, the route choice algorithms are so far too simple to cover the complex route choice behaviour of active commuters. Here the criterion method presented in Paper 1 could be a good starting point for further investigations, perhaps in combination with GPS and GIS techniques.

Monitoring and surveillance of prevalent behaviours, such as commuting, with a large impact on society are important in order to discover early on changes in behaviours that could be costly for society. Surveillance data could also help promotion and function as a support of policy implementation in line with the expression, ‘what gets measured gets managed.’ Prevalence and surveillance was described in section 1.1 and one conclusion was that the statistics were rarely comparable between countries and that data cannot provide a reasonable picture of the physical activity included in commuting and in transport. To improve the surveillance data and provide a better basis for decision-making, new survey methods are need to be implemented. The frequency variation and seasonality effects, especially in bicycle commuting, are important aspects of active commuting not covered by the present survey methods. Distance measurement methods should be implemented and enhanced to provide better indications of the amount of active commuting and also unmask the walking and bicycling hidden in the
data, e.g. when the walking and bicycling trip is combined with a longer public transport journey.

5.6 Final comments

I began this thesis with a quote from Roy Shephard that in a review paper expressed the need to further study the field of active commuting. His proposals for future work still remain uncompleted but, hopefully, this thesis has perhaps contributed a bit to the answers by the validity assessments of methods for measuring distance. My findings form a methodological base for further studies about the size of the typical dose arising from active commuting. Another contribution is the different mode groups that are found to accrue different doses of physical activity from commuting and the finding that this dose could vary largely over the year.
6. Tack


Tack!

Att skriva denna avhandling skulle inte varit möjligt utan stöd och hjälp från andra personer. Först av allt vill jag tacka min handledare Peter Schantz för möjligheten att påbörja detta doktorandprojekt, det har varit lärorikt.

Jag vill också tacka min biträdande handledare Andreas Nilsson för goda råd, kloka kommentarer i samband med all manusläsning som du fått utstå under det dryga året som du varit min handledare.

Jag vill också tacka:

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6. Tack


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Mina kollegor i rhm-gruppen: Lina Wahlgren för trevliga luncher och lunchpromenader fyllda med forskningssamtal, skratt och knivskarpa analyser av allt från statistik till handledningspedagogik; Jane Salier Eriksson för roliga fikapausar med samtal om familj och forskning och för peppande samtal i motiga stunder; Phoung Pihlsträd för en outsinlig energi och omtanke som du spred omkring dig när du jobbade i gruppen.

Ninitha Maivorsdotter, doktorandkollega i Örebro, för en massa inspiration, nya perspektiv på cykelforskning och för en smittande forskargläde.

Christer Eriksson, Mikael Quennerstedt, Idrott i Örebro, för gott leder-skap, ovärderligt stöd och skicklig problemlösning. Ni har hjälpit mig att förverka en stundtals svårt terräng och jag uppskattar er hjälp mycket.

Idrottskollegiet i Örebro för konstruktiva synpunkter på arbeten jag lagt fram och en trevlig och välkommande atmosfär. Tack också till Nina Nilsson och Annette Oskarsson för administrativt stöd.


Övriga doktorander på GIH, i synnerhet John Hellström och Britta Thedin Jakobsson för att ni delat med er av er stora kunskap om hur man
undervisar blivande idrottsslärare och för att ni lyssnat och gett mig goda råd.

Alla trevliga människor som jobbar på GIH som lärare och administratörer och vars esprit och sällskap jag fått njuta av under luncherna i Lingbaren, i synnerhet Sofie Kierkegaard för trevliga lunchpromenader. Ett tack också till biblioteket för hjälp med fjärrlån av artiklar och till Carolina Lundquist för statistikhjälp.

CYCITY-gruppen för att ha öppnat en dörr för fortsatt forskning om cykling. Det ska bli kul att jobba mer koncentrerat med er när detta är avslutat.

Cykelgänget med Krister Isaksson i spetsen, Jonas Thörnqvist, Per-Åke Tjärnberg och Erik Beckman för värdefulla inblickar i hur man ökar cyclandet i verkligheten. Tack också för en massa praktisk hjälp under åren och alla trevliga afterwork-öl.

Mina, sedan länge disputerade, vänner Svante Linusson, Cecilia Lundholm och Ludvig Löwemark för goda råd om hur den akademiska världen fungerar och för förklaringar om vad som är normalt och inte i en doktorandprocess.

Mina systrar Anna och Stina för uppmuntran, Stina särskilt för hämtningar på dagis som gett mig extra arbetstid.

Min mamma och min bortgångna pappa för stöd, kärlek och mycket uppmuntran under min uppväxt och för att ni alltid stimulerat min nytankenhet och trott på mig i mina livsstilar.

Mina svärförfäldrar Inga och Göran Malmqvist. Tack för att ni alltid ställer upp, hämtar på dagis, skjutsar, fixar och tar hand om familjen – ni fattar inte vad det betytt!

Till sist vill jag tacka min egen familj, mina underbara barn Estrid och Gillis för all glädje och alla skratt och att ni hela tiden påminner mig om att det finns en massa roligare saker i livet än att doktorera. Allra mest vill jag dock tacka dig Tove för du ställt upp så oerhört mycket för att få detta projekt i hamn, för alla försakelser du gjort och för all omtanke och kärlek. Du finns i mitt hjärta.

Tack!
7. References


Baranowski, T., Mâsse, L. C., Ragan, B., & Welk, G. (2008). How many days was that? We're still not sure, but we're asking the question better! *Medicine & Science in Sports & Exercise, 40*(7), S544-S549.


tators in the personal, social and physical environment. *International Journal of Behavioral Nutrition and Physical Activity, 7*(1), 89.


Gil Solá, A. (2009). ”Vägen till jobbet: Om kvinnors och mäns arbetsresor i förändring” [”The way to work: On women’s and men’s changing work trips”]. University of Gothenburg, Gothenburg.


Appendix
Går eller cyklar Du till arbetet?

Vi söker Dig som går eller cyklar hela vägen till arbets-/studieplatsen och gör det minst någon gång per år. Du bor inom 08-området i Stockholms län och är minst 20 år. Obs! Även korta avstånd är av intresse.

Det vore av stort värde om Du vill medverka i en studie av fysisk aktivitet och hälsoeffekter vid arbetspendling. Vi vill därför be Dig att svara på några frågor om Din arbetspendling. I den grupp som svarar kommer flera få möjlighet att bl.a. få sin kondition testad.

För att delta i undersökningen behöver Du bara ange namn och adresser (se nedan). Vi skickar sedan en kort enkät samt en karta där Du kan fylla i Din färdväg till arbetet.

Har Du frågor finns information på webbsidan www.ihs.se/faap. Du får även gärna ringa Erik Stigell, 08-16 14 53, som är kontaktperson på:

Åstrandlaboratoriet vid Idrottshögskolan i Stockholm.

Meddela Dina uppgifter till något av följande alternativ:
1. e-post: eriks@ihs.se , 2. telefonsvarare 08-16 14 53, 3. gratispost,
   ange på kuvertet: Idrottshögskolan, Att: Erik Stigell, FRISVAR
   111813600, 110 05 Stockholm, 4. fax: 08-660 75 11.

-----------------------------------------------------------------------------------------------------

Ditt namn: _________________________________________________________
Gatuadress: __________________________________________________________________________
Postnummer: __________ Postort: ______________________________________________
Arbets-/studieplatsens namn: __________________________________________
Gatuadress: __________________________________________________________________________
Postnummer: __________ Postort: ______________________________________________
Till Dig som går eller cyklar till arbets-/studieplatsen

I våras svarade Du på en annons riktad till personer som går eller cyklar hela vägen till arbets-/studieplatsen minst en gång per år. Vi har därefter bekräftat din intresseanmälan och sedan tagit fram kartblad till alla de c:a 2100 personer som vill delta i studien. Med detta brev bifogas kartan, en enkät och instruktioner för att fylla i dem.

Syftet med studien är att belysa din fysiska aktivitet vid arbetspendling, under arbets-/studietid och under fritid. Genom att delta i den kommer du att bidra till viktig och unik kunskap om hur fysisk aktivitet vid arbetspendling kan påverka folkhälsan.


Enkäten tar c:a 15 minuter att besvara. För att fylla i den ber vi dig att göra fyra enkla saker som finns beskrivna på baksidan av detta brev. Vi ber dig slutligen att skicka in den ifyllda enkäten och kartan så snart som möjligt i bifogat frankerat svarskuvert.

Databearbetningen av denna första enkät beräknas vara klar i början av nästa år. Då räknar vi också med att skicka ut enkät nr 2, som bland annat ska söka belysa vad som motiverar och hindrar dig att gå eller cykla till arbets-/studieplatsen. Vi hoppas att du även vill delta i studiens andra steg, men det är naturligtvis helt frivilligt. I slutet av enkäten får du därför svara på frågor om det samt om du vill vara med i studiens tredje steg med konditionstester och mätning av energiomsättningen under din gång-/cykeltur.

Efterhand som resultaten är färdiga kommer du att kunna ta del av dem på webbplatsen www.ihs.se/faap.

Tag gärna kontakt med oss om du har frågor om enkäten. Kontaktuppgifter finner du längst ned på sidan.

Stort tack för hjälpen!

Peter Schantz
forskningsledare

Erik Stigell
projektassistent

Var god vänd!
Instruktioner för hur Du fyller i enkäten och kartan

1. Fyll i din vanliga färdväg till arbets-/studieplatsen med ett heldraget streck för cykel ( ) och ett streck med kryss för gång ( ). Markera din bostad med B och din arbetsplats med (se figur 1 och 2). Fyll helst i med en blå eller röd bläck- eller kulspetspenna. Du ska alltså markera för både cykel och gång om du cyklar ibland och går ibland.

2. Om din färdväg hem från arbets-/studieplatsen skiljer sig åt jämfört med vägen dit ber vi dig att dra ett streck med cirklar för hemvägen om du cyklar ( ) och ett streck med trianglar om du går ( ).

3. Om du vanligtvis lämnar barn på förskola/skola ber vi dig markera det med S på kartan där förskolan/skolan ligger (se figur 1 och 2). Räkna bort den tid det tar att lämna barnen från färden.

4. Om du går eller cyklar på parkvägar, i tunnlar eller på stigar som inte finns utsatta på kartan ber vi dig att rita in den vägen på kartan så noggrant som möjligt.


Den bifogade kartan är oftast hämtad från telefonkatalogen. Om den inte stämmer kan du antingen komplettera själv genom telefonkatalogens karta i Gula sidorna eller kontakta oss (se nedan) så skickar vi en ny karta. Har du frågor får du gärna ringa tel 08-16 14 53 under dagtid.

____________________________________________________________________________________________________

Peter Schantz   Erik Stigell

____________________________________________________________________________________________________
Enkät till Dig som går eller cyklar hela vägen till arbets-/studieplatsen

### Allmänna frågor

1. Är Du kvinna eller man?  
   - □ Kvinnan  
   - □ Mann

2. Vilket år föddes Du?  
   - 19 □

3. Hur mycket väger Du? Svara i hela kilo  
   - □□□ kg

4. Hur lång är Du?  
   - □□□ cm

5. Är Du:  
   - förvärvsarbetande? □  
   - frivilligarbetande? □  
   - studerande? □  
   - sysselsatt med annat?, □
   
   ange vad:.....................

6. Har Du tillgång till dusch på arbets-/studieplatsen?  
   - □ Ja, på ett smidigt sätt  
   - □ Ja, men inte på ett smidigt sätt  
   - □ Nej  
   - □ Vet ej

---

Du som går hela vägen till arbets-/studieplatsen, men aldrig cyklar dit kan gå direkt till fråga 18 på sidan 5.
Frågor om din cykeltur till arbets-/studieplatsen


8. Uppskatta hur lång din färdväg är. Ange ungefärligt avstånd i kilometer, gärna med en decimal (t.ex. 600 meter = 0,6 km).

☐☐. ☐ km

9. Hur lång tid tar vanligtvis cykturen från bostaden till arbets-/studieplatsen?
Ta tid på färden en vanlig dag då du inte gör ärenden på vägen.

☐ Timmar ☐ Minuter

10. Hur lång tid tar vanligtvis cykturen från arbets-/studieplatsen till bostaden?
Ta tid på färden en vanlig dag då du inte gör ärenden på vägen.

☐ Timmar ☐ Minuter


<table>
<thead>
<tr>
<th>Från bostaden till arbets-/studieplatsen</th>
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</table>
12. Cyklar du vanligtvis till och hem från arbets-/studieplatsen under samma dag? 
Det vill säga du låter inte cykeln stå kvar på arbets-/studieplatsen.

☐ Ja  ☐ Nej  ☐ Vet ej

Om du svarat Nej ange gärna varför: ………………………………………………………
…………………………………………………………………………..………………..

Nu kommer en fråga som tillsammans med de färdvägar som du ritar in på kartan kommer att ge en värdefull bild av din fysiska aktivitet och även av möjliga hälsoeffekter av cyklingen.

13. Hur många cykelturer (se instruktion nedan) gör du mellan bostaden och arbets-/studieplatsen i medeltal per vecka under olika månader? Sätt ett kryss för varje månad.

Så här fyller du i dina svar:
• Om du cyklar till och från arbets-/studieplatsen 5 dagar i veckan under hela månaden blir antalet cykelturer i medeltal 10 per vecka.
• Om du istället är ledig halva månaden blir antalet cykelturer i medeltal 5 per vecka under den månaden.
• Om du har semester hela månaden blir antalet cykelturer 0.
• Om du i medeltal gör färre än 1 cykeltur i veckan men sammanlagt fler än 0 ska du fylla i rutan för <1.
• Om du cyklar till och/eller från arbets-/studieplatsen oregelbundet och vid ett fåtal tillfällen över året samt är osäker på vilka månader som du gör det kryssar du i rutan ”Annat alternativ”.

<table>
<thead>
<tr>
<th>Månad</th>
<th>Antal cykelturer i medeltal per vecka</th>
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<td>januari</td>
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☐ Annat alternativ

☐ Stannar ej
☐ Stannar. Ange antal stopp:

☐ 1  ☐ 2  ☐ 3  ☐ 4  ☐ 5  ☐ 6
☐ 7  ☐ 8  ☐ 9  ☐ 10  ☐ 11  ☐ 12
☐ 13  ☐ 14  ☐ 15  ☐ 16  ☐ 17  ☐ 18
☐ 19  ☐ 20  ☐ Mer än 20 gånger, ange antal……  ☐ Vet ej

15. Blir du svettig när du cyklar till arbets-/studieplatsen?

☐ Nej, aldrig
☐ Ja, 1-25 % av gångerna
☐ Ja, 26-50 % av gångerna
☐ Ja, 51-75 % av gångerna
☐ Ja, 76-100 % av gångerna
☐ Vet ej

16. Brukar du duscha efter cykelturen till arbets-/studieplatsen?

☐ Nej, aldrig
☐ Ja, 1-25 % av gångerna
☐ Ja, 26-50 % av gångerna
☐ Ja, 51-75 % av gångerna
☐ Ja, 76-100 % av gångerna
☐ Vet ej

17. Vilken typ av cykel använder du på cykelturen till arbets-/studieplatsen?

☐ Oväxlad cykel
☐ Växlad cykel (2-4 växlar)
☐ Växlad cykel (5 växlar eller fler)
☐ Vet ej

Fortsätt med nästa fråga om du under det senaste året vid något tillfälle gått hela vägen till din arbets-/studieplats. Fortsätt annars med fråga 28 på sidan 8.

19. **Uppskatta hur lång din färdväg är.** Ange ungefärlikt avstånd i kilometer, gärna med en decimal (t.ex. 600 meter = 0,6 km)

☐□ km

20. **Hur lång tid tar vanligtvis gångturen från bostaden till arbets-/studieplatsen?**
Ta tid på färden en vanlig dag då du inte gör ärenden på vägen.

☐ Timmar  ☐□ Minuter

21. **Hur lång tid tar vanligtvis gångturen från arbets-/studieplatsen till bostaden?**
Ta tid på färden en vanlig dag då du inte gör ärenden på vägen.

☐ Timmar  ☐□ Minuter

22. **Hur ansträngande i genomsnitt upplever du att gångturen till arbets-/studieplatsen vanligtvis är?** Sätt ett kryss i varje kolumn vid någon siffra i skalan 6-20.

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<th>Från bostaden till arbets-/studieplatsen</th>
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23. **Går du vanligtvis till och hem från arbets-/studieplatsen under samma dag?**

Ja  Nej                Vet ej
Om du svarat Nej ange gärna varför:
……………………………………….…………

………………………………………………………………………………………………

24. **Hur många gångturer (se instruktion nedan) gör du mellan bostaden och arbets-/studieplatsen i medeltal per vecka under varje månad?**

Sätt ett kryss för varje månad.

Så här fyller du i dina svar:

•Om du går till och från arbets-/studieplatsen 5 dagar i veckan under hela månaden blir antalet gångturer i medeltal 10 per vecka.

•Om du istället är ledig halva månaden blir antalet gångturer i medeltal 5 per vecka under den månaden.

•Om du har semester hela månaden blir antalet gångturer 0.

•Om du i medeltal gör färre än 1 gångtur i veckan men sammanlagt fler än 0 ska du fylla i rutan för <1.

•Om du går till och/eller från arbets-/studieplatsen oregelbundet och vid ett fåtal tillfällen över året samt är osäker på vilka månader som du gör det kryssar du i rutan ”Annat alternativ”.

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Nu kommer en fråga som tillsammans med de färdvägar som du ritar in på kartan kommer att ge en värdefull bild av din fysiska aktivitet och även av möjliga hälsoeffekter av gåendet.
23. Går du vanligtvis till och hem från arbets-/studieplatsen under samma dag?

☐ Ja  ☐ Nej  ☐ Vet ej

Om du svarat Nej ange gärna varför:.................................................................

.................................................................

Nu kommer en fråga som tillsammans med de färdvägar som du ritar in på kartan kommer att ge en värdefull bild av din fysiska aktivitet och även av möjliga hälsoeffekter av gåendet.

24. Hur många gångturer (se instruktion nedan) gör du mellan bostaden och arbets-/studieplatsen i medeltal per vecka under varje månad? Sätt ett kryss för varje månad.

Så här fyller du in dina svar:
• Om du går till och från arbets-/studieplatsen 5 dagar i veckan under hela månaden blir antalet gångturer i medeltal 10 per vecka.
• Om du istället är ledig halva månaden blir antalet gångturer i medeltal 5 per vecka under den månaden.
• Om du har semester hela månaden blir antalet gångturer 0.
• Om du i medeltal gör färre än 1 gångtur i veckan men sammanlagt fler än 0 ska du fylla i rutan för <1.
• Om du går till och/eller från arbets-/studieplatsen oregelbundet och vid ett fåtal tillfällen över året samt är osäker på vilka månader som du gör det kryssar du i rutan ”Annat alternativ”.

Månad Antal gångturer i medeltal per vecka

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<td>januari</td>
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</tr>
</tbody>
</table>

☐ Annat alternativ

- ☐ Stannar ej
- ☑ Stannar. Ange antal stopp:

☐ 1  ☐ 2  ☐ 3  ☐ 4  ☐ 5  ☐ 6  ☐ 7  ☐ 8  ☐ 9  ☐ 10  ☐ 11  ☐ 12  ☐ 13  ☐ 14  ☐ 15  ☐ 16  ☐ 17  ☐ 18  ☐ 19  ☐ 20  ☐ Mer än 20 gånger ange antal……  ☐ Vet ej

26. Blir du svettig när du går till arbets-/studieplatsen?

- ☐ Nej, aldrig
- ☐ Ja, 1-25 % av gångerna
- ☐ Ja, 26-50 % av gångerna
- ☐ Ja, 51-75 % av gångerna
- ☐ Ja, 76-100 % av gångerna
- ☐ Vet ej

27. Brukar du duscha efter gångturen till arbets-/studieplatsen?

- ☐ Nej, aldrig
- ☐ Ja, 1-25 % av gångerna
- ☐ Ja, 26-50 % av gångerna
- ☐ Ja, 51-75 % av gångerna
- ☐ Ja, 76-100 % av gångerna
- ☐ Vet ej
28. **Hur fysiskt ansträngande har ditt dagliga arbete eller din dagliga sysselsättning (ej fritid) varit under de senaste 12 månaderna?**

<table>
<thead>
<tr>
<th>Alternativ</th>
<th>Beskrivning</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ Mycket lätt, övervägande stillasittande</td>
<td></td>
</tr>
<tr>
<td>☐ Lätt fysiskt arbete men där jag rör mig en hel del (t.ex. lätt industriarbete, affärsbiträde, lärare)</td>
<td></td>
</tr>
<tr>
<td>☐ Ganska fysiskt ansträngande arbete (t.ex. lokalvårdare, brevbärare, sjukvårdsbiträde)</td>
<td></td>
</tr>
<tr>
<td>☐ Mycket fysiskt ansträngande arbete (tungt kroppsarbete, t.ex. cykelbud, tyngre skogsarbete eller byggnadsarbete)</td>
<td></td>
</tr>
</tbody>
</table>

29. **Har du möjlighet att motionera/träna på betald arbetstid?**

<table>
<thead>
<tr>
<th>Alternativ</th>
<th>Beskrivning</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ Nej</td>
<td></td>
</tr>
<tr>
<td>☐ Ja, men utnyttjar det ej</td>
<td></td>
</tr>
<tr>
<td>☐ Ja, och jag utnyttjar det</td>
<td></td>
</tr>
<tr>
<td>☐ Vet ej</td>
<td></td>
</tr>
</tbody>
</table>

Om du svarat ”Ja, och jag utnyttjar det” fortsätt med nästa fråga, i andra fall fortsätt till fråga 32 på sidan 10.


<table>
<thead>
<tr>
<th>Aktivitet</th>
<th>Antal tillfällen per vecka</th>
<th>Tid per träningspass</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ Styrketräning</td>
<td>…………… ganger</td>
<td>……… min</td>
</tr>
<tr>
<td>☐ Konditionsträning</td>
<td>…………… ganger</td>
<td>……… min</td>
</tr>
<tr>
<td>☐ Bollspel</td>
<td>…………… ganger</td>
<td>……… min</td>
</tr>
<tr>
<td>☐ Motionsgymnastik (t.ex. aerobics/Friskis &amp; Svettis)</td>
<td>…………… ganger</td>
<td>……… min</td>
</tr>
<tr>
<td>☐ Annat, ange vad:</td>
<td>…………… ganger</td>
<td>……… min</td>
</tr>
<tr>
<td>☐ Annat, ange vad:</td>
<td>…………… ganger</td>
<td>……… min</td>
</tr>
<tr>
<td>☐ Annat, ange vad:</td>
<td>…………… ganger</td>
<td>……… min</td>
</tr>
</tbody>
</table>

☐ 6
☐ 7 Mycket mycket lätt
☐ 8
☐ 9 Mycket lätt
☐ 10
☐ 11 Lätt
☐ 12
☐ 13 Något ansträngande
☐ 14
☐ 15 Ansträngande
☐ 16
☐ 17 Mycket ansträngande
☐ 18
☐ 19 Mycket mycket ansträngande
☐ 20
Frågor om din fysiska aktivitet på fritiden, undantaget arbetspendling


☐ a) Har rört mig mycket litet

☐ b) Har rört mig mycket litet men ibland tagit någon enstaka promenad eller liknande

☐ c) Har fått ”vardagsmotion” i samband med städning, att gå i trappor, trädgårdsarbete, sällskapsdans, promenad eller lättare cykelturer (bortsett från gång-/cykelturer hela vägen till arbets-/studieplatsen), att man går ut med hunden etc.

☐ d) Har, utöver aktiviteterna i c), ägnat mig åt lätta form av motion som promenader (eller andra aktiviteter med motsvarande ansträngning) minst en gång per vecka

☐ e) Har ägnat mig åt mer ansträngande motion som t.ex. snabba promenader, joggning, simning, motionsgymnastik eller motsvarande minst en gång per vecka

☐ f) Har regelbundet ägnat mig åt hård träning eller tävling där den fysiska ansträngningen varit stor, t.ex. löpning och olika bollspel

Du som fyllt i svarsalternativen e) och/eller f) i fråga 32 kan fortsätta med nästa fråga. Övriga kan fortsätta med fråga 35 på nästa sida.


<table>
<thead>
<tr>
<th>Aktivitet</th>
<th>Kategori</th>
<th>Tid per tillfälle</th>
<th>Antal gånger per vecka</th>
<th>Antal månader per år</th>
</tr>
</thead>
<tbody>
<tr>
<td>Styrketräning</td>
<td>e) f)</td>
<td>........ min</td>
<td>........................</td>
<td>........................</td>
</tr>
<tr>
<td>Konditionsträning</td>
<td></td>
<td>........ min</td>
<td>........................</td>
<td>........................</td>
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<tr>
<td>Bollspel</td>
<td></td>
<td>........ min</td>
<td>........................</td>
<td>........................</td>
</tr>
<tr>
<td>Motionsgymnastik (t.ex. aerobics/ Friskis &amp; Svettis)</td>
<td></td>
<td>........ min</td>
<td>........................</td>
<td>........................</td>
</tr>
<tr>
<td>Annat, ange vad:</td>
<td></td>
<td>........ min</td>
<td>........................</td>
<td>........................</td>
</tr>
</tbody>
</table>

Du som fyllt i svarsalternativen e) och/eller f) i fråga 32 kan fortsätta med nästa fråga. Övriga kan fortsätta med fråga 35 på nästa sida.
34. Du som fyllt i alternativ e) respektive f) i fråga 32 och 33, med vilken genomsnittlig ansträngningsnivå motionerar/tränar du vanligtvis? 
Sätt endast ett kryss i respektive kolumn. Använd således ett medelvärde för de olika aktiviteterna om du utövar flera aktiviteter inom alternativ e) respektive f).

<table>
<thead>
<tr>
<th>Alternativ</th>
<th>Värde</th>
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<tbody>
<tr>
<td>e)</td>
<td></td>
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<tr>
<td>f)</td>
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</tr>
<tr>
<td>6</td>
<td>Mycket mycket lätt</td>
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<tr>
<td>7</td>
<td>Mycket lätt</td>
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<td>8</td>
<td>Lätt</td>
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<td>Något ansträngande</td>
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<td>Ansträngande</td>
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<td>Mycket ansträngande</td>
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<td>18</td>
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<tr>
<td>19</td>
<td>Mycket mycket ansträngande</td>
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<td>20</td>
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</table>

35. Är du intresserad av att delta i studiens kommande steg?

Steg 2. Enkätstudiens andra del. □ Ja □ Nej □ Vet ej


36. Om du har synpunkter på denna undersökning och dess frågor så skriv dem gärna här och vid behov fortsätt på baksidan.

___________________________________________________________
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___________________________________________________________
___________________________________________________________
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___________________________________________________________

Stort tack för hjälpen!
### Table 9.
Participants commuting time per week over the year and mean value for the whole year, in minutes, median values (first – third quartile) and mean values ± 1 SD

<table>
<thead>
<tr>
<th>Mode</th>
<th>Gender</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Mean/year*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking</td>
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<tr>
<td><strong>Single mode</strong></td>
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<tr>
<td>Men</td>
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<td>90</td>
<td>250</td>
<td>200</td>
<td>90</td>
<td>250</td>
<td>200</td>
<td>120</td>
<td>270</td>
<td>215</td>
<td>120</td>
<td>270</td>
<td>162±112</td>
</tr>
<tr>
<td>Women</td>
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<td>175</td>
<td>100</td>
<td>244</td>
<td>180</td>
<td>120</td>
<td>250</td>
<td>200</td>
<td>124</td>
<td>250</td>
<td>198</td>
<td>130</td>
<td>266</td>
<td>140±125</td>
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<tr>
<td><strong>Dual mode</strong></td>
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<tr>
<td>Men</td>
<td></td>
<td>80</td>
<td>17</td>
<td>174</td>
<td>81</td>
<td>17</td>
<td>174</td>
<td>48</td>
<td>7</td>
<td>120</td>
<td>18</td>
<td>0</td>
<td>120</td>
<td>80±115</td>
</tr>
<tr>
<td>Women</td>
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<td>35</td>
<td>210</td>
<td>116</td>
<td>35</td>
<td>210</td>
<td>64</td>
<td>0</td>
<td>160</td>
<td>100</td>
<td>0</td>
<td>180</td>
<td>42±77</td>
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<tr>
<td>Walking + Cycling</td>
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<td>0</td>
<td>120</td>
<td>0</td>
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<td>139</td>
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<td>180</td>
<td>100</td>
<td>44</td>
<td>168</td>
<td>133±89</td>
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<tr>
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<td>10</td>
<td>16</td>
<td>0</td>
<td>38</td>
<td>50</td>
<td>0</td>
<td>100</td>
<td>65±49</td>
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</tbody>
</table>

*Mean/year = mean commuting time per week in a year, a=Significant gender difference within a mode group, b=Significant mode group difference within a walking and cycling gender group, respectively. The total commuting time per week in the dual mode groups have not been compared statistically with the total commuting time of the single mode groups of each gender.

---

**Publications in the series**

**Örebro Studies in Sport Sciences**

3. Wåhlin Larsson, Britta (2009). *Skeletal Muscle in Restless Legs Syndrome (RLS) and Obstructive Sleep Apnoea Syndrome (OSAS).*
10. Eliason, Gabriella (2010). *Skeletal muscle characteristics and physical activity patterns in COPD.*