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A new approach to accessibility – Examining perceived accessibility in contrast to objectively measured accessibility in daily travel

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ABSTRACT

Accessibility has conventionally been measured and evaluated ignoring user perceptions in favor of focusing on travel time and distance to a number of pre-determined destinations. Acknowledging this gap, we recently developed a scale for perceived accessibility PAC (Lättman, Friman, & Olsson 2016b) aimed at capturing the individual perspective of accessibility with a certain travel mode. In this paper, we 1) further develop the PAC measure of perceived accessibility in order to capture how easy it is to live a satisfactory life with the help of the transport system, 2) compare levels of perceived accessibility between residential areas and main travel modes, and 3) compare residents' perceived accessibility to the objective accessibility level for the same residential area. Data from 2711 residents of Malmö, Sweden show that perceived accessibility is consistently different from objective accessibility across 13 residential areas, with minor differences in levels of perceived accessibility between areas. Surprisingly, bicycle users rate their accessibility significantly higher than those who mainly use the car or public transport for daily travel, contrary to objective accessibility assumptions. These differences point at the importance of including perceived accessibility as a complementary tool when planning for and evaluating transport systems.

1. Introduction

A development toward a more sustainable transport system (as in increasing walking, cycling and public transport, and decreasing car-use) has been regarded an important aim in the field of transportation research the last decades due to an array of reasons, including environmental issues and congestion (Lyons, Chatterjee, Marsden, & Beecroft, 2000; Van Exel & Rietveld, 2009). Together with upcoming issues of growing and ageing populations worldwide, this wave toward modal changes makes it increasingly important to ensure that levels of accessibility are and remain sufficient regarding sustainable transport options in peoples' day-to-day activities (daily travel), to avoid transport disadvantage (Pyrialakou, Gkritza, & Fricker, 2016) and social exclusion (Church, Frost, & Sullivan, 2000). Moreover, as accessibility "for all" is an explicit goal in transport policies across Europe (European commission, 2015; The Swedish Government, 2008) it is important to make sure that the needs and perceptions of (different groups of) individuals are included when accessibility is planned for, and evaluated. As objective accessibility evaluations are limited in capturing perceptions of accessibility (Curl, Nelson, & Anable, 2015) and unable to differentiate between groups of individuals, they are limited in their abilities of capturing accessibility for everyone (Thériault & Des Rosiers, 2004), and in evaluating variations in accessibility within geographical areas. This makes subjective approaches to accessibility, such as perceived accessibility, an exceedingly relevant area for complementing contemporary research, implementation, and evaluations of accessibility in transportation. We define perceived accessibility as "how easy it is to live a satisfactory life with the help of the transport system" (Lättman, Friman, & Olsson 2016a, p.36). This definition includes, but is not limited to, accessibility while using the transport system per se, ease of getting to the transport system, and the perceived possibilities and ease to live the life one wants (e.g. ability to reach activities of choice) with help of the transport system. In line with the definition of accessibility offered by the Social Exclusion Unit (SEU, 2004) which emphasizes the ease of access to activities, perceived accessibility is dependent upon individual perceptions of context and opportunities, which may include feelings of safety and security, or available information of transport options (Lättman, Friman, & Olsson, 2016a; SEU, 2004). In contrast, most objective approaches to accessibility rely mainly, or solely, on travel times and distances to selected destinations. By including perceptions of accessibility and exploring the relations between objective and subjective approaches, a more complete understanding of accessibility can be expected. This includes a better base for following up policy goals and aims such as long-term

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intentions of improved life-quality for individuals, groups, and even cities, by pursuing liveability and accessibility for all (City of Gothenburg, 2014; The; European commission, 2015). Despite this, researchers and planners have found it difficult to include and capture perceived accessibility in transport-related research and practice, partly due to practical measurement issues, such as a lack of meaningful, practical measures of perceived accessibility (Lucas, van Wee, & Maat, 2016; van Wee, 2016). This means that there still exists a need for research incorporating this complementary but essential dimension (Schwanen et al., 2015; Shay et al., 2016).

Acknowledging this gap, we recently developed a scale for perceived accessibility – PAC (Lättman et al., 2016a) – aimed at capturing and evaluating the individual perspective of accessibility within a certain travel mode. Although PAC has merit, it was designed for specified travel modes and is limited in its ability to capture perceived accessibility of daily travel, which may consist of combinations of different modes. As the current paper aims to capture overall perceived accessibility (with the options of any transport modes available), the existing PAC measure was initially modified. In order to evaluate and compare perceived accessibility between residential areas and main transport modes, and also look at differences between perceived and objective accessibility with sustainable transport modes, we gathered empirical data from 2711 urban residents (for the comparison between perceived and objective accessibility data from 1570 residents was used).

The remainder of this article is structured as follows: First, we present a general discussion of transport accessibility and its four different dimensions. We thereafter focus on objective measures defining the objective options for travel. In the next sub-section we present perceived accessibility and how people rate the conditions in which they live, and finally we focus on studies comparing objective and perceived accessibility. In section 2.4, we then state the study objectives. The methodology of our research and the statistical analyses utilized in our investigation are described before we turn to the results where we explore and compare individuals' perceived accessibility to their objective accessibility. Lastly, we conclude our work by highlighting its theoretical and practical implications, acknowledging its limitations, and offering avenues for future research.

2. Literature

Transport accessibility is important, as it enables individuals to live their daily lives and travel to destinations and activities with help of the transport system. Accessibility is also an important prerequisite for social inclusion (Farrington & Farrington, 2005), and has been linked to psychological concepts such as well-being and quality of life (De Vos, Schwanen, Van Acker, & Witlox, 2013; Olsson, Gärling, Ettema, Friman, & Fujii, 2013; Parkhurst & Meek, 2014). Accessibility is generally understood as a multidimensional concept, and the Geurs and Ritsema van Eck (2001) conceptualization includes a transport dimension (e.g. transport mode), a land use dimension (e.g. the built environment), a temporal dimension (e.g. travel times), and an individual dimension (the needs, abilities and opportunities of individuals). However, despite being one of the most recognized and explored concepts in the field of transportation, research and practice on transport accessibility mainly depend on conventional, objective measures and evaluations that for the most part ignore the individual dimension and perspective of accessibility. The individual perspective is usually at best represented in empirical research by sociodemographic data (age, income, place of residence) whereas place-based dimensions of accessibility, such as travel time and distance to a number of pre-determined destinations, constitute most of the contemporary empirical knowledge of accessibility (Titheridge, Mackett, & Achuthan, 2010). This is unfortunate as when it comes to planning for and evaluating transport accessibility, it is expected that the individual dimension strongly affects the total aggregate level of accessibility (Geurs & van Wee, 2004). Thus, it is likely that the individual dimension (as in perceived accessibility) differ from objective accessibility within different contexts and between transport modes.

In short, as perceived accessibility is based on the individuals' own preferences and abilities, rather than objective references, the choice of *which* shop to go to for groceries, at *what* time of day, and *the options* the individual actually is aware of or has the ability to use, largely affects his or her perceptions of accessibility (Lättman, 2016; Wong, 2018). A study by Combs, Shay, Salvesen, Kolosna, and Madeley (2016) found differences between how individuals perceived their own travel needs in relation to their travel possibilities, and objective indicators of transport disadvantage (age, physical mobility, income, vehicle access).

Given the theoretical differences between objective and perceived accessibility, there is reason to believe that perceived accessibility, by comprising the perspective, knowledge, and travel horizon of the individual, captures accessibility in a way that conventional accessibility measures cannot (Curl, Nelson, & Anable, 2011; Lättman et al., b, 2016a). Previous research confirms this belief, as Curl et al. (2015) comparison of objectively measured (GIS) travel time accessibility and perceived travel time accessibility to a number of destinations revealed discrepancy between the two, with perceived accessibility levels being greater than objective levels in urban areas, and vice versa in rural areas. They conclude that both objective and perceived approaches to accessibility are necessary for informing policy decisions. A study set in Teheran (Lotfi & Koohsari, 2009) provided different levels of accessibility for the same two residential areas (A and B) depending on if accessibility was measured by objective indicators (GIS modelling) or by subjective two-question interviews capturing the satisfaction (low, moderate, good, very high) with accessibility to selected target destinations. If the included target groups (elderly, housewives) stated a low or moderate accessibility they were asked to give a reason as to why they considered accessibility to be below good. Among the reasons named where distance to, and the number of target destinations included. Moreover, low quality of the urban settings, feelings of unsafety, and personal preferences were given as reasons by up to 76%, 23%, and 13% of the participants (depending on area), indicating that measures capturing only objective aspects of accessibility, are incomplete. Previous empirical findings also support the suggestion that subjective experiences and perceptions may be as important as conventional objective indicators when designing and evaluating a socially inclusive transport system. For instance, feelings of safety (Lättman et al., 2016a), attitudes, and affective and symbolic factors (Curl, 2013) have assessable effects on perceived accessibility.

Not only may perceived accessibility lead to different results than objective accessibility, but often evaluations and presentations of accessibility studies do not even acknowledge that this subjective perspective is missing, which has led to assumptions that the accessibility level of all residents within a specific area are consistent with the results of an evaluation based on objective measures, thus ignoring individual and subgroup variances.

2.1. Objective accessibility

Objective accessibility determines the objective options for travel, such as the built environment, attributes of transport modes, travel times, travel costs, and travel distances. There are several approaches for measuring objective accessibility, ranging from the simpler conventional methods that capture distances and travel times from A to B, up to more complex measures that capture and compare aspects of several different accessibility-dimensions, such as the SNATMUS-tool developed by Curtis and Scheurer (2016). The overviews by Scheurer and Curtis (2007), Curl (2013), and Ryan, Lin, Xia, and Robinson (2016) provide thorough descriptions and evaluations of different accessibility measures commonly used in research, divided into six methodological categories; Spatial separation measures, Contour measures, Gravity measures, Competition measures, Time-space measures, Utility measures, and Network measures. Although these measures each have merit, they have been criticized for putting too much focus on (reducing) travel times and the importance of travel times to the users (Curl, 2013), and by relying on levels of accessibility to a specific set of destinations, when other destinations may be equally or more important for overall accessibility. Moreover, Curl (2013) points out that the current (objective) measures may not even meet their intended outcomes, such as helping in providing accessibility to those most in need (e.g. those experiencing or at risk of experiencing social exclusion), as these measures are unable to differentiate between individuals, and mainly focus on aggregate levels of accessibility. In practice this could mean that an assessment of the accessibility-levels of a specific area provides satisfying results, but that there are (one or several) segments of individuals in that area with poor accessibility that are not captured on the aggregate level, and thus will fail to be identified. The more recent SNATMUS-tool (Curtis & Scheurer, 2016) brings together the conventional measures of accessibility by including the land-use, temporal, and transport mode-dimensions in one measure allowing for complex evaluations and comparisons between different contexts. The individual dimension of accessibility (e.g. individual expectations and perceptions) is however still absent (Lättman, 2017).

Of recent, research using objective indicators of accessibility has resulted in a number of GIS-based mappings of accessibility levels within specific cities using time, place, distance and travel-mode based data (e.g. Siegel, 2016; Trivector, 2013). Objective accessibility measures have also helped providing research roadmaps for accessibility (Bekiaris & Gaitanidou, 2012) and comparisons between objectively mapped accessibility and actual travel (travel behavior), such as the Dalton, Jones, Panter, and Ogilvie (2015) study. This study of work commuters in Cambridge, UK determine that the geographical overlap between objectively mapped routes (the shortest route to and from work) and actual trips made by working adults, is as low as 39%, with 27% of the trips made being further than modelled. Dalton et al. (2015) conclude from this that other aspects than minimizing time and distance are important when individuals choose which route to travel and which mode to use. The result is interesting as there probably exist a similar discrepancy regarding objectively modelled accessibility and what aspects individuals actually take into account when they assess their own accessibility (perceived accessibility). Results like this alongside theoretical understandings of accessibility as multi-dimensional suggest that objective measurements are indeed not capturing the entire concept of accessibility. Thus, objective measures should be complemented with the individual dimension (such as perceived accessibility), to be able to more accurately identify accessibility levels and needs of different subgroups of the assessed population, in order to meet the goal of “accessibility for all”.

In summary, objective indicators are essential for capturing distances, travel times, frequencies of services, and objective aspects of the built environment and relevant transport modes. However, they lack in their ability to take into consideration other contextual determinants (such as the climate, or culture that determine walking- or cycling preferences) and individual preferences, such as where individuals actually want or need to go, which may not be the nearest food-store or the work-out facilities that are closest to home. Neither do objective indicators have the ability to capture the awareness of options that different individuals’ experience, as this awareness may not correlate with calculated accessibility levels (van Wee, 2016).

2.2. Perceived accessibility

Perceived accessibility is about how people rate the conditions in which they live. Different individuals may perceive accessibility differently due to which travel opportunities that are known to them, or lie in their interest. Alas, contrary to objective accessibility, perceived accessibility is not about setting up a priori assumptions of the (most) important indicators of accessibility, as these may vary between individuals, groups, cultures and contexts. Instead, perceived accessibility consists of perceptions of the level of ease to access and use the built environment and transport system, or access to activities of choice. Perceived accessibility captures the subjective aspect of accessibility, and complements objective approaches. On a more specified level, indicators of perceived accessibility may consist of perceptions of (classical objective) determinants such as distance to the nearest transit station or shop, perceived ability to get to the bus stop, or perceived safety when using the transport system (Lättman et al., 2016a). On the other hand, perceived accessibility may also include perceptions of the information (opportunities) known to the individual or personal preferences, attitudes and abilities. In other words, perceived accessibility is not limited to measurements of travel times and distances, but take into account what is important to the individuals. As Handy and Niemeier (1997) pointed out already in the late nineties, in order to be useful, the practical definition of accessibility must be based on how residents evaluate and perceive their surroundings, and reflect the elements that are most important to them.

Perceived accessibility is important in itself since it reflects the individual's (or groups of individuals') perceived ability to reach destinations and participate in preferred activities using the transport system, alas it captures the individual dimension (Lättman et al., 2016a). The individual dimension has previously been overlooked when evaluating and planning for accessibility, despite its theoretical importance. This is unfortunate, as including perceived accessibility as a complementary dimension when assessing levels of accessibility within a specific context can help in identifying subgroups that differ significantly in their perceptions of accessibility, such as the elderly (Lättman et al., 2016b; Ryan et al., 2016). Moreover, it has been established that accessibility is positively connected to several important outcomes, such as well-being (Parkhurst & Meek, 2014), transport-related social inclusion (Farrington, 2007; Stanley, Stanley, Vella-Brodrick, & Currie, 2010), and physical activity (Scott, Evenson, Cohen, & Cox, 2007), making identifications of subgroups that experience lower accessibility important for the task of identifying social exclusion and other social disadvantages.

2.3. Comparing objective and perceived accessibility

As indicated previously, it is expected that objective and perceived accessibility differ. Objective approaches to accessibility rely on place-, transport-, and temporal aspects of the concept, and measurements are often reduced to attributes such as travel times and distances to a specific set of destinations. Perceived accessibility complements the objective approach by including the view of the individuals, and measure perceptions of accessibility within a specified context, or with a specific transport mode, without specifying what is to be included in the individual assessment of accessibility (Lättman et al., b, 2016a). Alas, perceived accessibility may rely on the same attributes (time and distances to specific destinations, and features of the built environment) as objective accessibility assessments, although individuals may evaluate them differently to an objective measure. Moreover, perceived accessibility may also include other attributes that are important to the individual, such as feelings of safety and security, preferences and abilities, and accessibility to destinations and activities that are not included in the objective assessment.

Although Morris, Dumble, and Wigan (1979) distinguished between objective and perceived measures of accessibility already in the late seventies, the concept of accessibility and how it is measured and evaluated in transport research and planning still mainly rely on objective indicators of accessibility, such as travel times, distances, or place characteristics. Those studies that have actually included the individual perspective seem to be content with including demographic characteristics (Dong, Ben-Akiva, Bowman, & Walker, 2006; Hanson & Schwab, 1987; Kwan, 1998), or at best capturing subjective data by non-quantifiable methods such as semi-structured interviews (Curl et al., 2011; Lotfi & Koohsari, 2009). This is unfortunate, as social dimensions of accessibility (such as levels of accessibility for specific population groups and their related social outcomes), and destinations/activities building on social interaction (e.g visiting family and friends) are not captured by traditional accessibility measures (Lucas, Wee, & Maat, 2016, Vitman-Schorr, Ayalon, & Khalaila, 2017). Lotfi and Koohsari (2009) identify an optimism in objective measures of accessibility and what they actually cover, and call for more qualitative evaluations of the concept. Although this suggestion is important and necessary, researchers also need to capture perceptions of accessibility in a way that can provide more generalizable and practically useful results, so that levels of accessibility may be compared between contexts, and so that common determinants of perceived accessibility can be identified. Up until now however, quantitative comparisons of perceived and objective accessibility have remained scarce.

Wong (2018) differentiate between place-based and people-based measures of accessibility. Place-based measures usually assess accessibility through calculating the number of (or a ratio of) activities and destinations available from a specific starting point within a certain time- or distance constraint. While these measures capture the accessibility of various geographical areas they are not able to differentiate between individual (or group) variations in accessibility, such as abilities to access activities at times of convenience or need (Wong, 2018), or access to activities or destinations that are not included in the measure (Lättman et al., 2016b, 2016a). People-based measures on the other hand consider the travel behavior of individuals, often by calculating the "actual mobility" of individuals' within the spaces they access on a daily basis (Activity spaces) (Wong, 2018). Activity space measures are generally applied when the aim is to understand travel behavior, however comparative studies have found that people-based measures better capture the accessibility of individuals (to destinations and activities) than place-based measures do (Kwan, 1998; Wong, 2018). Wong (2018) raise questions as to the completeness of either of the existing measurement methods for capturing perceived accessibility as; a) activity space measures do not consider the actual travel routes of individuals, and b) space-based measures are likely to include activities and destinations that individuals' do not actually travel to, or want to travel to. In addition, there is a possibility that measures based on a priori destinations fail to include activities and destinations essential and important to individuals, such as work or friends and family or other social gatherings (Lättman et al., 2016b, 2016a).

There are few studies comparing objective and perceived accessibility. A study by Scott et al. (2007) comparing subjective to objective accessibility (to recreational facilities) found that subjective accessibility predicted physical activity (actual use of the facilities) whereas objective measures were unrelated to use (apart from basketball courts), suggesting that perceptions of accessibility are useful for predicting actual use. In line with this, Hui and Habib (2014) established that individuals who experience the transport system as accessible also experience less social exclusion. Scheepers et al. (2016) study of 3663 individuals in the Netherlands found that perceived accessibility is linked to transport choice, regardless of objective accessibility levels, indicating that a focus on perceived accessibility is superior if the aim is to get individuals to choose active travel modes. Another study by Ryan et al. (2016) compared (objectively) measured accessibility with perceived accessibility (to train stations) between age groups and travel modes in Australia. They found that measured accessibility (a composite measure of route directness, distance and quality of facilities etc.) and perceptions of overall accessibility (subjective rating from 1 to 5) don't match, and that there are differences in measured accessibility and perceptions of accessibility for different transport modes and age groups, with elderly experiencing the lowest accessibility.

According to Tobias and Ferreira (2014), researchers need to include the perceptions of the users in order to make investments more responsive to the needs and expectations of the population. Curl et al. (2015) take this reasoning a step further by arguing that none of these measures (objective or subjective) should be allowed to inform policy decisions at all before we have an understanding of the differences between them, and how they relate to each other. In line with this, recent findings indicate that there are indeed gaps between conventionally measured or modelled accessibility, and how accessibility is perceived by individuals (Budd & Mumford, 2006; Curl et al., 2011; Scheepers et al., 2016). Moreover, although seldom included in objective measures or evaluations, social activities are clearly the most important activities for travellers to have access to (Titheridge et al., 2010). Instead of assuming homogeneity in geographical areas or groups of individuals, a distinction between objective accessibility and perceived accessibility is highly relevant, as the opportunities and abilities to travel and access activities are likely to be perceived differently between individuals, alas also between objective and subjective measurements.

2.4. Study objectives

In the current study, we argue that by measuring perceived accessibility on an aggregated level, and looking at and comparing levels of perceived accessibility between residential areas and between travel modes, we expect to gain further knowledge of perceived accessibility itself, and whether there are significant differences between levels of perceived accessibility depending on where individuals live and what mode of travel they prefer. By also comparing levels of perceived accessibility to an objectively measured accessibility-index in thirteen residential areas in a Swedish urban setting, we expect important insights to the more or less unexplored relationship between objective and perceived accessibility.

More specifically, the study objectives are:

1) Further development of the PAC measure of perceived accessibility (based on Lättman et al., b, 2016a).
2) Exploring and comparing levels of perceived accessibility between different residential areas and between travel modes.
3) Comparing individuals' perceived accessibility to the objective accessibility level for the same residential area.

3. Material and methods

3.1. Study setting, participants and procedure

In October and November 2016, data from 2711 structured telephone interviews were collected in Malmö, which has approximately 300 000 inhabitants and is the third largest city in Sweden. Malmö was selected as it has recently been divided into 15 residential "sump"-areas (Sustainable Urban Mobility Plan guidelines; The European Commission, 2014) within a project aiming at long-term evaluating and planning for increased accessibility and mobility by sustainable transport options in the city (Malmö Stad, 2016). This project includes temporal- and place-based data that has provided Malmö with an objectively mapped, aggregated GIS accessibility-index score for each of these residential areas, based on accessibility scores for a number of specific sustainable travel modes (walking, cycling and public transport). A lower accessibility score indicates lower accessibility (as in longer distances and/or travel times to target destinations). Due to this index, Malmö was deemed suitable for comparisons between objective and perceived accessibility.

Apart from four items measuring overall perceived accessibility, the structured interviews consisted of questions of age, income, gender, main transport mode (the respondents indicated the mode most commonly used in daily travel), residential area, and a number of items considering perceptions of the built environment in Malmö. We also asked participants being car-users about their perceived accessibility "given that the car was no longer an option for transport". In this study, we include and analyze data primarily on overall perceived accessibility, transport mode, and residential area. The other data is analyzed

Table 1
An overview of the distribution of participants per residential area and compared to the population, age (mean and range), and gender.

Place of Residence	n (% of sample)	N (in % of population)	Age Mean (SD)	Age Range	Gender distribution sample	
					% men	**% women**
Bunkeflostrand	143 (5.3)	12 900 (4.2)	50.13 (16.34)	18–95	44	56
Centrum	420 (15.4)	61 900 (20.0)	45.72 (17.95)	18–86	48	52
Fosie	251 (9.4)	38 600 (12.5)	50.60 (19.97)	18–89	42	58
Holma/Kroksbäck	187 (7.1)	23 500 (7.6)	55.97 (20.46)	18–94	43	57
Husie	184 (6.8)	21 000 (6.8)	53.43 (17.88)	18–88	47	53
Hyllie	91 (3.3)	5700 (1.8)	54.39 (18.05)	18–88	45	55
Kirseberg	192 (7.2)	15 800 (5.1)	45.67 (18.00)	18–93	48	52
Limhamn	260 (9.5)	25 000 (8.1)	53.48 (18.92)	18–91	50	50
Oxie	147 (5.3)	12 300 (4.0)	54.23 (16.77)	18–87	41	59
Rosengård/Sorgenfri	342 (12.8)	51 500 (16.6)	43.80 (18.51)	18–91	52	48
Slottsstaden	293 (10.7)	32 000 (10.3)	52.31 (19.62)	18–92	42	58
Tygelsjö	104 (3.8)	4200 (1.4)	51.09 (17.92)	18–85	43	57
Västra Hamnen	97 (3.5)	6700 (2.2)	47.51 (16.72)	20–75	56	44
Malmö	**2711**	**310 000**[*]	**49.85 (18.90)**	**18–95**	**46**	**54**

and reported elsewhere. Anyone with a registered phone number, living in Malmö and above 18 years of age was a possible participant in the study. The participants were contacted by phone in a randomly selected order until the sample frame was adequately representative of the population. The total number of participants per residential area alongside age (mean and range), gender distribution, and comparisons to population data can be found in Table 1.

The overall gender distribution was satisfying as approximately half of the participants were men in the overall sample (46%) and across residential areas (41%–56%).

When asked about which mode of transport the participants use most often (main mode), 1141 specified car (51% men), 743 bicycle (49% men), 616 public transport (38% men), and 176 walking (41% men) as their main mode of transport. The distribution per main transport mode in percentage (sample) and the population mode distribution (for all trips made in Malmö) are presented in Table 2.

3.2. Instruments

Perceived accessibility was measured by an updated version of the Perceived Accessibility Scale, PAC (Lättman et al., 2016a). The modification from the previous version of the scale consisted of updating the items of the scale so they are no longer limited to assessing accessibility within a specific transport mode. The revised PAC consist of 4 items (Table 4, section 4.1) that together were designed to measure overall perceived accessibility of daily travel, regardless of transport mode, or combination of modes. After the participants were asked to state their primary transport mode - car, bicycle, walk, public transport or other - they rated their perceived accessibility within Malmö on 7-point Likert scales. The perceived accessibility items assess "the ease to do daily activities", "the ability to live the life one want's", "the ability to do all

Table 3
A brief overview of the indicators for the objective accessibility index.

Indicator	Definition
1	Walking travel time to 10 different target destinations[a]
2	Cycling travel time to 10 different target destinations
3	Cycling/car ratio of travel duration to 10 different target destinations
4	Public transport/car ratio of travel duration to the city center, the nearest shopping mall and the nearest major public transport hub
5	Distance to nearest bus-stop
6	Distance to nearest public transport hub
7	Distance to nearest carpool
8	Range of travel possibilities

[a] Target destinations: 1. Public transport hub, 2. City center, 3. Shopping mall, 4. Preschool, 5. Elementary school, 6. Health center, 7. Grocery store, 8. Park, 9. Exercise facility, and 10. Playground.

Table 2
Distribution in % of sample (per indicated main mode of transport) and the distribution in % per mode for all trips made (population) in Malmö and per residential area.

Place of Residence	Mode							
	Car		Bicycle		Public transport		Walking	
	sample	population	sample	population	sample	population	sample	population
Bunkeflostrand	74	62	6	9	19	18	1	8
Centrum	18	25	41	25	26	23	14	25
Fosie	44	49	18	18	30	24	7	6
Holma/Kroksbäck	40	40	30	22	21	17	7	18
Husie	67	63	17	14	12	15	4	8
Hyllie	52	56	15	12	31	14	2	18
Kirseberg	33	34	31	24	30	24	3	16
Limhamn	53	54	25	20	17	14	3	10
Oxie	65	64	6	6	24	20	3	8
Rosengård/Sorgenfri	30	31	33	28	27	25	8	15
Slottsstaden	32	33	39	34	20	16	7	14
Tygelsjö	79	72	6	4	13	12	2	9
Västra Hamnen	21	30	41	25	21	25	16	17
Malmö	**42**	**40**	**27.5**	**22**	**23**	**21**	**6.5**	**15**

Table 4
Descriptive Statistics, Correlations, Skewness (Sk), Kurtosis (Kur) and change in Cronbach's alpha for 4 items (N = 2711, α = 0.90).

Item	1	2	3	4	M	SD	α if item deleted	Sk	Kur
1. Considering how I travel today it is easy to do my daily activities	–	–	–	–	5.64	1.54	.89	−1.19	0.92
2. Considering how I travel today I am able to live my life as I want to	0.67*	–	–	–	5.80	1.53	.86	−1.38	1.38
3. Considering how I travel to day I am able to do all activities I prefer	0.60*	0.73*	–	–	5.66	1.62	.86	−1.19	0.68
4. Access to my preferred activities is satisfying considering how I travel today	0.65*	0.68*	0.76*	–	5.61	1.54	.86	−1.11	0.67

* $p < .001$.

preferred activities", and "satisfaction with perceived access to preferred activities" with ratings from "I don't agree" = 1 to "I completely agree" = 7 (Table 4). A perceived accessibility index is received by calculating the mean from the 4 items. For objective 2 and 3 in the current study, the scores for each of the items was re-calculated in order to match the objective accessibility index score of 0–5 when conducting one sample t-tests and to facilitate visual comparison and understanding.

Data for the objective accessibility-index for each of the residential areas (sump-areas) was compiled by Malmö City between January and March 2017. These data are GIS-based and determine: A) Travel duration to selected target destinations defined by Haugen (2011) (indicator 1–4 in Table 3). Indicator 3 is the ratio of travel duration by cycle compared to travel duration by car, and indicator 4 is the ratio of travel duration by public transport compared to by car. B) Distances to public transport interchange, stops and carpool (indicator 5–7 in Table 3), and range of travel options (indicator 8 in Table 3). The data was calculated and indexed on a scale of 0–5, where 5 denotes high accessibility, 3 denotes an acceptable level, and 0 denotes poor accessibility. The calculation of the index is done in several steps. Step one identifies and calculates each of the 8 indicators. In the second step the indicators are weighted (depending on travel mode and target destination) with the aim of giving all included travel modes and destinations the same significance in the index. In a third step the now weighted indicators are summarized and divided by the total number of indicators. This procedure results in an arithmetic accessibility mean per area (for a full description of the calculation methods, see Trivector, 2013). Two of the 15 sump-areas were excluded from analysis due to the low number of residents living in the areas (mainly industrial grounds).

The variables gender, income, and age were measured by self-report questions included in the questionnaire. For gender the participants indicated whether they were male or female, for income the participants stated the monthly income of their household with the choice between three income levels (previously used in Swedish settings) and the alternative of "I don't know". The participants were also asked for their current age, and later divided into six age groups (18–25, 26–35, 36–45, 46–55, 56–65, 66 and above).

4. Results

4.1. Descriptive statistics

Data was first analyzed for the revised four PAC items of perceived accessibility, redesigned to measure perceived accessibility in daily travel with the option of combination of modes rather than perceived accessibility of single travel modes. A Cronbach's alpha analysis revealed a satisfying overall item correlation (α = 0.90) with no improvement for item deletion. The between-items correlations (Table 4) indicate that the items are related and that each of the items also uniquely contribute to the concept. These statistics alongside means, standard deviations, skewness and kurtosis are presented in Table 4.

4.2. Statistical analyses

In this section, we provide descriptions of how factor analysis, analysis of variance, and t-tests are used in order to validate the perceived accessibility scale and explore and compare levels of perceived accessibility between residential areas, main transport modes, and how perceived accessibility relates to objective accessibility for the same residential areas. The analyses are further described for each objective below.

Study objective 1; further development of the PAC measure of perceived accessibility.

An exploratory factor analysis (Maximum Likelihood method) was performed in order to explore if the revised PAC items measure the same concept, e.g. if they are unidimensional. An exploratory type of analysis was chosen, as there were no clear predictions of which factors existed for the revised perceived accessibility items and how they related to the variables (Byrne, 2010; Gorsuch, 1997). The analysis extracted one factor with an eigenvalue over 1 that explained 76.29% of the variance, with a meritorious sampling adequacy (Kaiser-Meyer-Olkin) of 0.81. The scree plot further confirmed the extraction of one factor. Factor loadings are provided in Table 5.

The factor analysis results alongside the measure of internal consistency together demonstrate satisfying results for the creation of an index.

Study objective 2; comparing levels of perceived accessibility between residential areas and between travel modes.

With the main purpose of exploring the variation in overall perceived accessibility of the existing transport network by mode and by residential area, an initial PAC index value (between 1 and 7) was calculated for each participant in the study. As this index value was also to be compared to the objective index value (study objective 3) the score was recalculated to match the objective index values of 0–5. A univariate Anova was performed in order to analyze any differences in perceived accessibility levels between urban residential areas and between main transport modes. As a secondary aim in order to explore further differences between levels of perceived accessibility of the participants, gender, age and income were included as covariates in the analysis.

The Anova (F_{welch} $^{(12,2698)}$ = 2.10, $p < .001$, $R^2 = 0.019$) revealed significant between-subjects effects of main transport mode (F_{welch} $^{(4,2706)}$ = 9.44, $p = .003$), residential area (F_{welch} $^{(12,2698)}$ = 2.11,

Table 5
Factor loadings for Maximum Likelihood exploratory factor analysis of accessibility scales (N = 2711).

Item	Accessibility index (PAC)
Considering how I travel today it is easy to do my daily activities	0.87
Considering how I travel today I am able to live my life as I want to	0.86
Considering how I travel to day I am able to do all activities I prefer	0.84
Access to my preferred activities is satisfying considering how I travel today	0.75
Eigenvalue	2.74
% of variance	76.29

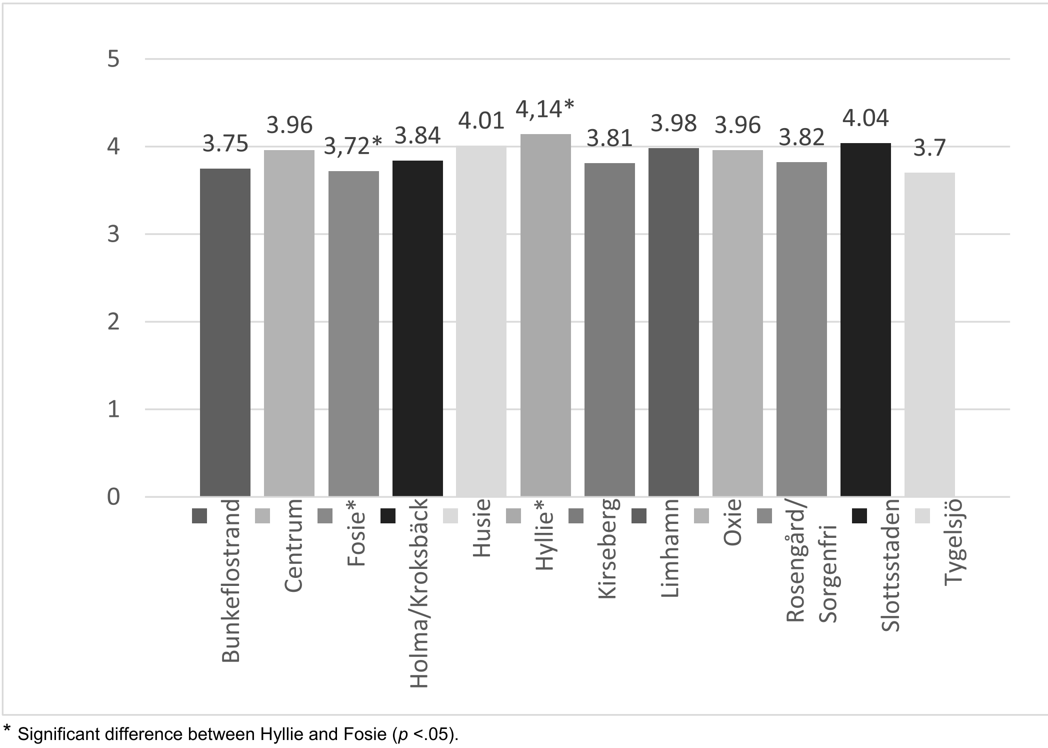

Fig. 1. Means of perceived accessibility per residential area in Malmö (N = 2711).
*Significant difference between Hyllie and Fosie ($p < .05$).

$p = .003$), and gender ($F_{welch}{}^{(1,2710)} = 16.04$, $p < .001$), but no significant effects for age ($p = .210$) or income ($p = .328$). Since the variance was unequal in the groups (Levene $p = .014$), the asymptotic F is reported.

Residential areas. To further explore the differences between residential areas a Games-Howell post hoc test was conducted. This revealed significant differences in perceived accessibility between two residential areas; Hyllie and Fosie ($p = .041$), indicating that between the other 11 residential areas included in this study, there are no significant differences in levels of perceived accessibility. The means for each residential area are presented in Fig. 1.

These results are somewhat surprising, as we were expecting bigger differences between the areas, as we know that there are differences in objective accessibility. Perhaps perceived accessibility was assessed within a bigger geographical area than was objective accessibility, and the results would have been different had we assessed perceived accessibility within a specific area rather than day to day travel opportunities, which may include the entire city of Malmö.

Main travel mode. In order to further look at differences in perceived accessibility levels between main travel modes, a Games-Howell post hoc test was conducted. This revealed (as can be seen in Fig. 2) significant differences in levels of perceived accessibility between main travel modes bike and car ($p < .001$), bike and public transport ($p < .001$), and bike and other ($p < .05$). No significant differences were found between the perceived accessibility of walkers and any other travel mode or between drivers (car) and public transport travelers. The mean level of perceived accessibility reveal that individuals using bike or walking as their main travel mode are experiencing the highest accessibility levels, followed by car-users and public transport travelers respectively.

The results are surprising as they indicate that individuals using mainly active sustainable modes (bicycle and walking) perceive their accessibility higher than individuals mainly using the car, contrary to common principles that the car is the most accessible option. Looking at the distribution of active mode users, it appears that they are relatively evenly distributed across areas, rather than gathered in a specific “bike-friendly” residential area, which could have offered an explanation to the results.

Gender, age, income. The analysis of variance showed no significant differences in perceived accessibility between the groups with different income or between age groups. There was however a difference between the levels of perceived accessibility of men (Mean 3.82, SD = 1.14) and women (Mean = 3.97, SD = 1.12) at the $p < .001$ level of significance, indicating that women perceive their accessibility as higher than men. A closer look at the distribution of main transport modes between men and women revealed no immediate explanation for this discrepancy regarding main mode use, other than that men use the car as their main mode of transport somewhat more (men 46%, women 38%), and that women use public transport as their main transport mode to a greater extent (26.5%, men 18.6%), with bike and walking being equal (walking men 6%, women 7.6%; bike men 28.4%, women 25.9%).

Study objective 3; comparing residents' perceived accessibility to the objective accessibility level for the same residential area.

As the objective accessibility index is based on accessibility by sustainable transport modes (bicycle, walking, and public transport) and not by car, the 1141 participants that stated the car as their main transport mode were excluded from the comparison. A bivariate analysis (Pearson's *r*) initially revealed that the correlation between perceived and objective accessibility was no higher than $r = 0.014$ ($p = .584$, n = 1570), indicating a very weak and non-significant relationship between objectively measured accessibility and perceived accessibility (by sustainable transport options). Scores for the objective accessibility index and PAC index per residential area are presented below in Table 6.

In order to examine the potential differences between objective accessibility and perceived accessibility for each of the residential areas of Malmö, a number of one sample t-tests were conducted. One-sample t-tests were chosen as the value for objective accessibility lacks variance within areas and needs to be treated as a normative value. The t-tests

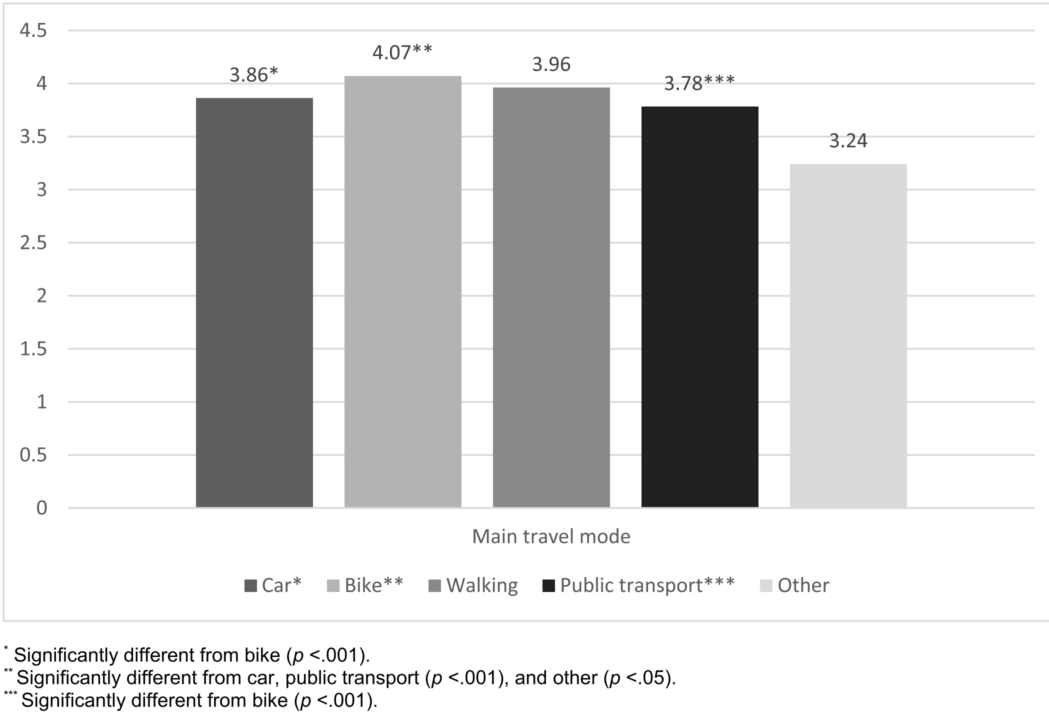

Fig. 2. Means of perceived accessibility per residential area in Malmö (N = 2711).
[*] Significantly different from bike ($p < .001$).
[**] Significantly different from car, public transport ($p < .001$), and other ($p < .05$).
[***] Significantly different from bike ($p < .001$).

showed that for each of the residential areas, perceived accessibility was significantly different from objective accessibility, p-values between $p < .001$ and $p < .005$. The results of the t-tests are presented in Table 6.

As proposed, we found significant differences between perceived and objective accessibility in all of the included residential areas, with the largest discrepancy in area Husie (diff. 2.59) and the smallest in area Centrum (city centre) (diff. 0.18). As area Husie ranked as number 4 in levels of perceived accessibility, and as the lowest in objective accessibility (and with similar results for the other included areas) it appears that perceived and objective accessibility do not correspond in levels of accessibility. Thus, levels of objective accessibility cannot be expected to predict perceived accessibility, or vice versa. This is further confirmed by the low correlation of $r = 0.014$.

5. Discussion

5.1. Conclusions

As expected, perceived accessibility differs significantly from objective accessibility, leading to the conclusion that perceived accessibility indeed capture other aspects of accessibility than objective accessibility. There were only two areas that differed significantly in perceived accessibility, indicating that perceptions of accessibility are more even across residential areas, than is objective accessibility.

In summary, the findings of this paper suggest that individuals use the mode (or combination of modes) of transport that offer satisfactory levels of accessibility. In Malmö, bike users' display significantly higher perceived accessibility than all other travel modes apart from walking, contrary to beliefs that the car is always the most accessible option for daily travel.

Table 6
One sample t-tests comparing objective and perceived accessibility with sustainable transport modes, per residential area and overall in Malmö. (n = 1570).

Residential Area	n	Objective accessibility (M)	Perceived accessibility (M)	Perceived accessibility (SD)	One sample *t*-test			
					Diff (M)	t	df	Confidence interval 95%
Bunkeflostrand	38	1.45	3.76	1.37	2.31	10.39**	37	1.86–2.76
Centrum	344	3.79	3.97	1.10	0.18	3.09*	343	0.07–0.30
Fosie	137	1.71	3.72	1.16	2.01	20.18**	136	1.81–2.20
Holma/Kroksbäck	111	1.83	3.77	1.23	1.94	16.62**	110	1.70–2.17
Husie	61	1.41	4.00	1.17	2.59	17.07**	60	2.26–2.86
Hyllie	44	1.51	4.26	0.87	2.25	10.12**	37	1.80–2.70
Kirseberg	127	2.02	3.85	1.21	1.83	17.06**	126	1.62–2.04
Limhamn	121	1.52	4.07	1.03	2.55	27.31**	120	2.37–2.74
Oxie	52	1.75	3.91	1.22	2.16	12.81**	51	1.83–2.50
Rosengård/Sorgenfri	236	2.16	3.87	1.04	1.71	25.10**	235	1.57–1.84
Slottsstaden	201	1.65	4.06	1.03	2.41	33.18**	200	2.27–2.56
Tygelsjö	22	1.15	3.64	1.40	2.49	8.32**	21	1.86–3.11
Västra Hamnen	76	2.00	3.95	1.19	1.95	14.21**	75	1.67–2.22

**$p < .001$, * $p < .005$.

We propose that since levels of perceived accessibility may be high despite low levels of objective accessibility, transport and accessibility related investments should not rely on only objective accessibility-evaluations. Including perceived accessibility will provide additional information for more thorough and knowledge based decision-making, that is not based on a priori assumptions of individual choices of travel destinations and activities. Moreover, perceived accessibility may be used to distinguish between segments of individuals that experience lower levels of accessibility, alas may help in identifying groups in danger of social exclusion. There is also a possibility that objective accessibility fails to capture where people actually travel, or want to travel. We know for instance that objective accessibility doesn't capture social travel and that Malmö index does not capture commuter-travel. There is also a risk that other important indicators are omitted by objective measures, but may be captured including evaluations of perceived accessibility.

5.2. General discussion

Our results show that there exists a discrepancy between objective accessibility and perceived accessibility ($r = 0.014$) with sustainable transport modes. This was further confirmed by the t-tests as accessibility as perceived by the residents of Malmö was significantly different from the calculated objective accessibility for each of the residential areas. These considerable differences between the two approaches to accessibility indicate that a full understanding of accessibility cannot be reached by relying on objective or perceived accessibility exclusively. This conclusion is in line with previous recommendations by Tobias and Ferreira (2014) and Curl et al. (2015).

The results further imply that a low objective accessibility doesn't necessarily mean that accessibility is perceived low by the residents, and that perceived accessibility can, and perhaps should, be a valuable contributor in the understanding of accessibility. In fact, comparing the two measures statistically showed that the perceived accessibility score was consistently higher than the objectively calculated score for all of the residential areas, with the city center-area showing the least difference in accessibility between the two measurement methods (3.79 in objective accessibility score and 3.96 in perceived accessibility score). As for the objective score, which placed the city center (Centrum) at the top in accessibility, the high rating is expected as objective measures of accessibility (including the Malmö index) commonly consider city centers as packed with eligible destinations. The perceived accessibility score however, rated four other areas higher in accessibility, suggesting that objective measures indeed are missing out on some important indicators of accessibility relevant to individuals. These findings confirm the importance of further exploring perceived accessibility and especially looking at which attributes that affect this dimension of accessibility, such as perceived access to activities for social interaction, or feelings of safety (Lättman et al., 2016a). The findings also confirm previous research results of differences between objectively and subjectively measured accessibility (e.g. Lotfi & Koohsari, 2009; Scott et al., 2007).

The results are important as the exclusion of perceived accessibility when evaluating and planning for accessibility can lead to assumptions of accessibility levels that are not in line with the experiences and perceptions of the individuals that are living in these areas and that are reliant on the transport systems.

Further analyses revealed significant differences in perceived accessibility between only two of the thirteen residential areas, proposing that perceived accessibility is more stable across urban areas, than is objective accessibility. Looking at the two areas that did differ in perceived accessibility (Hyllie and Fosie, Table 6), the distribution of main modes of transport and also objective accessibility levels appear relatively consistent, leading to the conclusion that other aspects than those measured in this study affect these levels. Given the high rates of perceived accessibility, these findings further infer that individuals across Malmö perceive that they are able to live the lives they want with help of sustainable transport options and are overall happy with their sustainable daily travel accessibility, regardless of area of residence. Considering the abilities of individuals to think and act in accordance with their environment and travel options, it is likely that most individuals use the transport mode, or combinations of transport modes, that offer them a satisfactory level of accessibility. Hence, even if the objective accessibility is considered low in certain areas, there still exists satisfying options for travel.

As perceived accessibility is not constricted to measure accessibility to specific destinations and activities, one explanation for the non-significant differences between residential areas may be that the areas residents take into account when assessing perceived accessibility overlap, and may be greater or smaller than the included sump-areas.

The comparison of perceived accessibility levels between transport modes revealed that individuals using bicycles as their main travel mode experience the highest accessibility levels of all participants in the study. The bicycle users' mean level of perceived accessibility was indeed significantly higher than both car users', public transport users', and those using “other travel modes”. Individuals that are mainly walking perceived their accessibility nearly as high as the bikers, but with no significant differences to any of the other main travel modes. These results propose that Malmö city planners have been successful in providing accessible routes for active travelers, contrary to the results of the objective index, where only one area (Centrum) reaches a high accessibility level.

Car users' and public transport users’ perceived accessibility levels were both significantly lower than bicycle users', but level with all other travel modes. These are surprising results, considering the conventional accessibility assumption that the car is the most accessible option (e.g. Lättman et al., 2016a), although consistent with the previous idea that individuals choose the mode most suitable to fulfil their travel needs and preferences. A surprising finding was that perceived accessibility doesn't seem to differ between age groups or groups with different income in Malmö. These results may be due to the inclusion of only three different income-levels and the specification of age groups in the current sample, as these results contradict previous research, which suggests that levels of perceived accessibility are lower for the elderly (Lättman et al., 2016a) and that income affects accessibility. There were significant differences between men and women however, with women perceiving their accessibility as higher than did the men. Following this, it would be interesting to continue to look into differences in perceived accessibility for different segments of the population, and at factors that may affect perceived accessibility in itself (both psychological factors such as cognitive dissonance or attitudes, but also common sociodemographic factors, or attributes of the built environment).

5.3. The PAC-measure and policy implications

As the modified version of PAC was found psychometrically valid, and appears both conceptually and empirically complementary to conventional accessibility measures, it can be a valuable contribution to further our knowledge of (perceived) accessibility within and between different groups of people, for instance the elderly or others at risk of transport-related social exclusion. It can also contribute to knowledge of the relations between the residents' perceived possibilities for daily travel and activities, and the objective description of accessibility for a residential area. This is important as the choices individuals face and rely on when deciding if and how to use the transport system (given known available options and transport modes), are not fully captured with conventional accessibility-measures. We know for instance that conventional accessibility measures, such as objective evaluations of daily travel accessibility, do not include transport opportunities for social activities, for example visiting friends and family or going to the football field for watching a game or playing with friends. This is especially worrying, as social travel is considered the most important aspect of travel by the travelers themselves (Titheridge et al., 2010). The Malmö-index for objective accessibility, among others, even omit work-opportunities and alas commuter travel, as these aspects are difficult to capture (Malmö Stad, 2016). These omissions could contribute to the explanation of some of the differences we found between objective and perceived accessibility, and illuminate the need for capturing also these aspects of accessibility.

In all, the findings of this paper indicate that it can be beneficial to include perceived accessibility when evaluating accessibility and transportation projects and investments. A more inclusive approach to accessibility is also in line with guidelines within EU (The European Commission, 2014; 2015) that promote accessibility for all, and emphasize citizen-involvement in planning for livable urban areas that take into consideration the needs and wants of the residents.

Not only do objective and perceived accessibility differ significantly, perceived accessibility may also better account for user-perspectives (including social and commuter opportunities for travel) than can conventional accessibility-measures. Perceived accessibility can also help advance accessibility considerations (e.g. where, when, for whom) and compare impacts of investments for different groups (Lättman et al., 2016b) and between geographical areas. As the Perceived Accessibility scale (PAC) proposed in this study, and in previous studies (Lättman et al., b, 2016a) is a quantifiable measure, based on a small number of items, and with an output that is easy to interpret, it is convenient for assessing perceived accessibility also on a larger scale. The PAC can be included as part of other continuous surveys of the living environment, transport-systems or other areas related to accessibility (as in Malmö).

5.4. Limitations and future research

This study has explored differences between perceived accessibility and objectively measured accessibility in a Swedish urban setting. We welcome future studies to scrutinize our findings and address perceptions of accessibility across demographic groups, populations in other cities, in rural environments, and in other countries to find out more about perceived accessibility and how it differs from objective accessibility. A relevant area of study would be to look at what factors can explain the differences between objective and perceived accessibility levels found in this study, for instance with respect to the built environment and potential self-selection bias in residential choice. As we know little of possible adaptation processes related to perceived accessibility, it would be interesting to design a longitudinal study among new residents and follow perceptions of accessibility over time. Also, our knowledge would benefit from further studies of perceived accessibility within sustainable modes, for instance by looking at current non-sustainable-users (e.g. car-users) and their perceptions of accessibility if limited to sustainable transport modes. As we already know that accessibility (objective) relates to overall well-being (Parkhurst & Meek, 2014), another important area to look into, given the differences found in this study, would be the relation between perceived accessibility, subjective well-being, and social inclusion.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.retrec.2018.06.002.

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