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Mobilities and commons unseen: spatial mobility in homeless people explored through the analysis of GPS tracking data

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Abstract The aim of this study was to examine the spatial mobility of homeless people in urban areas, exploring homeless mobility, its drivers, limits and links to personal attributes, and whether there is an association between the extent of spatial activity and an individual's housing situation. To our knowledge, there has been no prior exhaustive attempt to explore the spatial mobility of homeless people using Global Positioning System (GPS) location devices. The theoretical background of the research was based on time-geography approaches. The research used a mixed method approach involving participatory GPS mapping. Spatial mobility was measured by GPS location devices. GPS tracking made it possible to capture the precise location of a person in time and space, and subsequently to identify the daily and weekly mobility rhythms of such people. The GPS data were further contextualised by conducting interviews with homeless people and asking about their daily mobility. The groundwork for the interviews resulted in printed maps of the participants' daily spatial mobility (n = 598). The combination of time-location data and ethnographic methods presented several technical and organisational difficulties, but the pilot study provided valuable knowledge about the everyday-life mobility of homeless people in cities. A novel understanding of the links between homeless mobilities, urban commons and the life conditions of homeless people can inform current welfare policies relating to the poor.

Keywords Mobility · Homelessness · GPS tracking · Mixed-methods · Gender · Commons

Introduction

Homelessness is a global phenomenon, challenging contemporary urban societies all over the world. The emergence of new homeless populations (Minnery and Greenhalgh 2007), the commonality of housing crises (Takahashi 1996), the deinstitutionalisation of care (Zlotnick et al. 2013), disease prevention (Beijer et al. 2012), and the spread of punitive policies (Johnsen and Fitzpatrick 2010; O'Sullivan 2012) have created a strong demand for a better understanding of current homelessness as a prerequisite for better public policy (Busch-Geertsema 2015; COST Action 15218 2016; Šimon et al. 2019). The body of homelessness research is increasing (DeVerteuil et al. 2009) and covers many aspects of homeless life, including less expected topics, such as leisure (Hodgetts and Stolte 2016) and digital communication (Reitzes et al. 2016). However, surprisingly little is known about the spatial mobility

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of homeless people (Rollinson 1998; Wolch and Rowe 1992). There is a lack of communication between research on the social condition of homelessness (located mainly in social work and social policy) and that on homeless transport and mobility (located mainly in geography and the sociology of mobility). Although there have been attempts to rethink the politics of mobility and to include more just mobilities (potentially including homeless people) through commoning practices (Cook and Butz 2019; Freudendal-Pedersen 2015; Nikolaeva et al. 2019), these accounts mostly stay within the mainstream frameworks of transport modality and lowcarbon mobility. Furthermore, the dynamics between the mobility patterns of homeless people and the policies and service provision (or urban commons in general) that shape homeless life have not been scrutinised together in empirical research (Murphy 2019).

Measuring the mobility of homeless people is critical for understanding the influence of daily paths and routines in homeless coping strategies. In this time-geography framework, human activities are spatially and temporarily limited (termed the space–time 'prism'). Activities can occur only at specific locations and for limited time periods. Thus, dissecting particular time–space activities help us understand constrains, capabilities, and mobility trade-offs in human spatial behaviour (Ellegård 2018; Hägerstrand 1970; Miller 2005). Furthermore, it helps us to understand the impact policies have on homeless lives, as mobility patterns can be the direct products of, or adaptations to, policies and services. Particular mobility practices and routines are largely unknown, despite their importance to the survival of homeless people. The ubiquitous presence and uniformity of Global Positioning System (GPS) satellite signal coverage makes it feasible for replicating and comparing results across different urban, institutional and cultural settings.

The city of Odense (Denmark) carried out a pilot GPS tracking study aimed at obtaining improved evidence for marginalised people's preferences and habits (Busch-Geertsema 2015). This first GPS tracking study of homeless people received broad media attention worldwide (O'Sullivan 2014). The Odense pilot study aroused a lot of controversy, but it nevertheless demonstrated the usefulness and helpfulness of the new insights it revealed in homeless mobility for the purposes of public policy and the location of services. The Odense study set a path for follow-up studies of spatial homeless mobility.

This paper employs a time-geography framework to examine the basic factors affecting the spatial mobility of homeless men and women. It presents the methods and results of a participatory GPS mapping study of a large sample of homeless people from two cities in Czechia. First, we developed a process for sample recruitment and the methods for data collection. Second, we describe the results of the participatory GPS mapping, with regard to gender, city and housing status. Homeless mobility has so far been treated as a qualitative travel experience, but it has not been analysed using computational tools and measures, enabled by GPS tracking data. In our analysis, we use the geographic mobility of individuals, as measured by the extent and quality their of spatial mobility. As a proxy for personal resources. In a similar vein, we use the current housing situation of homeless people as a measure of wellbeing, and we test how it affects the spatial activity of homeless people. This approach was inspired by older-age health studies, which have explored the causal links between daily mobility and quality of life (Chaix et al. 2013; Hirsch et al. 2014; Rainham et al. 2010). Third, we summarise the article and discuss the implications for public policy and the provision of urban commons. Homeless research and policy reflects tense power relations between non-governmental organisations (NGOs), policy-makers, politics, the public and the vulnerable population (Farrugia and Gerrard 2016; Marquardt 2016).

Researching homelessness and mobility

Homelessness has been connected with mobility or movement in the popular and legislative imagination for centuries (May 2000). The first to think of homelessness in terms of mobility was Nels Anderson, a member of the Chicago School. In his book, *The Hobo*, Anderson (1923) distinguished between 'hobos', 'tramps' and 'bums' according to the dimensions of work and mobility. Later, Spradley (1970) captured the perceived spatial fluidity and versatility of homeless life by an analysis of heavily-drinking homeless people in Seattle. He described homeless people as urban nomads, separated from mainstream society, who ritually follow a specific culture and way of behaving. Recently, scholars have started to study mobility as a specific tactic used by homeless people to

deal with punitive policies (Wright 1997). Homeless people are forced into constant motion because they have nowhere to go; they are in a condition of permanent 'placelessness' (Kawash 1998) or are 'fixed in mobility' (Jackson 2012). Managing mobility became a tactic for homeless people to deal with systematic expulsion from urban spaces (Robinson 2017). In general, studies of the homeless have used the terms 'mobility' or 'movement' as metaphors and have not carried out an analysis of time–space mobility using GIS. Homeless mobilities have neither been theorised nor substantially empirically investigated.

The spatial accessibility to services, resources and social support plays a crucial role in coping strategies and the health of homeless people (Hall and Smith 2013; Wolch et al. 1993). Exclusion from mobile and immobile private spaces (high time-geography constrains) and limited means to overcome these distances and barriers (low time-geography capabilities) limits the possible extent of individual activity space. The declining accessibility to support leads to increasing risk in the daily lives of homeless people, and further exacerbates the adverse circumstances they face. However, knowledge about the spatial mobility of the homeless population is sporadic and fragmented (Murphy 2019). According to Bretherton (2017), our definitions, methodologies and conceptualisation of homelessness have been developed to capture lone adult male homeless. Women not only move differently in heavily-gendered urban space (Casey et al. 2008), but, more critically, they tend to rely on informal support strategies instead of street services for the homeless (Bretherton 2017). The gender imbalance in homelessness research is hard to address when using of convenience sampling in qualitative research (usually missing the non-users of shelter services) or point-in-time censuses in quantitative research (usually missing women; Mostowska 2019).

A common approach to studying homeless mobility behaviour is through participant observation (Bourlessas 2018; Rollinson 1998) or other ethnographic methods (Bukowski and Buetow 2011; Hoolachan 2016), which focus on understanding the experience of mobility. Similarly, the interactions between homeless mobility and institutional settings or transportation policy are understood based on interview data (DeVerteuil 2003) or focus groups (Jocoy and Del Casino 2010). Only recently have new analytical options revived an interest in the spatial mobility of homeless people. So far, studies using GPS to track the spatial movements of the homeless population are rare (Šimon et al. 2019; for contrast see DeVerteuil et al. 2009; Murphy 2019), and the potential for new data (Helbich 2018; Kwan et al. 2018) has not been exploited. Nevertheless, similar GPS studies have focused on marginalised groups, such as specific sex groups (Duncan et al. 2016) or drug users (Martinez et al. 2014).

To the best of our knowledge, there have only been two previous studies using GPS tracking to gain insights into the spatial mobility of homeless persons prior this article and directly related article by Šimon et al. (2019). A recent systematic review of the English-language transport and homelessness literature identified only 13 studies dealing explicitly with the topic word-wide (Murphy 2019), but only one study used GPS data. First, North et al. (2017) presented a pilot study measuring homeless mobility for a day. The study combined GPS with narrative interviews and urine sample collection to demonstrate the feasibility of tracking the homeless population's spatial mobility in health research. North et al. (2017) pointed out wide discrepancies between the GPS-measured data and self-reported travel distances, which highlights the need to collect 'objective' GPS data[1] to actually measure and understand the geospatial behaviour of homeless people. The findings were based on a small convenience sample, recruited at a homeless day service centre in Dallas (TX, USA). Second, the municipal council in Odense experimented with GPS tracking in order to understand the needs of socially-marginalised persons (Busch-Geertsema 2015). They collected two consecutive measurements of a small sample of homeless people over a week-long period. The GPS data were used for policy purposes only, for the optimisation of the location of service provision and a modification of its opening hours, in particular.

Methods and data

The daily mobility of homeless people analysed in this article is based on GPS location data. Participants in the study (n = 80) collected their unique space–time paths for a week via wearable GPS devices.

[1] Obviously, this numerical data is also socially constructed and its seeming objectivity is therefore only relative. To highlight this issue, we placed the word 'objective' in quotation marks.

Subsequently, they described and explained this mobility, visualised on printed maps showing their daily spatial trajectories. This mixed-method approach was designed to validate the spatial data and to enrich them with contextual information. As a result, an interactive geodatabase, allowing a deeper insight into homeless mobility, was assembled. Altogether, almost 600 daily trajectories were collected and analysed for this study.

New methods

For our study, we used the terminology of time-geography (Hägerstrand 1982) to describe the daily and weekly mobility of homeless persons. Wolch et al. (1993) were the first to explore this research direction; however, it was not replicated elsewhere for many years, probably because it was undertaken prior to GPS technology being made available for public use by the US Clinton administration, and before technological innovation achieved small, wearable GPS devices. The concepts and tools provided by time-geography are critically important in the analysis of mobility data, with the location of, and access to, resources being central to the survival strategies of homeless people. However, time–space diaries or retrospective interviews place high demands on such respondents, and require them to use discipline in reporting. These requirements are difficult to apply in the study of a vulnerable population, such as the homeless, for three reasons. Firstly, and most importantly, homeless people are exposed to a high amount of stress. It is hard to keep a time–space diary when you are hungry, cold and tired; you have more urgent needs and priorities. Secondly, according to our experience many activities homeless people undertake are not driven by the time on a clock, and consequently the reporting itself and the practical organisation of the research is demanding. Thirdly, the homeless population has a greater prevalence of psychological disorders and substance use, which has an impact on memory recollection. The collected data thus do not cover the entirety of the spatial mobility due to the selective memories of, or mistakes made by, the participants.

Recently, traditional time-geography methods have been supplemented by cell phone location data or GPS tracking data (Shoval and Ahas 2016), along with a proliferation of new communication technologies in all areas of life. New methods are able to capture large volumes of data in real time, but this inevitably poses a serious threat to the respondents' privacy, security and ethics (Taylor 2016). The discussion about conflicts between personal data protection and the practical application of spatially-explicit data is still unfolding (Hartter et al. 2013) and it is leading to controversy and litigation (Propen 2005). In contrast to conventional self-reported time–space diaries or retrospective interviews, time–space activity collection by GPS tracking has higher spatial and temporal resolution, allows continuous tracking and has proved to have a low reporting demand on the participants. Many studies in the health sciences have applied a combination of GPS with other wearable measuring devices, such as accelerometers or cameras, to capture physical mobilities, modes of transport, and environmental exposure (Chaix et al. 2013).

A little controversy arose when we explained our research plan to the local service providers for homeless people. People are generally not aware of how tracking technologies works in any detail, or what can be learned from an analysis of the data. This despite the fact that tracking technologies are literally omnipresent in everyday life, via phones, cars or wearable sensors (Sano et al. 2018). The local service providers enquired about the necessity to use this method, compared to the usual narrative interviews, and worried about the possible criminalisation of the homeless stemming from, for example, any trespassing captured by the GPS data. Firstly, we explained that GPS participatory mapping is data driven (not narrative driven), and provided a quantifiable account of homeless daily life. We explained that all the research participants would receive explicit information about the purpose and value of the research, how we intended to obtain the data, and how they could leave the study at any time (Ensign 2003). They would sign an informed consent form and we would not share their data beyond the specific purposes of the research project, either with the authorities or with social work NGOs. We told them our research was guided by the ethical codex of the Czech Association for Social Anthropology (2019), according to which the researcher must do the maximum to minimalise the risk of potential participant injury. Secondly, the issue of the possible criminalisation of homeless people is relevant; however, it was not explicitly related to the methods or data used in our

research. The police, law-makers or city officials can criminalise homelessness based on their own initiatives or data, as indicated by examples from many countries (Robinson 2017; Udvarhelyi 2014). For example, homelessness was illegal in Czechoslovakia before 1989, and the Orbán government made homelessness practically illegal in Hungary in 2018 (Noack 2018).

Sample recruitment and management

The strategy of recruitment for the GPS participatory mapping study was to collect a diverse sample of homeless people with respect to age and housing condition. We decided not to limit ourselves to the so-called visible homeless, to individuals without shelter or dwelling, or to the regular clients of homelessness services. In accordance with Rossi (1989), we understand homelessness to be a broad and dynamic phenomenon. To us, the homeless people who inhabit public spaces are only the visible top of the pyramid of urban poverty and marginalisation. Our sample included people from the street, from institutions, and from commercial hostels. An overwhelming majority of them complied with the criteria of Europe's ETHOS typology (Amore et al. 2011); that is, they were persons: (1) without shelter (living on the street); (2) without an apartment (living or staying in institutions); (3) in precarious housing (staying in garden sheds, etc.); or (4) living in inadequate housing (staying in mobile homes, etc.). However, the sample also included a few individuals who were doubling up, sleeping in friends' apartments. What all the respondents had in common were certain social activities and ties, and unstable/precarious forms of dwelling. The diversity-driven structure of the sample was expected to balance out the outliers in the data, and thus improve the reliability of the findings. According to our research plan, we recruited similarly large samples in both Prague and Pilsen. We also attempted to capture the gendered nature of homelessness by including similar numbers of men and women in our sample by overrepresenting women. We did not set any physical disability criteria for our sample selection. The role of physical ability/dis-ability is pivotal to the possibility of mobility and experiences of it; however, the people with physical disabilities are covered by Czech welfare and health laws, and thus they are rarely homeless. All participants were informed about the research plan, and all signed an informed consent form enabling their research participation.

The recruitment process itself utilised several methods for making contacts with homeless people, which were mutually supportive. Firstly, the participatory GPS mapping study was part of a broader homelessness research project, so we were able to build on contacts established through prior phases of the research (photo voicing, ethnographic interviews). This sequence of cooperation helped to establish the trust between the research participants and the research team that was necessary to conduct the GPS tracking activity successfully. Secondly, some homeless individuals who were known to members of the project team from previous ethnographic research were approached. Thirdly, we asked study participants from the first groups to recommend homeless friends and acquaintances who might be willing to participate in the GPS study. Fourth, participants were recruited with the assistance of various local NGOs working with homeless people in places of support or on the streets. This strategy was applied more often in the case of homeless women, who were extremely difficult to reach on the street. Fifth, homeless people were recruited directly in places of support for homeless people. We approached both service users and homeless people simply hanging around. The recruitment relied on the first two options at the start of the study, while in the advanced stage of the project we increasingly recruited people witht no previous links to the research team.

The recruitment and GPS data collection was conducted in three rounds in the winter/spring months of 2016, the autumn/winter months of 2017, and the winter/spring months of 2017. Each participant was contacted at least three times during the course of the research. The first contact was during the recruitment phase, and consisted of survey instructions and device deployment. This contact was followed by a week of data measurement. The second contact was in the collection phase, when the GPS devices were returned and the first feedback was obtained. Subsequently, GPS the data were processed and converted into maps. The third contact was in the map interview phase, where the printed maps of daily mobility were discussed with each participant. The interval between the meetings was usually 1 or 2 weeks, depending on circumstances. Individual schedules were arranged

with each participant in order to adjust the research to the respondent's life situation, and to ensure smooth time–space coordination throughout the course of the research.

The participation of the homeless people in the study, and the return of the GPS devices containing location data, was ensured both by their willingness to participate and by the provision of an incentive. Motivation to be involved in research about homelessness, and to learn about their own spatial mobility, was important for the homeless people who joined the study, and this created a solid grounding for successful practical implementation. Many participants expressed an interest in helping the research about homelessness or in letting other people know about real life on the street. An inclusive and attentive approach to the individuals proved to be crucial in the recruitment process. In order to ensure the practical conduct of the study – namely returning the GPS devices—we consulted with the local homeless service providers, who had past experience of the incentives used for homeless research participants. After this consultation, we included the offer of a small cash incentive (the equivalent of €20 in Czech crowns) for participants in the project. The aim of the incentive was to balance the value of the borrowed GPS device and the willingness of the participants to keep to the terms of the verbal agreement. The incentive was due after completion of the GPS data collection and map interview, which usually took about 3 weeks. Ultimately, the return rate of the GPS devices was not an issue, and only a few devices were not returned or were lost during the study. The participants in the study reported very good GPS acceptability and ease of use, with only marginal comments relating to the carrying of the device.

Geospatial data

After successful recruitment, all participants received a GPS device and practical instructions for its use. Due to the conditions associated with homelessness, we kept the data collection process as simple as possible. We asked the participants to carry the device with them all the time for a period of one week and then return it. We instructed them to charge the device every second day, or whenever possible or suitable for them. Typically, the participants collected from six to eight days' worth of GPS measurements.

We decided to use passive tracking technology in our study. This decision is analogous to a related branch of research that use mobility data from cell-phone operators (Shoval 2008). The use of active tracking technology would have incurred an additional cost for GSM infrastructure and SIM cards, which would have significantly increased the risk of device theft. The GPS device was set to record a mobility trace every 5 min and store it in the internal memory. With this setting, the device was able to cover two days' mobility under testing circumstances. The two-day threshold is crucial for measuring homeless mobility because it covers instances when a respondent is off the grid or forgets to charge the device for a day.

The length of spatial GPS trajectories is not exact when a 5-min interval measurement is used; it approximately measures the direct distance between subsequent points of measurement. This interval of measurement does not portray the path between subsequent measurements in full detail, but it does capture all the significant places and journeys involved in homeless mobility. This minor length error probably shortened the overall length of the movement; however, the discrepancy was similar for all subjects and it did not limit within-group comparison.

Map interview

Interviews with the participants to discuss their daily and weekly mobilities were conducted as a final step in the data collection. Prior to that, the GPS data were processed, converted into maps using geographic information system software, and printed. The maps illustrated the GPS points and lines for each individual day. For easier reading, all the maps contained hourly time-stamps for the GPS points, with major features of the urban fabric in the background. The beginnins, ends and directions of the daily trajectories, as well as significant places, were highlighted on the maps for better orientation and reading. Additional maps, with focus areas magnified were provided in cases where the mobility traces were too dense. Altogether, more than 700 maps of daily mobility were created. Those mobility maps were described and explained by the participants during the interviews in order to validate and contextualise the GPS data.

The map interviews focused primarily on describing and explaining the daily paths from

the participatory GPS mapping. The interviewer went through all the maps with the homeless participant, day by day, and asked for basic descriptions of their daily stops and journeys. Follow-up questions focused on the characterisation of places visited, activities undertaken and social contacts made in places or during journeys, and the drivers and motivations of the mobility behaviour. The information from the map interviews allowed us to gain a deeper understanding of urban homeless mobility, its patterns, drivers and motivations. However, a detailed analysis of the map interviews data was beyond the scope of this article.[2]

Utility of participatory GPS mapping

The research design used here was developed to capture the mobility and fixity of homeless daily life through a technology-enabled method of GPS participatory mapping. An exhaustive measurement of time–space presence was converted into maps of daily movements. Only after that were the narrative interviews with the homeless people conducted, guided by the maps. This approach is fundamentally different from the ethnographic research used in mobility studies (Cresswell 2012; Sheller and Urry 2006). For example, a recent ethnographic account of homeless mobility by Bourlessas (2018) was based on a six-month field study that included semistructured interviews and participant observation. As such the collected data were narrative in nature, providing explanatory insights into homeless mobilities and frictions, and presented via quotes from the interviews. The researcher interacted with the research participants throughout the process, in person. In contrast, participatory GPS mapping splits the mutual interaction into a time with a researcher and a time with a thing—the GPS tracker. There is less emotional labour and attachment involved in the personal interactions because these are relatively brief, in contrast to month's long, day-by-day schedule of participant observation. We assume that this setting put less pressure on the homeless people participating in the research to perform their mobility behaviours in certain ways. Humans are creatures of habit and they are likely to move as usual when not supervised by a researcher. A second contrast lay in the possible quantification and statistical elaboration of the participatory GPS mapping data (Šimon et al. 2019). Research of this nature is extremely rare due to a lack of data. The field of Geographic Information Science / time-geography provides a plethora of well-established tools and methods, which enable the testing of quantitative hypotheses relating to homeless. For example, it can compute how often various groups of homeless people visit local Salvation Army premises, and how distance from their sleeping location affects their frequency of service use. Similarly, it can be determined how stable the sleeping locations of homeless people are through time, thus providing a good estimate of the accuracy of a point-in-time homeless people census. Such results have the potential to be highly valuable for social and welfare provision.

Area under study

The empirical research was conducted in two large Czech cities. The capital city of Prague is the largest city in Czechia, with a population of approximately 1.3 million inhabitants. Pilsen is a regional capital in the West Bohemia region with a population of 200,000 inhabitants. Recent homeless counts reported approximately 4000 homeless people in Prague and approximately 300 in Pilsen (Šnajdrová and Holpuch 2010; Váně and Kalvas 2014). The percentage of males among the homeless is 80 per cent in Prague and 65 per cent in Pilsen. It is estimated that about 10,000 people in Prague and 2000 people in Pilsen are at risk of becoming homeless (Ministry of Labour and Social Affairs 2015).

Both cities 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 that completely cover their metropolitan regions. Public transport is co-funded by municipal budgets, the fares are cheap, and it is used by a majority of the urban population (1,600,000 passenger rides per day in Prague). Access to public transport is open, with no turnstiles or ID-based entry to the vehicles. Therefore, we can consider the public transport infrastructure in terms of important urban commons. The key differences between Prague and Pilsen, such as the number of homeless people or services for the homeless, stem

[2] The map interviews will be analysed in detail in a separate article, that will complement this one.

from the different sizes of the cities. Both cities are roughly similar from a policy perspective. Punitive policies, in the sense of revanchist urbanism (MacLeod 2002; Mitchell 2003; Smith 1996), are focused on the expulsion of homeless people from tourist sites and glossy public spaces. Although these punitive policies exist, Temelová et al. (2017) pointed out that they are largely unsustainable and inefficient. Support policies are heavily driven by the 'not-in-my-back-yard' effect. Places of support for homeless people tend to be located on borders between city district, so that both city districts halls can claim service coverage for their territory. Places of support for homeless people tend to be located in marginal spaces close to the transport infrastructure, or even on board a boat, but still in central parts of the cities.

Results

The spatial mobility of homeless people was examined through a combination of two kinds of data—sociodemographic indicators and GPS-based mobility indicators. Firstly, key mobility differences were examined with respect to gender, city and housing status. Although men and women face different challenges when homeless, it is not clear how exactly their spatial mobility is shaped by their gender. The discourse on women's homelessness is scarcely supported by data, and the issue of mobility is often perceived only through the literature connecting women's homelessness with domestic violence. Similarly, comparative studies of homelessness across cities, with different urban contexts and different urban commons, are exceptional. Cities of different sizes provide different opportunities and constraints for their inhabitants, and therefore city size is an important factor in homeless mobility. It is generally known that larger cities have larger homeless populations; however, the effect of city size on the extent and structure of homeless mobilities remains unexplored. Secondly, the volume of mobility, which is the extent of walking and riding combined, is measured by the length of a daily trajectory. The indicator measures a straight line between all subsequent GPS points within a 1-day period. Our assumption was that the volume of mobility is a proxy for personal resources, reflecting the jointly physical abilities of a person and their access to advanced means of transport. Public transport is used daily, or almost daily, by 70 per cent of the homeless; however, 80 per cent usually did not pay a fare (2016 survey in Prague and Pilsen). The more mobile a person is, the more opportunities that person can access. Thirdly, the quality of mobility is measured by the average speed indicator and the cumulative average speed indicator. The value of average speed measures the access to advanced (faster) means of transport, which can boost and speed up the mobility-related tasks of a homeless person. The cumulative average speed indicator is computed as the sum of average speed values for every half-hour during a full day. The value of the cumulative average speed indicator shows the frequency of use of advanced transportation means; that is, how important a role advanced transport plays in the daily life of a homeless individual.

Sample characteristics

Table 1 shows the basic gender, age, education and housing structure of the study sample. Women were purposefully overrepresented in our sample, in order to be able to discern gender differences statistically. The middle-aged group dominated the age structure of our sample and approximately reflects the age structure of the homeless population in the country. The education levels of the homeless are generally low. The subsamples from Prague and Pilsen were balanced from the age and gender perspectives, with slightly higher education levels in Prague and a similar structure of the housing situation in both cities.

The housing conditions of homeless people are temporally and spatially unstable, and reflect the diversity in living conditions, as well as individual habits and routines. The participatory GPS mapping study provided a deeper insight into how a particular housing situation can shape the mobility of homeless people, and how fluid/stable the particular housing situations of homeless individuals are. For the purpose of an international comparison of homelessness, the European Federation of National Organisations Working with the Homeless developed the European Typology on Homelessness and Housing Exclusion (Amore et al. 2011). The ETHOS typology distinguishes between rooflessness, houselessness, living in insecure housing, and living in inadequate housing.

In our study, the housing conditions of homeless people were initially coded into seven categories

Table 1 Sample structure according to city

Variable	Full sample (n = 80)	Prague (n = 45)	Pilsen (n = 35)
Gender (male/female)	42/38	24/21	18/17
Age group (%)			
Age 0–30	13.3	15	11.4
Age 31–55	53.3	52.5	54.3
Age 55+	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	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]See Table 2

[b]Ibid

Table 2 Housing conditions of the study sample

	Housing condition (n = 80)	Number of participants
Poorer housing condition (n = 30)	1 On the street (under the bridge, in the park, on a bench)	7
	2 Colony (in a tent, in the woods)	11
	3 Squat (in buildings, garages or cabins)	11
Better housing condition (n = 50)	4 Institutions (homeless shelter, sanctuary)	32
	5 Hostel (all types)	10
	6 Doubling (all types)	3
	7 Conventional housing	6

(Table 2), extending the ETHOS typology. Due to the small number of records in the individual categories, we reclassified the data into two main categories. First, housing categories 1–3, denoting the most disadvantaged forms of housing, were merged into the 'poorer' housing category. Second, housing categories 4 to 7, denoting less disadvantaged forms of housing, were merged under the 'better' housing category.

Figure 1 shows the volume of mobility for each day and each homeless person, dividedt by city, gender and housing category. The illustration provides an insight into the absolute values of mobility and into the variance in the volume of mobility between individual days. The data shows key differences in homeless spatial mobility, and extends our knowledge about the spatial behaviour of homeless men and women. Firstly, there is a clear distinction in the volume of mobility between the large capital city of Prague and the small regional city of Pilsen. The mobility of homeless people in Pilsen only rarely goes

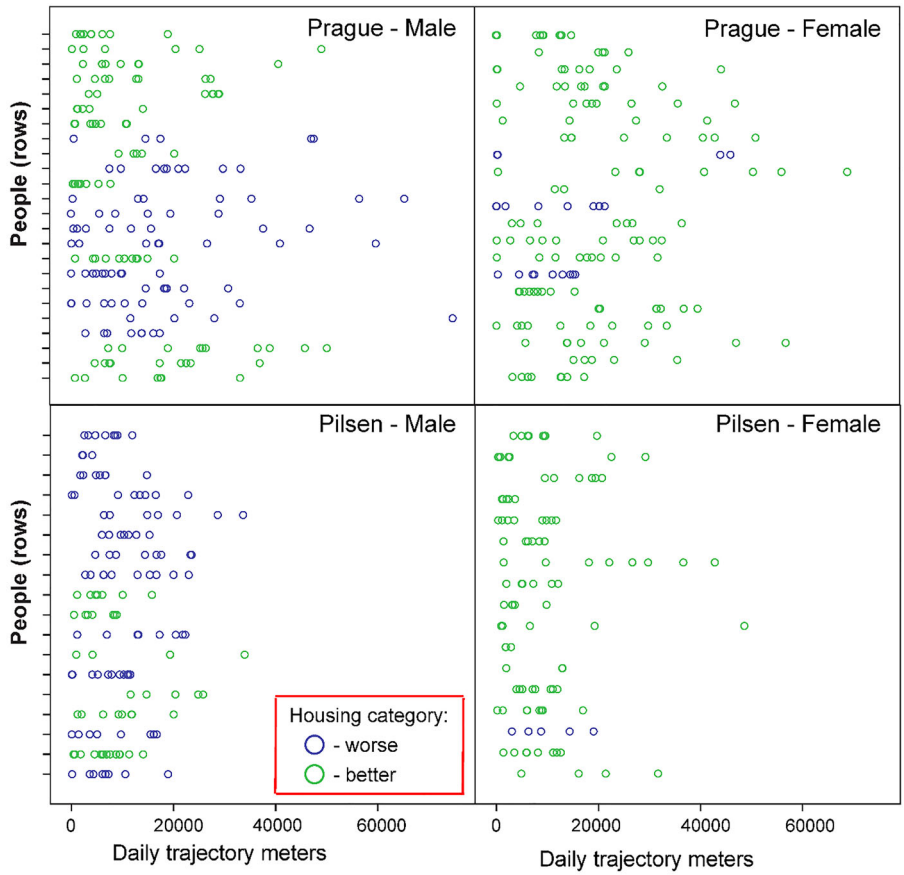

Fig. 1 Volume and variability in daily trajectories of homeless people. Note: Rare cases of mobility beyond 60 kilometres are excluded from the figures in order to improve visual readability

beyond twenty kilometres per day, whereas homeless people in Prague regularly exceed this distance. In general, the daily trajectories up to 10 kilometres per day are probably based on walking only. Mobilities beyond this, and certainly beyond 20 km per day, are enabled by the use of public transport. Car ownership or car use is extremely rare among homeless people in Europe, and therefore auto-mobility does not play any role in homeless spatial behaviour. The multiplicity of sources of support, greater distances between places, and the greater density of public transport lines associated with a large city increase the length of the daily trajectories of homeless people. Secondly, there are notable gender differences in the volumes of spatial mobility. Women have slightly longer daily trajectories than men. This finding seems rather surprising, since males are generally perceived as being more mobile due to their more common presence in public spaces. This is due to a psychological phenomenon called the 'mere-exposure effect', in which people tend to develop a preferences based on familiarity (Zajonc 1968). Similarly, females are perceived as being less mobile as they are less visible to the public. This account is further accentuated in the domestic violence/female homelessness literature, where victimised women tend to restrict their mobility and presence in public spaces (Casey et al. 2008; Huey and Berndt 2008). This common belief is clearly dispelled by the GPS data. Qualitative research (Casey et al. 2008) and the quantitative analysis of our GPS data confirm differences in spatial mobility between men and women, but these differences do not directly translate into volumes of spatial mobility. Thirdly, the housing conditions of homeless people clearly shape the volume of spatial mobility. People with better housing conditions have longer daily trajectories than those with poorer housing conditions. The access to better housing options is driven by the

economic situation of homeless people. Therefore, individuals in a better economic situation will probably have better access to the main facilitator of spatial mobility—public transport. The economy-driven relationship between housing condition and volume of mobility is probably not straightforward. In an extremely poor population, such as the homeless, their limited resources might be sufficient for just one of these two spending options. Access to a better category of housing might effectively block access to advanced mobility options, and vice versa.

A statistical breakdown of daily mobility volumes into city, gender and housing category is provided in Table 3. The data shows median values for daily trajectories. Median values are less sensitive than average values to extreme values in a sample, and provide information about the most typical volumes of mobility in a particular subgroup. The multiple splits in the data show which attributes drive the differences between groups. The strongest predictor of volume of mobility is city size, with gender playing a less important role and housing status the least. However, this arrangement does not indicate a direct representation of disadvantage, nor does it uniformly translate to all subgroups. For example, men in Pilsen are typically more mobile than women, whereas men in Prague are less mobile than women. Housing conditions shape volumes of spatial mobility more markedly for men than for women. This is logical, because homeless men tend to have a wider variety of housing conditions than do homeless women. Additionally, the correlation between housing condition and volume of daily mobility is the reverse for men and women. Whereas women in better housing have longer daily trajectories than women in worse housing, men in better housing have shorter daily trajectories than men in worse housing. This result suggests that a part of the homeless mobility that correlates with poorer housing conditions is forced mobility. With improved housing conditions, the share of forced mobility decreases markedly. In Prague, the volume of mobility decreases from better to worse housing for men, but increases for women. In Pilsen, the volume of mobility decreases from better to worse housing for both men and women. These results call into question an oversimplified conception of homeless mobility as being measured by the simple length of a daily trajectory. Further indicators that can add qualitative measures of mobility are therefore required to provide an in-depth understanding of homeless mobility.

Table 3 Daily trajectories according to city, gender and housing condition

Length of daily trajectory (median value; in meters)	
Prague	13 942
Male	12 053
Female	15 517
Pilsen	7 858
Male	8 497
Female	7 047
Worse housing	10 072
Prague	14 717
Pilsen	8 701
Better housing	11 529
Prague	13 335
Pilsen	7 144
Male	9 787
Worse housing	11 529
Prague	15 395
Pilsen	8 701
Better housing	7 767
Prague	7 767
Pilsen	7 860
Female	11 942
Worse housing	11 942
Prague	13 585
Pilsen	7 508
Better housing	12 117
Prague	16 715
Pilsen	7 074

Indicators using recorded speed data from individual GPS points measure the quality of daily mobility. The interpretation of speed data is based on real velocities of different types of movement. A velocity of around 0 kilometres per hour indicates staying in place, while a velocity of 1–4 kilometres per hour indicates walking and 5+ kilometres per hour indicates movement by public transport. The average speed indicator measures the velocity of movement during the day, and serves as a measure of public transport use.

Figure 2 shows the link between quality of mobility and quality of housing conditions. The overall trend suggests a weak correlation between average daily speed and quality of housing situation, but the data tend to be U-shaped. The figure indicates a non-linear

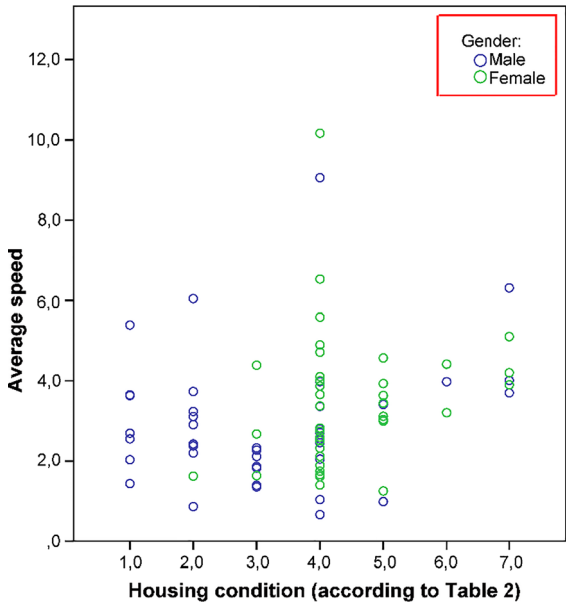

Fig. 2 Average speed of homeless mobility by gender and housing condition

relation between the variables and points to a significant role of gender difference.

A further split in the data shows that people with worse housing conditions have slightly lower mobility than those with better housing conditions in both Prague and Pilsen. People with worse housing conditions probably use public transport less; therefore, their mobility is more limited in terms of quality of movement. The mobility of homeless people with worse housing conditions is also less variable in terms of quality of movement, suggesting that a significant share of mobility is non-optional forced mobility. Homeless people with worse housing conditions have to move in order to cope with their daily life circumstances such as obtaining resources or finding a place to sleep. This pattern is consistent across different city sizes.

The first two steps of the analysis showed separately the quantitative and qualitative aspects of homeless mobility. They illustrated the links among the volume of the spatial movement of homeless people and city, gender and housing, and highlighting connections between the quality of the spatial movement of homeless people and their housing conditions. In both cases, the results indicate a link between different measures of mobility and housing conditions as a measure of disadvantage. In other words, there is a functional relationship between the social disadvantage of homeless people and their spatial mobility. For a complex measurement of homeless mobility, we combined the previous volume of movement indicator with a new advanced indicator of movement quality. The cumulative average speed indicator measures the commonality of rapid movement during the day. In practical terms, the indicator measures the frequency and length of public transport use as expressed via speed averaged over 30-minute periods for one day. The indicator is a sum of all partial values of average speed. Higher values of the indicator demonstrate the rising importance of public transport in everyday situations and the overall higher mobility of a homeless person.

Figure 3 provides comprehensive information on how housing conditions influence the mobility behaviour of homeless people. Our initial thesis expected that the geographic mobility of individuals, as measured by volume and quality of movement, is in fact a proxy for personal resources. Figure 3 clearly indicates that the particular housing situation of homeless people is reflected in the volume and quality of their spatial movement. People with better housing situations have higher values of average daily path trajectory, meaning they can access more places of opportunity to enable their survival strategy than can people in worse housing situations. People with better housing situations can also access places of opportunity more easily due to their higher average speed of movement than can people with worse housing situations. The data for the two groups overlap to a certain extent, but the data provides clear evidence that the particular housing conditions of homeless people shapes the volume and quality of their spatial movement.

Access to better housing improves mobility measures and thus improves the life opportunities of homeless people. This finding affects men and women disproportionately, as shown in the disaggregation of the mobility results into gendered housing categories (Fig. 3). The regression lines show that women with worse housing are the most disadvantaged in terms of mobility. On the other hand, women with better housing are the least disadvantaged in terms of mobility. The results for men are similar in direction, but differ in the intensity of the difference. Housing condition plays a much more important role for women than for men. The GPS data confirm previous

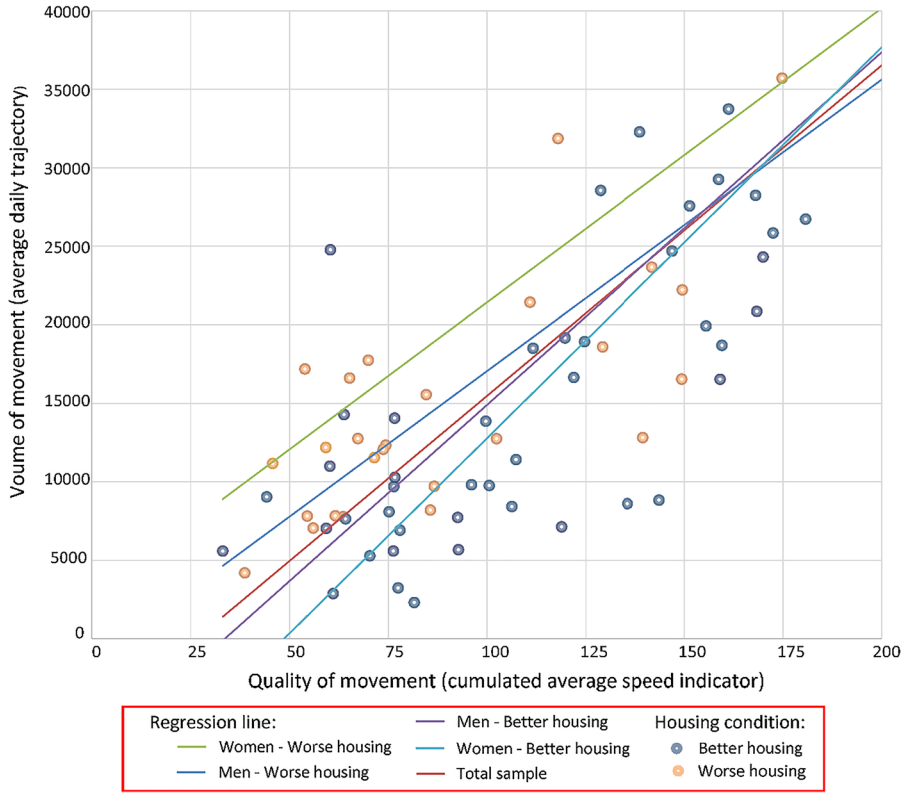

Fig. 3 Housing conditions: Volume and quality of homeless mobility

knowledge about gender differences in the challenges faced by homeless men and women (Casey et al. 2008). With a hypothetical shift from better to worse housing conditions, women face a greater deterioration in their mobility than men. This finding is consistent with the body of knowledge that highlights the lower number of homeless women in general and the lower number of homeless women in worse housing conditions in particular (COST Action 15218, 2016). For homeless men the difference in mobility between worse and better housing conditions is smaller. Particular housing conditions are more similar for homeless men, so shifts between individual housing categories are less constraining for them.

The quantitative approach to homeless mobility is new and exploratory, so it is open to criticism and improvement. The results are based on the premise that the geographic mobility of individuals is a proxy for personal resources when both the volume and quality of movement are included as measures. The results shows that this premise is useful for analysing homeless mobility, but caution is needed with respect to the key circumstances shaping homelessness such as gender or city size. The findings describe connections between measures of spatial mobility and particular housing conditions as a measure of wellbeing. Nevertheless the data are not able to discern how exactly these connections work, although we can reasonably assume that a change in housing situation would likely be translated into a change in geographical mobility and vice versa. These conclusions are consistent with the qualitative part (not elaborated in detail in this article) of our GPS participatory mapping study.

Discussion and conclusions

This article sheds light on the mobility of homeless people and on the key role of public transport infrastructure as urban commons for homeless people. The pilot study demonstrated that participatory GPS mapping is feasible and acceptable in the homeless population. The research was conducted with a special sensitivity to the rights, beliefs, and cultural context of the researched individuals as required by ethical

principles and the valid code of conduct. The research methodology combined GPS tracking with interviews that describe detailed daily mobility with the help of tailor-made maps. This mixed methodology enabled the collection of a large and detailed dataset of homeless spatial trajectories, and a discussion of the role of gender, housing, and urban context on the extent and quality of spatial mobility. The complete data enable further evidence-based enquiries into homeless life, which are beyond the remit of this article.

The spatial mobility of vulnerable or elusive populations (Agans et al. 2014) can be approached through qualitative research benefitting from methods such as participant observation, ethnography, or action research. The appropriate application of these methods requires spending considerable periods of time with the studied populations (Hoolachan 2016). Qualitative-based studies provide a solid insight into homeless mobility (Bourlessas 2018; Hall and Smith 2013), but with limited options for generalisation (intrinsic to the method and due to a qualitative literacy issues (Small 2018)). In a similar vein, large surveys of homeless populations provide point-in-time information about the presence of homeless people, but they are uninformative about their spatial mobility. Many studies have shown that retrospective recollections of spatial mobility are not reliable, even for the homed population. The use of participatory GPS mapping in research reduces the intrinsic limits of both previous methods and provides a novel insight into homeless mobility and the daily lives of the homeless. On the other hand, the use of GPS tracking poses new challenges for research. For example, GPS records point to locations or journeys that the respondents would omit or even deny in an ordinary interview or even in a communication with their peers. The knowledge of specific locations is both an asset and a power for many homeless people. Such sensitive locations/activities in locations include safe spaces, not-to-be-shared resources, and shameful or illegal activities. However, the GPS data are just bare geographic coordinates, and it is still up to the respondent to decide whether to provide information on the nature of such places and journeys in the interview or to decline to comment. GPS technology can be used to study vulnerable populations (such as mobility research on homeless people) but ethical principles and the protection of sensitive personal information have to be assured (Ensign 2003; Šimon et al. 2019).

The description of mobility based on GPS data can demonstrate the 'objective' mobility of homeless people and educate the public and policy makers. Negative stereotypes depict the (male) homeless as either lazy people hanging around in public spaces or as utility seekers moving between places of support that offer free services. Both of these negative stereotypes are clearly disproved by the GPS data. Not only are homeless people more mobile than has been assumed, but also the structures of the places they visit only partially overlap with the official places of support.

The use of GPS tracking in homelessness research is challenging on many levels, but in our project it proved useful for cognitive and educational purposes. The 'objective' data from the GPS have the potential to improve our understanding of the life circumstances of the homeless in different temporal, cultural, or institutional settings and in different countries. Comparative studies of this type can forward our understanding of homelessness. They can provide new insights how how exactly public policies, welfare infrastructure and access to public transport or other urban commons affects everyday homelessness. For example, GPS data permit an evidence-based insight into the overlap between the activity spaces of homeless people and places of support. The data can measure the regularity and rhythm of the daily mobility, which gives us information about homeless people's transport use or time-use routines. GPS-based research can inform specific policy interventions (Busch-Geertsema 2015). Finally, a better knowledge of homeless mobility patterns can also enable the evidence-based location of services and interventions for homeless people in need.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Research involving human participants and/or animals All participants were informed about the research plan and all signed an informed consent form enabling their research participation.

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