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Activity spaces of homeless men and women measured by GPS tracking data: A comparative analysis of Prague and Pilsen☆

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ABSTRACT

The aim of this article is to investigate the factors that influence the size of activity spaces of homeless men and women in cities. Vulnerable population groups such as the homeless face the risk of mobility challenges that can exacerbate their social exclusion even more through mobility-driven spatial exclusion. The extent of an individual's activity space is a key precondition for the daily coping strategies and life opportunities of homeless people. This study is the first to combine GPS tracking of homeless people based on a week-long GPS measurement with mobility interviews. The article tests five hypotheses as to the influence of city size, age, gender, housing situation and education on the size of activity space. Data obtained for a large city (Prague) and for a small city (Pilsen) are analysed using three geospatial measurements of activity spaces. In line with mixed-method approaches, the results are further triangulated through mobility interviews. By mapping the objective activity spaces, we were able to evaluate the role of individual and contextual factors in shaping homeless life and discuss the theoretical and practical implications of activity space measurement for social policy and urban planning.

1. Introduction

Access to services and economic opportunities enabled by transportation opportunities in cities are crucial for the extremely poor homeless population in contemporary cities (Hwang & Burns, 2014; Pollio, North, Eyrich, Foster, & Spitznagel, 2003). Social problems, health issues, substance use, criminal victimisation (Garland et al., 2010), and stigmatisation are over-represented within the homeless population (Fazel, Geddes, & Kushel, 2014). Urban policy makers and social policy experts dealing with homelessness highlight a need for a diverse, integrated and accessible service provision (Moore, Manias, & Gerdtz, 2011) mitigating the consequences of homelessness. Recent reports indicate underutilisation of services for homeless people (Canavan et al., 2012) and point to the persistence of structural barriers limiting service use for particular gender or age groups. The geographic location and opening hours of services are a crucial factor affecting the use of these services and thus subsequently affecting the outcomes of intervention. However, very little is known about the geo-spatial behaviour of homeless people and about the role it plays in service utilisation (North et al., 2017; Snow & Mulcahy, 2001). An understanding of the geo-spatial behaviour of homeless people is needed to inform optimal placement of services (Chan, Gopal, & Helfrich, 2014). As such, this study uses an innovative mixed-method approach and can serve as a feasibility study for GPS-based participatory mapping surveys of homeless people beyond the US context (North et al., 2017). The practical utility of this type of study is illustrated by Chan, Helfrich, Hursh, Rogers, and Gopal (2014), who demonstrated that spatial routines related to social networks at places of service provision play an important role in community integration after permanent housing is obtained (Chan, Gopal, & Helfrich, 2014). This article analyses how individual variables such as age, education, gender and housing situation shape the size of activity space of homeless people in different urban contexts. A broad definition of homelessness covering all ETHOS categories (Amore, Baker, & Howden-Chapman, 2011) is employed in the empirical analysis. Activity spaces or areas of daily experiences are measurable characteristics derived from individual spatial mobility and temporal presence in particular places (Chaix et al., 2013; Sherman, Spencer, Preisser, Gesler, & Arcury, 2005). Activity spaces measure the spatial extent of daily activities and reflect where participants have chosen to go and to interact within their social environment. The quantitative GPS data provides uniquely rich spatial information for measuring various aspects of homeless mobility. However, these quantitative data need to be validated through mobility interviews with respondents in order to fully explore and understand different patterns

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of homeless mobility.

1.1. Mobility research and homelessness

Recent reports about the health of homeless people in high-income countries point to a rising number of homeless people and an ageing of the homeless population (Fazel et al., 2014). Changing needs of the homeless population have implications for social policy and health provision in cities. However, as pointed by Canavan et al. (2012: 1): "*Entitlement to health care for homeless people does not always mean access. Limited accessibility is often due to factors such as opening hours, inflexible appointment procedures, and location. Homeless people may also encounter attitudinal barriers within services and there is often an unwillingness or difficulty in the health services to accommodate the multiple and complex needs presented by homeless people.*" This example from the health care perspective clearly illustrates the need for a better understanding of the geo-spatial behaviour of homeless people. A similar argument can be made from the perspective of social care provision, transport use, access to economic opportunities, for social interaction, or community integration (Chan, Helfrich, et al., 2014).

A positive trade-off resulting from better access to service locations or better access to places for social activities or economic opportunities should apply to the homeless population. However, better spatial accessibility does not automatically translate into improvements in quality of life or service utilisation. For example, the health conditions of the homeless population (Fazel et al., 2014) are driven not only by spatial accessibility, but also by factual eligibility and previous user experience of healthcare. Homeless people often do not have health insurance and rely on free-of-charge care provided in the relatively sparse places providing homelessness support. Homeless people perceive health service provision based on previous place-based experiences. Ensign and Gittelsohn (1998) clearly pointed out that homeless people ignored healthcare locations deemed to be for other target groups even if they are eligible for care provision. We argue, in line with North et al. (2017), that further analyses of personal and social meaning meanings associated with service use and mobility decision (Cameron, Abrahams, Morgan, Williamson, & Henry, 2016; Moore et al., 2011; Vašát, 2014) beyond spatial analysis are required. Unfortunately, there is a lack of knowledge in both areas (Marquardt, 2016). A combination of geospatial analysis of homeless mobility combined with a qualitative understanding of service use will allow the improvement of placement and timing of services for homeless people.

In contrast with the potential stemming from the application of advanced geo-spatial analysis in research into homelessness, most homelessness research has dealt relatively little with the socio-spatial dynamics of homelessness. In general, nearly all homelessness research can be classified into three basic genres (Snow & Mulcahy, 2001). The first genre consists of cross-sectional, survey-based studies, the second includes macro-level, multivariate studies, and the third consists of ethnographic field studies. These three genres focus on various strands of homelessness ranging from housing affordability and the de-institutionalisation of care to the ethnography of street life. As Snow and Mulcahy (2001) pointed out, these three genres of homeless research deal with important issues shaping homeless life, but they do not fully recognize the importance of socio-spatial and ecological factors in forming the daily mobility routines of homeless people. An analysis of the activity spaces of homeless people can provide further insight into the constraints and enablers of daily mobility and thus may have implications for public policy, for example in terms of public transportation accessibility or service under-utilisation (Canavan et al., 2012).

The contemporary information society is defined by the ubiquitous presence, collection, and utilisation of location data. Every smartphone use, every social media login, every card payment creates location data in digital form. Location technologies have become increasingly relevant not only in urban planning (Shoval, Schvimer, & Tamir, 2018) and transport research (Herrera et al., 2010), but also in medical science (Webber & Porter, 2009), neighbourhood and health studies (Chaix et al., 2013; Shareck, Frohlich, & Kestens, 2014), and psychology (Saeb, Zhang, Karr, et al., 2015). These applications are further advanced by geographical information science (Richardson et al., 2013), which offers novel understanding of environmental exposure (Helbich, 2018; Kwan, 2018; Miller, 2017) and provide innovative methods and tools of measurement (Siła-Nowicka et al., 2016; Wang, Kwan, & Chai, 2018). However, despite recent developments in health research (Brusilovskiy, Klein, & Salzer, 2016) the utilisation of location technologies such as GPS is still relatively rare in research focusing on vulnerable (Hardy et al., 2018) or elusive populations (Busch-Geertsema, 2015; North et al., 2017). For example, Townley, Pearson, Lehrwyn, Prophet and Trauernicht (2016) used maps of daily activities drawn by young homeless people as an input for the geo-computation of activity spaces. The participatory mapping study highlighted the importance of service location for homeless young people as a key anchor of their daily activities. The engagement of young homeless people in service related activities was positively associated with their psychological wellbeing and sense of community (Townley et al., 2016). The focus on activity spaces is fundamental, as these express the range of experiences and opportunities presented to a person in a typical day. In line with this participatory mapping approach, Chan, Helfrich, et al. (2014) applied accessibility evaluation methods in GIS in order to assess community integration among formerly homeless adults. The study pointed out that the physical integration linked with obtaining permanent housing does not guarantee social or psychological integration into a particular community. Mapping of activity spaces expands our understanding of the daily life of homeless people and informs social policies focused on community integration of formerly homeless people. Recently, a pilot study by North et al. (2017) demonstrated a method for tracking the movements of homeless individuals using GPS technology. The pilot study compared self-reported travel distances with GPS measurement data revealing wide discrepancies between the two. North et al. (2017) demonstrated the need to collect objective data by GPS, as self-reporting of mobility by homeless people is prone to errors, forgetting, and incorrect representation of locations. Despite these findings, little research has investigated areas of daily experiences of homeless people and the relationship between activity spaces and individual or contextual variables.

The present study is the first to measure the impact of individual and contextual variables on the size of activity spaces of homeless people. The service needs of the homeless population coexisting with underutilisation of services are a major problem for urban and public policy. The analysis is based on participatory mapping of homeless men's and women's spatial mobility measured by GPS data in two cities, Prague and Pilsen in Czechia. The study conducted measured the week-long spatial mobility of 80 individuals. Three different measures of activity space are utilised as proxy indicators measuring the access of homeless people to services. Based on previous qualitative experience we propose and test five research hypotheses. This approach allows a better understanding of the geospatial movements of the homeless population and brings new implications for urban and public policy.

1.2. Research hypothesis

Well-being and quality of life is associated with mobility as it allows participation in daily activities and thus makes it possible to lead an independent and active life (Townley et al., 2016). The ability to move in space is measured by the size of activity space as areas of daily experiences indirectly measure the personal resources of a homeless person (Sherman et al., 2005). The study hypothesised that activity spaces vary in size across different groups of homeless. Five hypotheses are under consideration.

Hypothesis 1. Activity spaces of homeless people in Prague will be

larger than activity spaces of homeless people in Pilsen.

A larger city (Prague) offers more advanced urban infrastructure enabling more transportation opportunities and thus stimulates spatial mobility of homeless people. In addition, greater distances between points of interest for homeless people and the complex urban structure in a larger city create a need to overcome longer distances and thus increase personal activity space.

Hypothesis 2. Younger homeless people will have larger activity spaces than the older homeless due to fewer mobility constraints stemming from greater age.

According to ethnographic research (Jackson, 2015); young homeless people tend to have a less spatially grounded lifestyle with a tendency to nomadic movement, which increases their activity spaces. The existence of extensive social networks and travel related to substance use create an impetus for a more mobile life-style. On the other hand, older homeless people are generally in poorer health, which indicates restricted options for mobility solutions to their life situation.

Hypothesis 3. Homeless men are expected to have a larger activity spaces than homeless women due to the gendered nature of homelessness.

In general, the homeless population consists of a majority of men and a minority of women. Homeless women are not only less numerous in the homeless population, they are also less visible in public spaces. A fear of victimisation imposes restrictions on the mobility of homeless women and encourages avoidance strategies keeping women out of areas where there is a perceived danger (Cameron et al., 2016). Limited presence in specific public spaces driven by selective spatial mobility leads, in turn, to smaller activity spaces of homeless women (Townley et al., 2016).

Hypothesis 4. Homeless people living in worse housing conditions will have larger activity spaces than those living in better housing conditions.

The mobility of homeless people living in worse housing conditions includes forced mobility in addition to regular mobility, which increases the overall level of mobility and extends activity spaces (Kawash, 1998). Homeless people living in better housing conditions can exert a higher level of control over their mobility and thus avoid forced mobility due to unexpected or vicious events. The categories of the ETHOS typology (Amore et al., 2011) are utilised to define better and worse housing conditions.

Hypothesis 5. Homeless people with a higher level of education are expected to have larger activity spaces than those with lower education levels.

In general, the level of education is linked to the breadth of social networks and it shapes the scope of life opportunities, which leads to a higher impetus to spatial mobility. It is expected that the homeless population will mirror the general population in this respect and that more educated homeless people will have larger activity spaces.

2. Method

Prior to field research activities and after the approval of the project by the Czech Science Foundation the main NGOs and service providers dealing with homelessness in Prague and in Pilsen were consulted about the project plan (e.g. Hope Organisation, Salvation Army, etc.). They provided valuable feedback on the project plan and shared their expertise on practical issues stemming from project implementation in the Czech context.

2.1. Sample

The study was conducted in three rounds in the winter/spring months in 2016, autumn/winter months in 2017, and winter/spring months in 2017. The data for two comparable samples of homeless adults were collected in two cities – in the large capital city of Prague (n = 42) and in a small regional city Pilsen (n = 38). All participants were informed about the research plan and all signed an informed consent form enabling their research participation. The study attempted to find a representative sample of people experiencing homelessness. The recruitment strategy was to collect diverse sample of homeless adults with respect to age and housing conditions (ETHOS typology - Amore et al., 2011). The respondents were recruited initially through personal networks of the research team and through contacts provided by local NGOs, later through personal networks of study respondents and through recruitment in places of support for homeless people. This sequence of cooperation helped to establish the trust between research participants and the research team necessary to conduct the GPS tracking activity successfully. Previous knowledge from ethnographic research, a photo-voice study and a large-scale survey conducted as a part of a larger research project were used to inform sampling decisions. However, we purposely over-represented women in our sample in order to gain information about female homelessness and mobility (Table 1).

All recruited participants received a GPS tracking device (data-logger GPS Canmore GT-740FL with a small portable charger) which collected location data every 5 min throughout the mobility measurement. Participants were instructed about the use of the device and they then carried it with them for a week. GPS data were collected after a week of mobility measurement, processed in GIS software (ArcGIS 10.3 by E.S.R.I.), and converted into paper maps of daily mobilities for each participant. In rare cases when participant collected less than three full days of valid GPS data we repeated the instructions and asked the participant to collect data once more. Thus, the attrition rate was minimal. Finally, face to face interviews about the daily mobility maps were conducted and everyday mobilities were discussed with individual participants. The purpose of the interviews was to verify the accuracy of the GPS data and to explain mobility behaviour. We consider a day of measurement as valid if there were GPS data collected in at least two of four six-hour periods within a day starting from midnight. The

Table 1
Sample description.

	Full sample (n = 80)	Prague (n = 45)	Pilsen (n = 35)
Sex			
Male	42	24	18
Female	38	21	17
Age groups			
Young: age 18–30	13.3%	15.0%	11.4%
Middle-aged: age 31–55	53.3	52.5%	54.3%
Old: age 55 and more	33.3%	32.5%	34.3%
Education level			
Elementary education	46.8%	42.9%	51.9%
Vocational education	32.3%	31.4%	33.3%
Secondary school and higher education	21.0%	25.7%	14.8%
Housing condition			
Poorer condition[a]	37.5%	37.8%	37.1%
Better condition[b]	62.5%	62.2%	62.9%

[a] Poorer housing condition includes homeless individuals living on the street (under a bridge, in a park, on a bench), in a green space (in a tent, in the woods), or in a squat (in buildings, garages or cabin).

[b] Better housing condition includes homeless living in institutions (homeless shelter, sanctuary), in hostels (all types), in conventional housing (flat, house) or in doubling arrangement (all types).

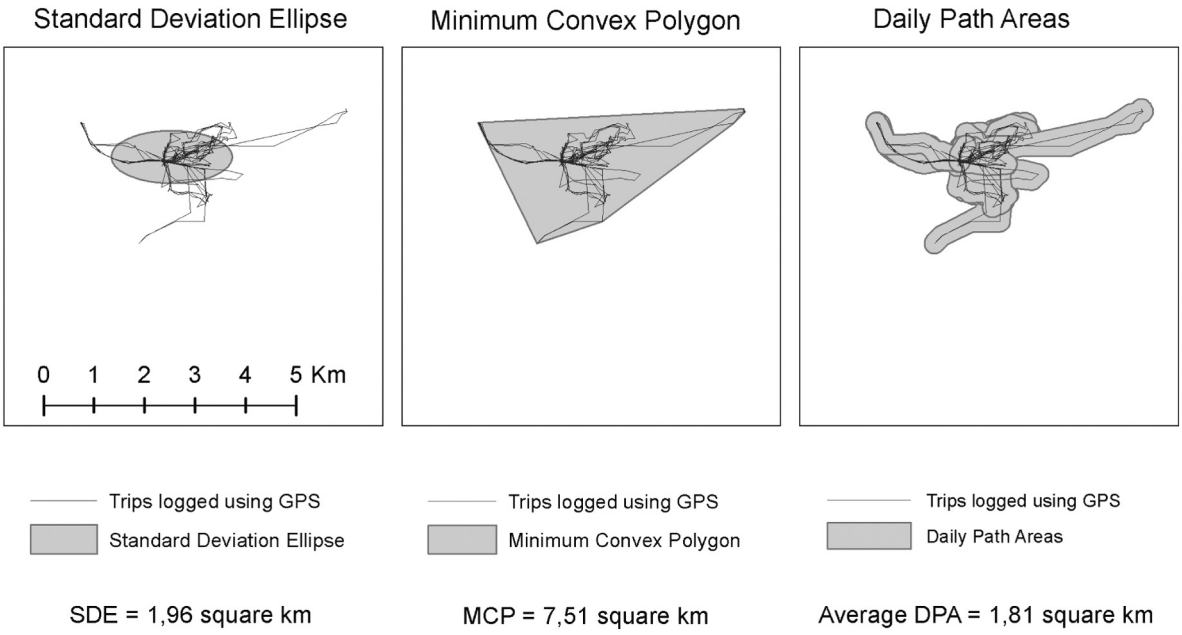

Fig. 1. Activity spaces of an elderly homeless man.

interview consisted of a) a description of daily trajectories, places, meetings, and activities and b) general questions focused on mobility routines and habits such as perception of safety in places or time planning. The final sample includes information about 598 days of homeless life. Participants were rewarded with the equivalent of 20 Euros in return for their participation after the completion of the map interview. Technical difficulties such as GPS signal drift or practical difficulties such as the loss of a device were very rare. Only two participants lost the tracking device. The cities in our study have a low-rise built environment without skyscrapers, therefore GPS signal for an accurate measurement is not limited. The field experiences with deployment of GPS were similar to a pilot study of GPS tracking in homeless research elaborated in detail by North et al. (2017).

2.2. Measures

2.2.1. Variables

The analysis tested several individual and contextual variables which were expected to shape the size of activity spaces of homeless people. Firstly, basic individual variables of age, sex, and education were requested directly from the participants. The contextual variable of housing was collected differently. In contrast with previous participatory mapping research with homeless people (Chan, Helfrich, et al., 2014, Townley et al., 2016), we did not rely solely on self-reported data, but used insights from the map interviews to gain a new variable for analysis. The categorical variable of housing situation was identified from interviews over the mobility maps. The variable represents the most frequent way of spending the night during the mapping activity. This new approach may mitigate any possible bias resulting from self-reporting as the new variable stems directly from past mobility behaviour. We consider the housing variable as contextual as its values depend heavily on the local context of service provision. The city variable is the location of mapping activity. However, the city variable measures a complex set of urban conditions stemming from different city sizes. Larger cities tend to have not only more homeless people, but also more diverse services for them and a denser transport network, which shapes the local conditions of homelessness.

2.2.2. GPS data

Hirsch, Winters, Clarke and McKay (2014) and Sherman et al. (2005) discuss various activity space measures at length, but the utility of these measures has not so far been tested on the specific mobility behaviour of the homeless population. Therefore, we decided to use three different measures of activity space. First, the Standard Deviation Ellipse (SDE) measures the directional distribution of a series of GPS points and thus expresses the dense area where most of the spatial mobility is realised. Secondly, the Minimum Convex Polygon (MCP) represents the smallest polygon that contains all the GPS points. This approach measures a person's “area of usual reach”. These two measures are based on the spatial distribution of points of location. Thirdly, a spatial buffer around all individual daily mobility trajectories creates a Daily Path Area (DPA). We used 200-meters buffer around the daily path trajectory, which is in line with previous studies of activity spaces (Zenk et al., 2011). This measure is based on trajectories linking points of location in space. In our analysis, we use SDEs and MCPs derived from week-long GPS tracking and an average value of the DPA computed from its daily values for a week. The use of weekly data narrows down the variability stemming from differences between individual days' mobility and thus mitigates the impact of outlier values in the sample (Chaix et al., 2013). The use of weekly data allow us to capture the usual size of activity spaces of homeless people more reliably than analysis relying on only one day of measurement (North et al., 2017). The geo-computational part of the study was implemented in ArcGIS 10.3 software by E.S.R.I. The geo-computation of activity spaces is based on the Python script developed by Hirsch et al. (2014).

2.2.3. Examples of activity spaces of homeless individuals

A lack of information about the real mobility of homeless people often leads to skewed stereotypes about homeless mobility. The homeless people in our study neither statically occupy a spot in public space nor constantly move through urban space as nomads. Figs. 1 and 2 illustrate the patterns of weekly mobility of two homeless adults – an elderly man and a young woman. The two sets of pictures are in the same scale and thus directly comparable. The more angular lines of the mobility path of the elderly man indicate that walking is his main mode of spatial mobility. Most of the mobility occurs in a relatively small area with a few trips per week to more distant locations. Bundling of mobility paths in certain directions suggests regularity in mobility behaviour. The longer straight lines of the mobility paths of the young woman indicate a predominance of public transport use as her main

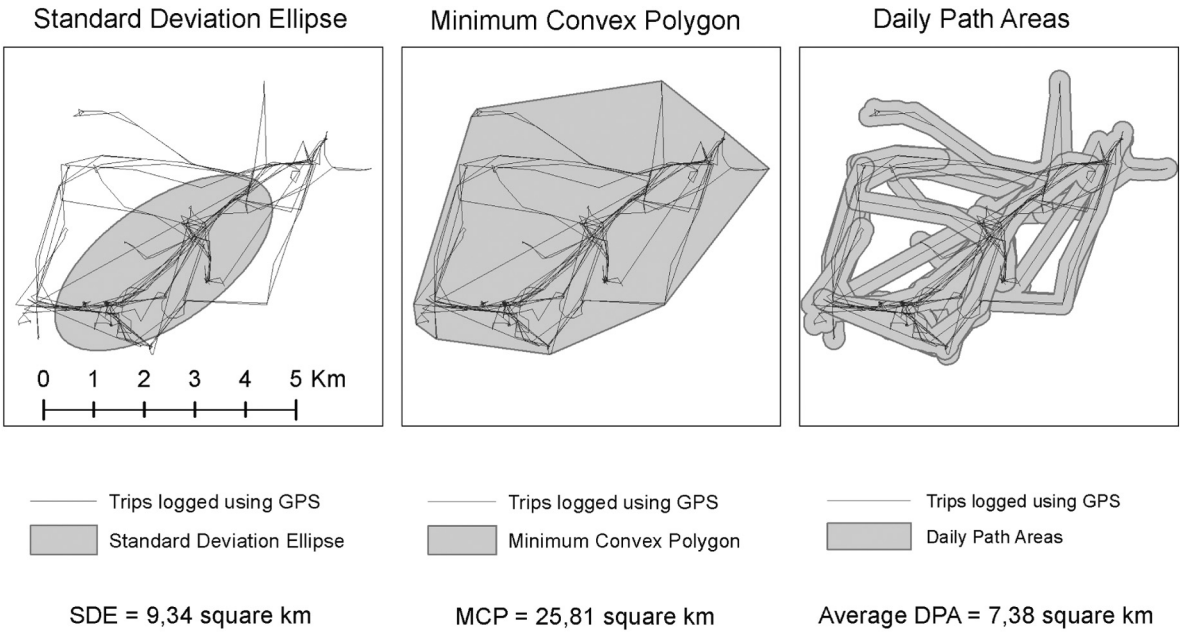

Fig. 2. Activity spaces of a young homeless woman.

mode of spatial mobility. The mobility patterns of the young woman are more diverse and cover a larger urban space. Dense nodes of mobility paths signify important places in term of time spent.

The two visualisations of daily mobility paths are further supplemented by examples of the three measures of activity space used in this article. The SDE provides information about the densest area of mobility, which is typical for the realisation of a majority of everyday activities. The MCP provides information about the area of reach of a person, which represents the space a person can cover with their regular mobility behaviour. The DPA provides information about the extent of the territory close to a person's daily mobility trajectories. The buffer area around daily trajectories overlaps. The average value of the DPA indicates how great an area a person can cover every day. In the whole sample, SDE activity spaces ranged from 0.02 km^2 to 391 km^2 (median value = 3.62 km^2), MCP size from 0.01 km^2 to 1376 km^2 (median value = 15.48 km^2), and average value of DPA ranged from 0.27 km^2 to 18.83 km^2 (median value = 2.98 km^2). Particular values of three activity space measures for two examples are provided.

2.3. Data analysis

The GPS mapping data provide extensive information about homeless spatial mobility. The sample collected in this study is relatively small for advanced statistical elaborations; however, it is relatively large for analysis of a vulnerable and sensitive population such as homeless people. Therefore, we opted for simple statistical measurement, which can provide insight into the drivers of the size of activity spaces. The data does not have a normal distribution (as it is typical for human mobility data – see Barbosa et al., 2018) and several outlier values are present. The results from Levene's Test of Equality of Error Variances were not significant, therefore we used the non-parametric Kruskal-Wallis test for the analysis of variance across selected categories. The data analysis tests for differences in the size of activity spaces grouped by demographic variables and contextual variables. Due to the size of the sample, we focused our interpretation on statistically significant results, but we also comment on trends suggested by the data with a slightly higher margin of error. The statistical analysis was conducted in IBM SPSS Statistics 23.

2.4. Study area

Prague and Pilsen are typical European cities with historical cores, dense inner cities, and outer cities with large-scale housing estates. Both cities have dense and well-connected public transport networks completely covering their metropolitan regions. Prague is the largest city in Czechia with a population of 1.3 million inhabitants. According to a recent homeless count, there are about 4000 homeless people in Prague (Šnajdrová & Holpuch, 2010) and a further 10,000 people are at risk of becoming homeless (Ministry of Labour and Social Affairs, 2015). Pilsen is the regional capital of the West Bohemia region with a population of 200,000 inhabitants. According to recent data, there are approximately 300 homeless people in Pilsen (Váně & Kalvas, 2014) and about 2000 people are at risk of becoming homeless (Ministry of Labour and Social Affairs, 2015).

Czechia is the only country in the EU which does not have a law governing social housing provision. This puts higher pressure on urban policy makers, as they are responsible for municipal housing policy and social service provision. The situation is further complicated by friction between the city council and individual councils of municipal districts within Prague (Temelová et al., 2017). Places providing support for homeless people tend to be driven by the NIMBY effect and they are often located on the borders between city districts. The difference in size between Prague and Pilsen shapes the complexity and the extent of service provision for homeless people. In Prague, there is more extensive and nuanced service provision than in Pilsen. In both cities, places of support for homeless people are accessible by public transport due to the dense transport infrastructure.

3. Results

Table 2 presents the mean values of activity spaces of homeless people using SDE, MCP, and DPA measures across tested characteristics (see Examples of activity spaces of homeless people). The variance in the sample is measured by the standard deviation within a particular subgroup. Table 2 also evaluates the difference between groups by a non-parametric Kruskal-Wallis test (median values are not shown in Table 2) and its statistical significance is indicated by p-values.

The results show that the size of activity spaces of homeless people is significantly driven by city size, therefore confirming **Hypothesis 1**.

Table 2
Activity spaces of homeless people.

		SDE (km^2)	Kruskal-Wallis test	MCP (km^2)	Kruskal-Wallis test	DPA (km^2)	Kruskal-Wallis test
	n	Mean (SD)	P-value	Mean (SD)	p-Value	Mean (SD)	p-Value
Total sample	80	17.3 (49.8)		63.8 (187.3)		3.9 (3.6)	
City			0.00		0.00		0.00
Prague	45	24.8 (63)		80.9 (218.4)		5 (3.7)	
Pilsen	35	7.7 (21.6)		42 (137.5)		2.6 (3)	
Age			0.77		0.51		0.65
Young	10	12.8 (21.6)		48.5 (83.4)		4 (2.4)	
Middle-aged	44	22.5 (65.1)		87.8 (245.8)		3.7 (3.4)	
Old	26	10.3 (16.9)		29.3 (46.1)		4.3 (4.4)	
Sex			0.19		0.47		0.32
Men	42	10.1 (22)		42.5 (107.6)		3.6 (3.6)	
Women	38	25.3 (68.2)		87.4 (247)		4.3 (3.6)	
Housing			0.54		0.77		0.87
Worse housing	30	10.2 (19.2)		33.9 (61.9)		4 (3.9)	
Better housing	50	21.6 (61.1)		81.8 (231.1)		3.9 (3.5)	
Education			0.33		0.48		0.39
Elementary education	29	12.5 (33.4)		37.6 (103.4)		3.3 (2.9)	
Vocational education	20	15.2 (27.3)		81.2 (176)		4.5 (3.8)	
Secondary school and higher education	13	16.6 (25.2)		50 (89.6)		4.7 (5.1)	

In contrast, the initial test of the four other hypotheses (**Hypotheses 2–5**) did not provide conclusive answers. However, the large differences between particular subgroups suggest that there might other significant differences if we replicate the analysis for differently split groups. We tested within subgroup differences for three-subgroup categories of age and education and their possible alternative aggregations into two group sub-samples, but none of these combinations confirmed statistically significant differences.

Due to the major influence of city size on activity spaces of homeless people, we also tested **Hypotheses 2–5** separately for Prague and for Pilsen. The relative structural similarity of the samples in Prague and Pilsen (see Table 1) allow such analysis and comparison.

Hypothesis 2 assumed, that there are age-driven differences in the size of activity spaces of homeless people. As in the population in general, the hypothesis expected declining mobility with rising age, which would in turn lead to a decrease in the extent of activity spaces. The differences in the size of activity spaces of homeless people are not statistically significant (Tables 3 & 4). However, if we look at the data per se, they provide important insights into the mobility of various age groups. Contrary to our expectation, the activity spaces of young homeless individuals by SDE and MCP metrics are smaller than those of the middle-aged homeless, but they are larger by DPA metrics. The apparent incongruity between the SDE and MCP measures on one hand and the DPA measure on the other was not expected from the literature. For example Hirsch et al. (2014) show that these three metrics of activity spaces are usually highly correlated and consistent. The results from our analysis indicate that the young group and the old group of homeless people have smaller activity spaces than the middle-aged homeless (smaller SDE and MCP values), but they move more often within their activity space area as suggested by higher DPA values. Although different reasons might drive this mobility difference, we decided to run the analysis for an aggregated group of young and old homeless and compare it with the middle-aged group. The results for the SDE and MCP values are not conclusive, but there is a significant difference in DPA values between those two groups in Prague (p-value = 0.042) and no significant difference in Pilsen (p-value = 0.175). The links between the mobility behaviour and activity spaces of different age groups of homeless people are more nuanced than we expected.

Hypothesis 3 expected that homeless men would have larger activity spaces than homeless women because of restrictions on women's spatial mobility due to the risk of victimisation and fear in public spaces. However, this difference was not confirmed. In separate analyses for the two cities, there is a significant difference between men and women in Prague, where, in contrast with our hypothesis, activity spaces of women are significantly larger than those of men. The functional relationship between sex and size of activity spaces seems to be the opposite of we expected. There is no significant difference between

Table 3
Activity spaces of homeless people in Prague.

		SDE (km^2)	Kruskal-Wallis test	MCP (km^2)	Kruskal-Wallis test	DPA (km^2)	Kruskal-Wallis test
	n	Mean (SD)	p-Value	Mean (SD)	p-Value	Mean (SD)	p-Value
Prague	45	24.8 (63)		80.9 (218.4)		5 (3.7)	
Age			0.79		0.78		0.12
Young	6	18.8 (26.9)		71.6 (104.2)		5.3 (2)	
Middle-aged	25	30.4 (82.6)		101 (287.1)		4.1 (3)	
Old	14	17.4 (20.7)		48.9 (56.2)		6.4 (5)	
Sex			0.00		0.10		0.02
Men	24	11.2 (19.3)		41.9 (66.3)		4.2 (3.7)	
Women	21	40.4 (88.5)		125.4 (309.8)		5.9 (3.6)	
Housing			0.27		0.93		0.94
Worse housing	17	15.9 (24.2)		53.8 (77.1)		5.4 (4.6)	
Better housing	28	30.3 (77.7)		97.3 (271.1)		4.7 (3)	
Education			0.48		0.96		0.50
Elementary education	15	22.3 (44.8)		65.3 (140)		4.7 (3.3)	
Vocational education	11	9.5 (7.2)		35.3 (27.9)		4.2 (2.4)	
Secondary school and higher education	9	23.6 (27.8)		71.3 (101.9)		6.4 (5.3)	

Table 4
Activity spaces of homeless people in Pilsen.

		SDE (km^2)	Kruskal-Wallis test	MCP (km^2)	Kruskal-Wallis test	DPA (km^2)	Kruskal-Wallis test
	n	Mean (SD)	P-value	Mean (SD)	P-value	Mean (SD)	P-value
Pilsen	35	7.7 (21.6)		42 (137.5)		2.6 (3)	
Age			0.35		0.33		0.34
Young	4	13.9 (11.3)		13.9 (11.3)		2.1 (1.3)	
Middle-aged	19	12 (28.8)		70.3 (183.8)		3.2 (3.9)	
Old	12	2.1 (2.3)		6.3 (5.8)		1.8 (1.3)	
Sex			0.21		0.25		0.25
Men	18	25.7 (0)		148.2 (0.3)		3.4 (0.4)	
Women	17	6.7 (17)		40.4 (129.7)		2.4 (2.7)	
Housing			0.81		0.97		0.94
Worse housing	13	2.7 (2.7)		7.9 (6.3)		2.2 (1.1)	
Better housing	22	10.7 (26.9)		62.1 (171.6)		2.9 (3.8)	
Education			0.08		0.05		0.03
Elementary education	14	2 (2.4)		7.8 (7.5)		1.7 (0.8)	
Vocational education	9	22.3 (40)		137.2 (257.3)		4.8 (5.2)	
Secondary school and higher education	4	0.9 (1.2)		1.9 (2.1)		1 (0.7)	

men and women in Pilsen. Therefore, we reject the **Hypothesis 3** for Prague because the relationship between activity spaces and sex categories are contrary to our expectations and we reject the **Hypothesis 3** for Pilsen because the results are not statistically significant.

Our **Hypothesis 4** linked the extent of activity spaces with differences in housing arrangements of homeless people. Homeless people without any place to stay (worse housing) are subjected to forced mobility, which in turn increases the size of their activity space. The comparison of homeless people living in worse housing and those living in better housing is significant neither in general, nor after splitting the data according to city category. We therefore reject **Hypothesis 3** altogether.

The **Hypothesis 5** assumed that the size of activity spaces of homeless people reflects their level of education. The basic comparison of groups by education suggests a positive relationship between level of education and the size of activity spaces, but the relation is not statistically significant. Further testing of the hypothesis for Prague and Pilsen separately or for different education subgroups did not provide a conclusive answer. Therefore, we reject **Hypothesis 5** altogether.

4. Discussion

This study analysed the spatial mobility of homeless men and women in two cities based on GPS tracking data and mobility interviews. This mixed method approach allowed an evidence-based understanding of the routines and patterns shaping the daily life of homeless people in unprecedented spatial and temporal detail. The paper evaluates the role of individual and contextual factors shaping the size of activity spaces of homeless people. This study advances previous research by Chan, Helfrich, et al. (2014), which relied on participatory mapping methods for formerly homeless individuals, and a feasibility study by North et al. (2017) mixing narrative interviews with GPS data on homeless mobility. Understanding the geospatial movement of the homeless population is an important input for assessing service location and service utilisation.

4.1. Activity spaces

Activity spaces are a useful tool for measuring the geo-spatial behaviour of homeless people and offer a novel insight into variables influencing spatial mobility. Firstly, the results presented in this article point to the importance of urban space and infrastructure as structuring factors of homeless mobility. The size of activity spaces of homeless people correlate positively with the size of a city. This functional relationship is not surprising, but it is striking to what degree the activity spaces of homeless people differ between Prague and Pilsen. We expected that extremely poor and socially excluded homeless populations would have limited access to the urban infrastructure and thus similarly-sized activity spaces in Prague and in Pilsen. Supporting evidence from map interviews suggests that a lack of entry barriers and a low level of oversight in public transport provide an opportunity for homeless individuals to increase their mobility. Dense and accessible public transport systems related to city size increase the size of homeless people's activity spaces and enable more frequent mobility within a particular activity space. According to the transport analysis of the same GPS data, the daily distance travelled by a typical homeless person is 3.5 km on foot and 5.1 km by public transport. The relatively large activity spaces of homeless people in our study suggest that transport-related exclusion is weak in Czech cities in comparison to countries with limited public transport (Chan, Helfrich, et al., 2014, Townley et al., 2016).

Secondly, the results show that in large cities homeless women have different geospatial behaviour than homeless men. Contrary to the victimisation literature, the size of the activity space of women is larger than that of men. Structural factors conditioned by city size indirectly influence the size of activity spaces of men and women. In Prague, the rising number of homeless women has led to the development of supporting infrastructure focused specifically on women. According to map interviews, activities of NGOs focused on women provide support for and enable networking of homeless women. In contrast, there are very limited opportunities and support for homeless women in Pilsen. The size of activity spaces of homeless women in contrast to homeless men are thus driven by the supporting infrastructure and networking opportunities in a particular city.

Thirdly, the analysis of activity spaces rather surprisingly did not find any significant differences between homeless people living in better housing situations and those living in worse housing situations. Higher values of trajectory-based measures suggest higher mobility of homeless people in worse housing situations; however, this is not translated into the size of activity space derived from point-based measures. Detailed analysis of data (Figure not shown here) indicates that the relation between housing situation and spatial mobility is U-shaped. People sleeping rough have large activity spaces, the activity spaces tend to diminish when they are accommodated in homeless shelters, and increase with a move to more regular types of housing. The result of our study are thus in agreement with the contemporary Housing First Approach (Busch-Geertsema, 2013).

4.2. Homeless mobility and participatory mapping

This study proposes a methodological innovation for participatory mapping methodology. Previous participatory mapping studies (Chan,

Helfrich, et al., 2014; Chan, Gopal, & Helfrich, 2014; Townley et al., 2016) used map drawings of exercise by homeless people or formerly homeless people as an input for geo-computation of activity spaces. This approach collects a list of activities and place-based resources that are perceived by participants as important for their daily life, or types of location directly asked for by a researcher. Trivial mundane mobilities or risk behaviour mobilities (trespassing, petty theft) might be omitted by error or on purpose (Townley et al., 2016). In our study, we reversed this logic and first used geodata to visualise activity spaces and we then conducted interviews aimed at explaining daily mobilities. Thus, our study does not rely only on respondents' memory and ability to capture nuances of past geospatial behaviours. This approach allows us to gain new insight into mobilities of homeless people who otherwise might not be able or willing to provide drawings of their neighbourhood or list all the places of their daily use (e.g. people with psychiatric disorders, drug and alcohol users).

Further, this study provides practical feedback on participatory mapping methodology enabled by the use of extensive weeklong measurement and by the use of three different measures of activity spaces. Firstly, week-long measurements mitigate possible biases related to selective daily mobility (Chaix et al., 2013). The diversity between individual days of mobility of homeless people is striking, so studies based on just one-day mobility might be biased. Secondly, utilisation of multiple activity space measures (Zenk et al., 2011) reduces possible pitfalls stemming directly from measurement tools. The SDE measure, as used by Townley et al. (2016) or Chan, Helfrich, et al. (2014), is mostly consistent with the MCP measure, but it does not always provide the same results as the DPA measure. For example, the young, middle-aged and old homeless groups in Prague (Table 3) provide rather different p-values measuring between-group differences. The inconsistency between measures suggests that SDE or MCP measures of activity spaces might not be sensitive to certain aspects of mobility of homeless people. Both the young and the old homeless move more often than the middle-aged group (high SDE and MCP), but they do so in a smaller territory (low DPA). The point-based (SDE, MCP) and trajectory-based (DPA) measures should be combined in order to properly understand activity spaces of homeless people. This finding has further validity for health studies measuring environmental exposure (Sherman et al., 2005) as they share methodological tools and overlap in studied populations.

5. Conclusion

The study offers a novel insight into factors shaping the geospatial behaviour of homeless men and women. There are differences in homeless mobility which cannot be explained only by individual factors. Differences in urban context driven by transport infrastructure and services provision also shape the extent of homeless mobility. In particular, the size of activity spaces of homeless people is strongly related to the size of the city. The effect of age and of gender on the size of activity spaces was confirmed in the large city of Prague but not in the small city of Pilsen. Middle-aged homeless individuals have larger activity spaces than young and old homeless people. Homeless women have larger activity spaces than men. The effect of housing condition and of education on the size of activity spaces was not confirmed at all. The basic data about the size of activity spaces of homeless people provide important information about the conditions of homelessness in Czechia. The incorporation of GPS tracking survey into participatory mapping of homeless mobility opens radically new opportunities for research into homelessness. The combination of objective GPS data with qualitative explanation of mobility creates new input for evidence-based policy. Furthermore, GPS based measures are directly comparable across cities and countries, therefore they can be utilised for comparative studies of contextual factors shaping homelessness (e.g. access to public transport). The analysis was made possible by the ubiquitous acceptance of location technologies and their widespread expansion in daily life.

From a methodological perspective, the study demonstrated the feasibility of incorporating a GPS tracking study into participatory mapping of homeless life. In contrast with previous studies of homeless populations, knowledge of geospatial behaviour is very detailed and does not rely on respondents' memory and their ability to draw mental maps. The collection of GPS data allowed a unique comparative analysis of homelessness in two cities. The methodology of activity space measurement is readily transferable and allows us to measure activity spaces of homeless people elsewhere in the world. There are probably large differences in the mobility of the homeless in different urban and national contexts. Such comparisons would make it possible to assess the role of urban infrastructure enabling / constraining mobility such as public transport density. The participatory mapping method combining GPS and the map interview can be applied in other research areas such as in health studies, where detailed information about spatial mobility is required.

From a policy perspective, the study pointed to individual and contextual factors shaping activity spaces of homeless people which can inform urban planning and health and social care provision. Detailed knowledge of the use of urban space by homeless men and women has great potential to be combined with eligibility and acceptance analysis of service provision in particular settings. Thus, spatial mismatch between service provision and target populations can be avoided. Homeless populations are very diverse and detailed insight into the geospatial behaviour of individuals provides supporting information for assessment of their needs.

The large database of GPS-based homeless mobility behaviour linked with narrative information from interviews over the maps of daily mobility is important also from a theoretical point of view. It combines an extensive amount of detailed data and thus offers an opportunity to answer further research questions beyond the narrow focus of this article. The application of new technologies in urban research allows us to revisit previous findings and can provide a new impetus for public policy.

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