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Department of Geography

A map-based tool to measure older adults' life-space mobility:

Development, usability and evaluation

GEO 620 Master's Thesis

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Abstract

The demographics of Switzerland and other industrialized countries reveal an aging population. At the same time, research is increasingly focusing on older adults as user groups, and a trend towards incorporating the spatial sciences in health studies can be observed. Both research fields are considered in Gerontology by studying the relationships between older adults' health condition and their mobility. For measuring older adults' spatial activity, current research mostly draws on the concept of life spaces which can be "defined as the spatial extent in which a person moves within a specified period […]"(Tung et al., 2013:155). Up until now, life spaces have mostly been measured by using self-reported measures, such as diaries or questionnaires, or with sensor-based, mostly GPS tracking. Spatially-locatable data and additional semantic information, respectively, are the main advantages of self-reported and sensor-based life-space mobility assessments. However, neither of these two measurement approaches can provide both types of information. Consequently, the question arises as to how spatially-locatable and semantically-enriched data on older adults' life-space mobility can be assessed.

The aim of this thesis is to provide a new map-based tool (MBT) for older adults, as such tools offer the capability to assess both spatially-referenced data and the relevant semantic information. Based on a list of identified tool and user-oriented requirements such an MBT is developed and implemented. To evaluate this newly-developed MBT, it has been used by 58 older adults in the "MapSpace" experiment which observed participants' spatial mobility behavior for one week using the MBT, GPS and a modified version of the "University of Alabama at Birmingham (UAB) Study of Aging Life-Space Assessment" (LSA). In this thesis, the usability of MBT for older adults, and the validity of the MBT compared to GPS and LSA is evaluated.

The usability of the MBT is addressed by considering the satisfaction, effectiveness and efficiency of using the tool as proposed by ISO (1999), and further measures, such as the study of participants' technical background. The results show that older adults rated their satisfactions as poor. However, effectiveness measures indicate that participants with some technical affinity could solve the MBT. Regarding efficiency, the results highlight that GPS assessments are markedly more time-consuming than that of MBT or LSA. However, the latter remains the most time- and cost-efficient approach.

The validity of the MBT is examined by comparing different semantic and spatial life-space indicators derived from the MBT to indicators generated from the LSA and GPS, respectively. The results only partially support the validity of the MBT in comparison to the LSA. However, a high similarity seems to exist between the MBT and GPS indicators.

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List of abbreviations

ADL	Activities of Daily Living
BBox	Bounding Box
CHull	Convex Hull
CSS	Cascading Style Sheets
DSBG	Department of Sports, Exercise and Health, University of Basel
FES-I	Falls Efficacy Scale – International Version
GIS	Geographic Information System
GIScience	Geographic Information Science
GP	General Practitioner
GPS	Global Positioning System
HTML	Hypertext Markup Language
IPAQ	International Physical Activity Questionnaire
JS	JavaScript
KDE	Kernel Density Estimation
LAMP	Linux, Apache, MySQL, PHP
LSA	Life-Space Assessment
LSD	Life-Space Diary
LSQ	Life-Space Questionnaire
MBT	Map-Based Tool
MEC	Minimum Enclosing Circle
MMSE	Mini-Mental State Examination
MOT	Mode of Transport(ation)
NH	Nursing Home
NIA	U.S. National Institute of Aging
NLM	U.S. National Library of Medicine
PHP	Hypertext Preprocessor
PPGIS	Public Participation GIS

QOL	Quality of Life
RDBMS	Relational Database Management System
RQ	Research Question
SBSOD	Santa Barbara Sense of Direction Scale
SDB	Standard Deviational Box
SDD	Standard Distance Deviation
SDE	Standard Deviational Ellipse
SF-36	Short Form-36 Health Survey
SPPB	Short Physical Performance Battery
SUS	System Usability Scale
TBS	Technical Background Score
UCD	User-centered Design
UniBas	University of Basel
UZH	University of Zurich

1 Introduction

1.1 Context

The demographics of Switzerland and other industrialized countries reveal an aging population, caused by increasing life expectancy and changing migration and birthrate patterns (Berlin-Institut für Bevölkerung und Entwicklung, n.d.; Bundesamt für Statistik, 2016). Accordingly, a variety of issues associated with an aging population have been raised in the media; e.g. fiscal problems regarding the pension plan, impacts on the health system and changes in the lifestyle of older adults (NZZ, 2005; Spiegel Online, 2015; Swissinfo, 2001). At the same time, research has been focusing on older adults as user groups (Gottwald et al., 2016; Rice & Alm, 2008), and a trend towards incorporating the spatial sciences in health studies can be observed (Hirsch et al., 2014; Rainham et al., 2010). Gerontology[1] considers both research fields by studying the relationships between older adults' health condition and their mobility. For measuring older adults' spatial activity, gerontologists mostly draw on the concept of life spaces. A life space can be "defined as the spatial extent in which a person moves within a specified period [...]"(Tung et al., 2013:155). Up until now, life spaces have mostly been measured by using self-reported measures, such as diaries or questionnaires, or with sensor-based, mostly GPS tracking (May et al., 1985; Stalvey et al., 1999; Baker et al., 2003; Boyle et al., 2010; Tung et al., 2013; Hirsch et al., 2014; Rantakokko et al., 2015; Portegijs et al., 2016).

As a first example, the "University of Alabama at Birmingham (UAB) Study of Aging Life-Space Assessment" (LSA) is a self-report questionnaire which is filled out in paper form at the end of a study period and typically lasts four weeks. It measures mobility as ordinal levels of spatial areas with increasing distance from an individual's bedroom. These distances are classified into different life-space levels: the smallest level would be "moving to another room at home" and the largest level "going out of town/the country" (Baker et al., 2003). Additionally, the frequency of movement and the help needed for activities per life-space level are reported. In the end, an overall life-space score is derived, which allows detecting changes in a person's mobility and differences among several individuals, and can be correlated with people's physical and cognitive functioning (Peel et al., 2005).

[1] The scientific study of old age, the process of aging, and the particular problems of old people. (Oxford Dictionaries, 2017)

Questionnaires and diaries are time- and cost-efficient, and they provide semantic information concerning, e.g., functional limitations that helps in approximating the size of an individual's activity space. However, such self-report questionnaires are not spatially locatable and cannot counter the problem of recall biases, which mostly arises when cognitively-impaired people report on their past activities or movements.

A sensor-based life-space measurement approach is GPS tracking, which "[…] has recently become a more popular option for measuring neighborhood exposure and context in health studies [...]" (Hirsch et al., 2014:5). This approach is more objective, because participants do not report on their mobility themselves. The data is continuously and digitally assessed. Furthermore, spatially-explicit measures such as home location, area, perimeter and compactness of a life space, average distance from home and time away from home can be calculated (Hirsch et al., 2014; Tung et al., 2013). However, study participants need to carry around a GPS-enabled device whenever measurements are to be taken. Furthermore, GPS devices have a number of limitations such as data accuracy and data outage caused by interference from buildings or atmospheric conditions, which can affect the connection between the GPS device and satellites. Consequently, there is often very little GPS signal available indoors, which means the home location, for example, has to be estimated. Moreover, movement trajectories collected with GPS have no semantic metadata attached (Laube, 2014).

Rainham et al. (2010) stated that knowing people's movement patterns can help in understanding their health condition. As the self-reported and sensor-based life-space measurement approaches which are currently used in epidemiological research have several advantages and disadvantages, the aim of this thesis is to develop a map-based tool (MBT) to assist in determining older adults' life-space mobility. On the one hand, it should overcome the disadvantages of commonly-used approaches by reducing the burden on participants of using GPS and by providing a higher accuracy compared to questionnaires. On the other hand, the MBT aims to combine the advantages of GPS, which means that the tool should at least collect spatially-locatable data with additional semantic information. To evaluate the newly-developed MBT, it has been used by 58 older adults in the "MapSpace" experiment which observed participants' spatial mobility behavior for one week using GPS and a modified version of the LSA, as well as some complementary measures. In this thesis, the usability of MBT for older adults was evaluated. Furthermore, the measurements given by MBT were compared to that generated from GPS and LSA in order to examine the MBT's validity.

1.2 Aims of the thesis

Understanding how spatial activity and health are interrelated is a central goal of epidemiological research. Accordingly, the aim of this thesis was to provide a new tool for older adults which incorporates the advantages while overcoming the disadvantages of the commonly-used life-space measurement approaches by considering the following subgoals:

- to develop a map-based tool (MBT) for measuring older adults' life-space mobility.
- to test the usability of the tool. The tool should be easy to use so that older adults are able to use it with as little personal support as possible.
- to evaluate the tool by generating spatial and semantic life-space indicators from the collected MBT data and comparing it to measures derived from the commonly-used sensor-based and self-reported approaches.
- to discuss usability in future applications by considering the results of this thesis. Further recommendations and adaptations are suggested to ensure that the tool will be qualified for future use.

1.3 Thesis structure

Following the introduction, Chapter 2 describes the background of the thesis including relevant definitions and research on the commonly-used life-space measurement approaches, thereof identifying gaps in the research, which gives rise to the research questions. In Chapter 3, the "MapSpace" user experiment is introduced including a description of the study participants. In Chapter 4, the workflow followed in this thesis is presented. The process of developing the map-based tool based on elaborated tool and user-oriented requirements is described in Chapter 5. The usability of the tool is assessed in Chapter 6 by considering the satisfaction, effectiveness and efficiency of using the MBT and self-reported and sensor-based measurement approaches. Chapter 7 first provides an overview of the collected spatial data and identifies which semantic information could be acquired. And second, several life-space indicators are established in order to evaluate the validity of the MBT by comparing measures given by the MBT with currently-used approaches. Chapter 8 discusses the results of the preceding chapters and gives recommendations regarding future applications of the tool. Finally, Chapter 9 presents a short summary of the thesis, highlights the contributions and gives an outlook for future work.

2 Background

2.1 Definitions

This thesis combines aspects of both health and spatial sciences, and some terms have different meanings in these two research fields. As a consequence of these distinctions, several definitions are introduced in order to clarify how the following terms will be used in this thesis.

2.1.1 Mobility

Mobility is a central element of physical functioning (Satariano et al., 2012). Two major components of mobility can be distinguished, which are closely related to each other:

1. the ability to move (Satariano et al., 2012).
2. "[…] a person's purposeful movement through the environment from one place to another" (Stalvey et al., 1999:460).

In this thesis, the main usage of the term mobility is based on the second definition, a person's movement in space. Otherwise, the terms physical activity or functioning are used.

2.1.2 Life space and activity space

The term *life space* has been used in different social research fields, such as in political science and careers education (Brody & Sniderman, 1977; Super, 1980), but mainly it is used in gerontology where a life space can be "defined as the spatial extent in which a person moves within a specified period […]" (Tung et al., 2013:155).

The term *activity space* originates from the social sciences and it has been conceptualized in different research fields, such as medical geography, spatial behavior, time-space studies, planning, travel and transportation studies, and human-environment interactions (Perchoux et al., 2013; Sherman et al., 2005). An activity space can be "[…] defined as the subset of all locations within which an individual has direct contact as a result of his or her day-to-day activities" (Golledge & Stimson, 1997:279).

Both terms are used in health-related sciences and relate to a comparable concept. According to Hirsch et al. (2014:2), "[a]ctivity spaces differ from the life-space measure, in that they focus on neighborhood (out of home) behavior only, rather than mobility both within and beyond the home." The study conducted in this thesis (Chapter 3) does not examine in-home behavior. Therefore, both terms, activity space and life space, will be used equivalently throughout the thesis.

2.1.3 Usability

To examine if a system or a tool is user-friendly—i.e. it is easy to use or understand—it is necessary to evaluate its *usability* for a specific group of users. It is hardly possible to define *usability* in an absolute sense. However, one definition could be that *usability* is "a general quality of the appropriateness to a purpose" (Brooke, 1996:189). In other words, usability can be defined as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" (ISO-9241-11, 1998, In: Gottwald et al., 2016). Based on Brooke (1996), effectiveness is the ability of users to complete tasks using the system, as well as the quality of the output of those tasks. Efficiency is the level of resource consumed in performing tasks, and satisfaction is a user's subjective reaction to using the system (Brooke, 1996).

2.1.4 Validity

When a new tool is developed with the purpose of being comparable to already known measurement approaches, the results of all approaches should be equal. As such, the *validity* of the new approach has to be evaluated. Based on Shiffman et al. (2008), *validity* can be defined as the relationship of a measure with other theoretically-relevant constructs. In this thesis, validity is used for the evaluation of the map-based tool by comparing the geospatial parameters generated from using this tool to the parameters generated from LSA and GPS.

2.1.5 Reliability

A tool should provide the same results for a similar behavior multiple times. This can be verified by evaluating its *reliability*, which can be defined as the "[…] ability to measure something the same way twice. It rests on the assumption that a person's score on a scale or a test is composed of his true (but unknown) score plus some component that is subject to variation because of error (by which we mean random variability)" (Smoller, 2004:164).

2.2 Related work

The following sections give an overview of research related to the central aspects of this thesis. The first Section 2.2.1 discusses the importance of physical mobility when aging, and the interrelations of mobility, health, and environment. Afterwards, uses of the concepts life space and activity space are presented in Section 2.2.2. Subsequently, Section 2.2.3 examines influences from related disciplines, such as time geography, transportation, and urban planning, and their impact on the health sciences. This section looks at the spatio-temporal aspect of mobility, accessibility, and environmental exposure. In Section 2.2.4, the different approaches to measuring life and activity spaces are described, such as self-reported questionnaires, GPS and map-based tools, and how they have been used in different health-related studies. As map tools have not been used widely in the health sciences, research background on public participation GIS (PPGIS) in planning research is given in this section to highlight opportunities to integrate geospatial technologies in health studies. And last but not least, the focus of Section 2.2.5 will be on the challenges faced by older adults in using tracking and computing technologies and maps, and on suggestions to improve their usability for this specific group of users.

2.2.1 Mobility and aging

"[…] Mobility refers to a person's purposeful movement through the environment from one place to another. Mobility can be conceptualized as a continuum from bed bound (immobility) on one extreme to making excursions to distant locations on the other extreme" (Stalvey et al., 1999:460). During the 20th and 21st centuries, improvements of the transportation system, accompanied by a travel time reduction, increased the mobility behavior of individuals in terms of distance (Perchoux et al., 2013). "Mobility is one of the key components of independent functioning" (Portegijs et al., 2016:1). With increasing age, mobility restrictions and physical, cognitive and sensory impairments can be observed (Stalvey et al., 1999). Accordingly, gerontological studies aim to enhance older adults' independence in actively conducting commercial, cultural and social activities. A high physical activity can help older adults to better maintain their independent mobility (Hirsch et al., 2014; Portegijs et al., 2016). In contrast, older people with physical limitations, limited social contact or cognitive impairment tend to confine their movement behavior to their home or only move within the surroundings of their home. This is likely because going outdoors requires strong physical and mental condition. However, when amenities are within a 5-minute walking radius of one's home, older adults may show a higher mobility (Hirsch et al., 2014; Tsai et al., 2015).

The *Activity Theory of Aging* assumes that the higher the rate of mobility, the more likely it is that older adults are more satisfied with life and can adjust to changes associated with aging (Lemon et al., 1972). Further, a person's well-being and quality of life (QOL) are closely linked to socioeconomic and health-related factors. Accordingly, with a decline in physical and psychological capability, participation in society can be restricted, which can influence a person's well-being and QOL. One of the most common restrictions is out-of-home mobility. But going outdoors is essential for older adults' independence (Rantakokko et al., 2015).

Some studies have investigated the effectiveness of outdoor activities as part of a QOL life. For example, Rantanen et al. (2015) conducted an experiment in which older adults with severe mobility limitations were accompanied by volunteers during individualized out-of-home activities once a week over three months. In this study, engaging in outside activity on a regular basis did not affect the QOL scores, but the authors concluded that volunteer intervention could positively influence older adults' QOL (Rantanen et al., 2015). Another study, by Kono et al. (2007), examined the effect of going outdoors on people's functional and psychosocial condition. Their study participants—community-dwelling, frail, older adults—had to report on how frequently they went outdoors over a period of 20 months. To relate older adults' going out-of-home behavior to their functional and psychosocial changes over the study period, a baseline and two follow-up surveys on their health condition were conducted. Their results show that older adults going outdoors more often had lower functional impairment, were socially more active, and less depressed than the ones who left their home less frequently. Hence, a high frequency of going outdoors—ideally daily—can counteract a decline in daily living activity (Kono et al., 2007).

To better understand the relationship between an individual's mobility, environment and health, Figure 1 visualizes the interaction of these three aspects. It emphasizes the importance of investigating the influence of individuals' mobility on their health condition. Firstly, a higher mobility can help in maintain a better health condition (Relation 2). In this case, mobility can be seen, e.g., as an indicator of transport-related physical activity. Secondly, mobility is a vector through space in which one is exposed to the environment, whereby health condition can be affected (Relations 3 & 4 — double lines) (Chaix et al., 2012). Furthermore, people's mobility can be directly influenced by the environment (Relation 1), e.g. through its accessibility (Setton et al., 2011), or by health-related impairments (Relation 6) which may restrict an individual's movement certain environments (Relation 5). All these relationships illustrated in Figure 1 are essential for understanding the mobility of older adults and the influences acting on their health condition. Consequently, as mobility is central to healthy aging (Satariano et al., 2012), the following sections will describe concepts and measurement approaches for investigating mobility in the context of the health, environment and mobility triad.

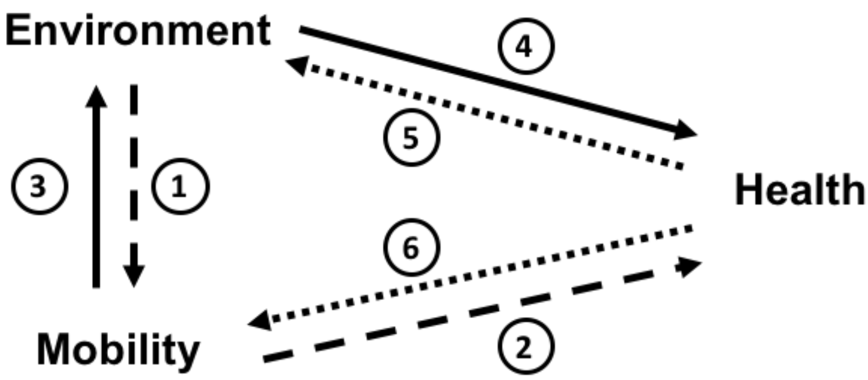

Figure 1: The mobility, environment and health triad (Chaix et al., 2012).

2.2.2 The use of life space and activity space

The main goal of this thesis is assessing older adults' mobility behavior. According to Stalvey et al. (1999), a key aspect of mobility is the spatial extent of movements within a person's environment. In health research, this is mostly referred to as life space. Other disciplines, such as urban planning or transportation science, use the term activity space. Recently, activity spaces have also been used in health-related studies. As mentioned in the definitions section (2.1), these two concepts of movement space will be used interchangeably in this thesis. But in the Sections 2.2.2 and 2.2.3, the terms life and activity space are used equally as in the referenced literature.

Life space is used as an indicator predicting the level of participation in life situations, as well as physical and cognitive functioning in studies of older adults. Life-space measures have been correlated to different health aspects including falls, mortality and nursing home admission. Accordingly, there is an increasing interest in measuring life space (Rantakokko et al., 2015; Tung et al., 2013). As already stated in the definitions section (2.1), a life space can be "defined as the spatial extent in which a person moves within a specified period [...]" (Tung et al., 2013:155) and life-space mobility, as used in this thesis, also considers the frequency of movements and an individual's need for assistance (Baker et al., 2003). Further, "life space is a multidimensional construct that integrates physical performance with motivational, psychological, and social factors that influence how one navigates and interacts with the real world" (Boyle et al., 2010:1925). Regarding nursing home and community-dwelling older adults, the notion of life space can assist in assessing and revealing interventions to enhance mobility and the effect of environmental factors on mobility. In contrast to functional and physical performance assessments, life space measures what people actually do, not only what they are able to do. Consequently, declines in life space can indicate changes in health condition (Baker et al., 2003; Peel et al., 2005).

Similar to life space, activity space can be "[...] defined as the subset of all locations within which an individual has direct contact as a result of his or her day-to-day activities" (Golledge & Stimson, 1997:279). The notion of activity space was first defined by Horton & Reynolds (1971) and was then adapted by Golledge & Stimson (1997). Compared with life space, activity space is not only used for measuring mobility among older adults, but also among other age groups. An activity space aims to measure an individual's daily spatial behavior and can also be related to health factors.

2.2.3 Mobility-related research fields and measures

The concept of activity space was first studied in the fields of transportation and planning which focused on the analysis of highly spatially- and temporally-resolved individual's mobility data. Hence, these fields provide a broad background of literature and applied research regarding the concept of activity space. Accordingly, Perchoux et al. (2013) discuss research fields which fundamentally affected and examined the concept of activity space, namely time geography, transportation and urban planning research, environmental psychology and social sciences. Fundamental achievements of those fields include identifying the importance of space and time in studying individuals' mobility and the measurement of accessibility and environmental exposure with activity spaces (Perchoux et al., 2013). The last two measures have been integrated in health-related studies. Accordingly, the following subsections highlight the importance of the space-time concept in mobility studies, and describe the use of accessibility and exposure measures in health science.

The importance of space and time in mobility studies

The concept of activity space has its roots in time geography. The study of human activities and movements in a space-time context has long been an important research field in the social sciences. Hägerstraand (1970) introduced *time geography* as one of the first perspectives that integrated space and time in the analysis of people's activities and movement patterns. This approach highlighted the importance of space in understanding everyday activities and movement patterns. Further, it has been increasingly acknowledged that different spatial and temporal aspects have a significant influence on people's activities. For a long time, only a few studies had incorporated space and time aspects in mobility research as analytical methods because there was a lack of detailed individual-level data and advanced analytical tools. But thanks to advances in GIS and the availability of more detailed movement data on individuals, time-geographic approaches are now widely used in different social science studies for describing and analyzing human movement patterns (Kwan & Lee, 2004).

Furthermore, the space-time approach highlights different constraints that should be considered in mobility analyses. These include physical capabilities, topological restrictions or regulations imposed by society, such as opening hours of grocery stores. Accordingly, these constraints should be considered when assessing, for example, the accessibility of regions and locations, or exposure to environmental influences (Perchoux et al., 2013).

Accessibility

Accessibility has predominantly been studied in transportation and urban planning research. These research fields have used spatial and temporal information to examine movements and activity spaces of mobility- and socioeconomically-restricted persons, such as older adults or people with a low income (Ohmori et al., 1999; Schönfelder & Axhausen, 2003), or of individuals moving in urban environments (Kahila & Kyttä, 2009).

In health research, the activity-space approach has been used to evaluate individuals' accessibility to, e.g., health care opportunities in rural mountain regions (Sherman et al., 2005). Further, a study examined the accessibility to healthy food. By including travel times, different modes of transport and the opening hours of grocery stores, Tenkanen et al. (2016) analyzed the accessibility of grocery stores in an urban environment with different transport modes at various times of the day. The results emphasize that it is essential to include time and semantic information in health-related spatial analyses. Contrary to simpler accessibility measures, the mentioned approach shows a more realistic model and provides a more accurate image of the realities of accessibility.

Generally, these findings have the potential to improve and support health-, mobility- and environment-related studies. As an example, Tsai et al. (2015) concluded that independent movement in different life-space areas should be enabled. This could be achieved by evaluating and enhancing the walkability of neighborhoods and other areas, whereby accessibility is one of several measures to assess a neighborhood's walkability.

Environmental exposure

The mobility, health and environment diagram (Figure 1) implies that health is influenced by different environmental factors. Similarly, Kerr et al. (2011) argue that environmental exposure is underestimated when relying only on the place of residence. On the one hand, mobility is influenced by the residential environment in which a person lives depending on the accessibility of certain locations. On the other hand, the environment and exposure to it have a direct impact on people's health. As activity space is a construct which can be defined in space and time, it can be used to measure spatial mobility over time as well as environmental exposure.

Relationships between environmental features and health-related factors have been examined in residential and non-residential locations, whereas the former refers to locations within a surrounding administrative unit or within a neighborhood buffer zone, while the latter considers the totality of locations of an individual's movement, the activity space. Earlier studies found that the non-residential space is more appropriate for measuring environmental influence on health. Reasons for these findings can be that a fixed administrative unit is static and does not account for the exact home location of an individual in this unit, and that someone living at the border of a particular area is exposed to different influences than somebody living in the center. By contrast, the activity-space approach considers an individual's unique spatial experience instead of relying on static spatial units that do not fully represent mobility (Perchoux et al., 2013; Zenk et al., 2011). Zenk et al. (2011) proved the utility of the activity-space approach by examining the interrelation between environmental measures and weight-related behaviors (dietary and physical activity) in residential and non-residential areas. Different environmental features were used to measure fast food outlet density, supermarket availability and park land use. The results underlined that most study participants did not move exclusively in their residential area. Further, the environmental features were different for residential neighborhoods and activity space, and some features of the non-residential space showed a relation to weight-related behaviors (Zenk et al., 2011).

Hence, the activity-space concept is the more appropriate approach for analyzing the influence of the environmental context on people's health because it takes into account the complexity of space (Perchoux et al., 2013). Additionally, the temporal aspect is an important factor for exposure measures, as it considers the time a person spent at a place. The longer a person stays at a place, the more she or he is exposed to certain environmental influences. For example, studies examining the influence of air pollution on health highlight that it is important to determine whether an individual is inside a building or outside. Furthermore, Setton et al. (2011) examined variations in traffic-related air pollution exposure based on residential space and mobility-based exposure, which also includes exposure at work places; that is, basically, the activity space. With increasing distance and time away from home, the environmental influences related to the workplace become more important (Setton et al., 2011).

In conclusion, environmental exposure studies have highlighted the importance of the activity space because it measures overall daily mobility and not only movements in a certain area. Further, the studies mentioned above showed that people are influenced by different environmental factors when moving beyond their neighborhood than staying near their home.

2.2.4 Different approaches for measuring life-space mobility

So far, different studies and findings related to the terms life space or activity space have been presented to conceptualize the mobility of individuals. But how do researchers effectively measure mobility? Over time, different measurement approaches have been elaborated. First, different self-reported questionnaires were devised. Later, geospatial sensor technologies, such as the Global Positioning System (GPS), were developed, and finally interactive map tools were established. The following subsections describe these three different approaches and discuss studies that made use of these.

Self-reported questionnaires

One of the first approaches for measuring older adults' life-space mobility as a spatial construct was suggested by May et al. (1985). The self-reported life-space diary (LSD) aimed to measure the area in which a person moved in a specified period. Over a period of one month, older frail adults were asked to report every evening how far they went from home. The distances were measured as predefined zones represented as concentric areas around the home, starting with the bedroom at the center. The areas were then extended to the remainder of the home, the home's surroundings, the block in which the dwelling is located, and across a traffic-bearing street. Based on these diary entries, a life-space diameter score could be generated to evaluate a person's mobility over one month. The LSD scores showed a significant correlation with performance measures such as gait speed and balance (May et al., 1985).

A few years later, Stalvey et al. (1999) argued that the LSD by May et al. (1985) only captures narrow life spaces and that this measurement approach is not appropriate for community-dwelling older adults who may travel more and further from home than frail older adults. Consequently, they developed the life space questionnaire (LSQ). To cover a broader range of environmental regions, the LSD zones were adapted and extended. The new areas encompassed other rooms and the immediate surroundings of people's homes, areas in the neighborhood and town, and outside the town, county and state, as well as outside the respective region of the United States. This approach gives nine specific life-space areas. Different to the LSD, participants report on their mobility only at the end of the study period and not every evening. Then, they are asked if they have been in a specific zone within the last three days. The answers are given only as yes or no. For every yes, 1 point is added to the LSQ score, which results in a score ranging between 0 and 9. The measurement period was adjusted to avoid potentially unrepresentative samples of one day or one month when scoring. The authors argue that one day is too short to show the potential span of travels and one month is too long as people are more likely to travel to each of the zones during a longer period. The final LSQ scores showed that older adults with functional impairments, e.g. depression or impaired cognitive skills, also have a smaller life space score (Stalvey et al., 1999). Further, a relationship between LSQ scores and measurements of activities of daily living (ADL), e.g. bathing or meal preparation, was found (Stalvey et al., 1999).

Later, Boyle et al. (2010) examined the relationship between life space and older adults' risk of mortality. The participants' life-space data were collected in two health-related longitudinal studies with an adapted version of the LSQ over periods of up to 8 years. During the study period, 22.8% of the participants died. The results of the study could relate a high mortality risk to low life-space scores (Boyle et al., 2010). Another study by Barnes et al. (2007) also used the LSQ to measure older adults' life-space mobility. But, they could not find a correlation between physical activity and life-space mobility measured with LSQ (Barnes et al., 2007).

A further questionnaire-based approach for measuring older adults' life-space mobility is the "University of Alabama at Birmingham (UAB) Study of Aging Life-Space Assessment" (LSA), which has been evaluated by Baker et al. (2003). The LSA is similar to the LSQ, as it measures life-space mobility at the end of a study period and it is conceptualized for measuring community-dwelling older adults' mobility. However, it relies again on a measurement period of one month, as used by May et al. (1985), because this minimizes the impact of environmental or health-related short-term changes on the assessment. Further, the areas around someone's bedroom are again reduced to five life-space levels, ranging from "moving to another room at home" to "going out of town/the country" (Figure 2). In addition to the LSD and the LSQ, which only measure the extent of movement, the LSA considers the frequency of movement and whether assistance (by equipment and/or a person) was needed to move within each of the levels. Different scores are proposed by Baker et al. (2003), but the composite score takes into account all three factors resulting in a score from 0 to 120. Hence, the composite LSA score is the most appropriate to detect increases as well as decreases in life-space mobility (Baker et al., 2003; Peel et al., 2005).

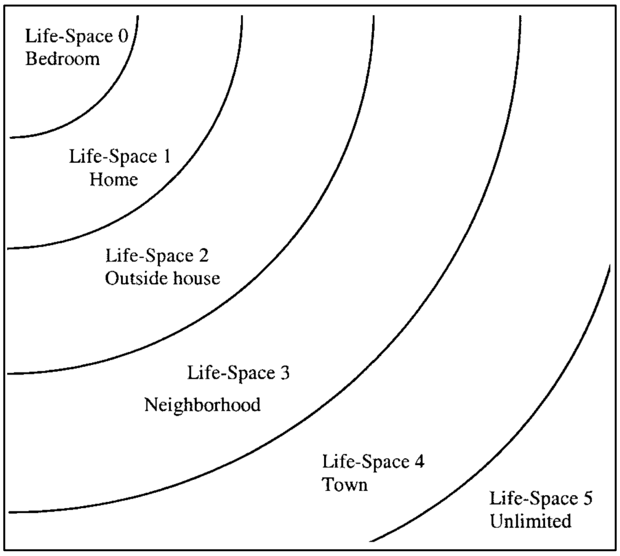

Figure 2: The LSA life-space levels (Peel et al., 2005:1010).

Recently, a Finnish research group (Portegijs et al., 2015; Tsai et al., 2015) incorporated the study by Barnes et al. (2007) in their examination of the association between objectively-measured physical activity and life-space mobility among community-dwelling older adults. In contrast to Barnes et al. (2007), who could not find a correlation between physical activity and life-space mobility based on the LSQ, Tsai et al. (2015) and Portegijs et al. (2015) used the LSA approach for measuring life-space mobility. A further difference was that they focused on an objective approach to measure physical activity, an accelerometer, instead of a self-reported measure. The physical activity variables used were step counts and activity time. The results of one study showed a positive correlation of higher step counts and activity time with life-space mobility scores (Tsai et al., 2015). The other study highlighted that the participants were more physically active when moving to more distant life-space areas than when remaining close to their dwelling (Portegijs et al., 2015). Hence, physical activity can positively correlate with life-space mobility, but the results depend on the measurement approach selected. As shown above, the LSA is arguably the more comprehensive approach for measuring life-space mobility, as it also comprises information on the frequency of visits of the different levels and whether assistance was needed to reach a particular level. This advantage has been acknowledged by many researchers, and the LSA is now widely used in different health-related studies.

For example, Peel et al. (2005) found correlations between the composite LSA scores and physical performance parameters of community-dwelling older adults, such as standing balance, their ADLs, cognitive functioning, depression and sociodemographic variables (e.g. age, income, transportation difficulty). Interestingly, the LSA score did not correlate with the residential environment distinguished as rural and urban areas (Peel et al., 2005).

Moreover, Sheppard et al. (2013) used the LSA to explore if there is a relationship between life-space mobility and nursing home (NH) admission in community-dwelling older adults. As NH admission is related to risk factors such as cognitive impairment or difficulties with ADLs, which have also been related to life-space mobility, it seems reasonable to use the LSA as a risk identifier of early NH admission. Over 6 years, Sheppard et al. (2013) assessed life-space mobility and the vital status at intervals of 6 months. The results showed a relationship between a decreasing LSA score (-1 point) and an increasing rate of NH admission (+2%). Due to this association, the authors state that the LSA could be used to predict an individual's risk of NH admission (Sheppard et al., 2013).

Another study, namely LISPE, examined in a 2-year follow-up if the changes of life-space mobility are related to changes in quality of life (QOL) in community-dwelling older adults. For this, the LSA and a short version of the World Health Organization (WHO) QOL assessment were used (The WHOQOL Group, 1998). The latter is a score comprising measures of physical and psychological health, social relationships and environment. Finally, a greater decrease in QOL scores emerged when the life-space mobility declined more than 10 points instead of remaining stable. The association between these two measures highlights the importance of maintaining high mobility among older adults (Rantakokko et al., 2015). Furthermore, the LISPE study examined the association of life-space mobility and the disability status in ADLs in older age. The results showed that declines and restrictions in life-space mobility could be used as an early indicator of disability in ADLs among older adults (Portegijs et al., 2016).

The sensor-based measurement approach

In contrast to the self-reported questionnaires discussed above, sensor-based measures, such as GPS, allow to objectively measure mobility behavior and environmental influences on health. Accordingly, several researchers rely on GPS tracking devices to measure people's daily mobility (e.g. Hirsch et al., 2014; Tung et al., 2013). For example, GPS tracking allows measuring an individual's position every second. Working with GPS offers multiple opportunities and challenges, a few of which are discussed by Kerr et al. (2011). An important aspect when using GPS is the awareness of possible positional errors in the data caused by interference from buildings or atmospheric conditions, which may affect the quality of the connection between the GPS device and the GPS satellites. Additionally, researchers should be aware of issues such as the accuracy of measured positions, battery life and memory constraints when using GPS for mobility measurements, as these aspects vary between different GPS devices. A further challenging aspect is the data processing and cleaning where researchers have to define how to handle spurious and missing data (Kerr et al., 2011). The opportunities of GPS, when measuring mobility, clearly are the higher resolution of the spatial and temporal information that is generated. Compared to the LSA, GPS can provide rather accurate spatial references to locations visited by a person. Therefore, GPS has mostly been used in studies in the geographic domain. But there is an increasing number of studies in the health and aging sciences using GPS to measure individuals' mobility.

Based on GPS, Sherman et al. (2005) examined different measures to calculate the activity space, such as standard deviational ellipses and network-based measures, and used them to obtain a better understanding of accessibility. The implementation of network-based measures has only been possible thanks to the high resolution of GPS data (Sherman et al., 2005). Moreover, Boissy et al. (2011) and Tung et al. (2013) are two of the specific examples of using GPS to measure life-space mobility. The authors argue that self-reported measures, such as LSA, can only be used within limit in studies with cognitively-impaired persons because these (partially) amnesic patients may not be able to completely remember all their movements. Hence, a GPS device could be more appropriate for measuring the mobility of older adults with mild-to-moderate Alzheimer's disease. GPS data allows deriving additional life-space measures such as life-space area and perimeter, or the average of distances travelled. Life-space area and perimeter could be associated with physical functioning and affective state. The results indicate that GPS technology is a promising approach to assessing life-space behavior (Tung et al., 2013).

As a further example, Kestens et al. (2014) conducted a study to evaluate the use of wearable sensors to measure and describe real-life mobility and physical activity. Their study group consisted of children and adolescents (aged 6-17 years) with cardiometabolic risk factors and the aim of the study was to promote physical activity and reduce sedentary time. To measure participants' mobility, physical activity and heart rate, a GPS receiver, an accelerometer and a heart rate monitor had to be worn over seven days by the study participants. For the evaluation, a mixed group of researchers—especially health scientists and geographers—established indicators of physical activity, spatial behavior and the device performance. The results addressed device performance by evaluating valid days of measurement, the daily step count and the activity-space area (Kestens et al., 2014).

And finally, Hirsch et al. (2014) extended the concept of life space by measuring older adults' mobility as an activity space. As in other activity-space studies, they used GPS to collect mobility data. Thereof, different types of geographic activity spaces could be derived, such as the standard deviational ellipse, the minimum convex polygon, a daily path area (Figure 3) and the compactness of each of these three measures. Hirsch et al. (2014) compared the three approaches and related them to other variables such as the walkability of a neighborhood. They concluded that each of these measures can be useful for different purposes of mobility analysis among older adults (Hirsch et al., 2014).

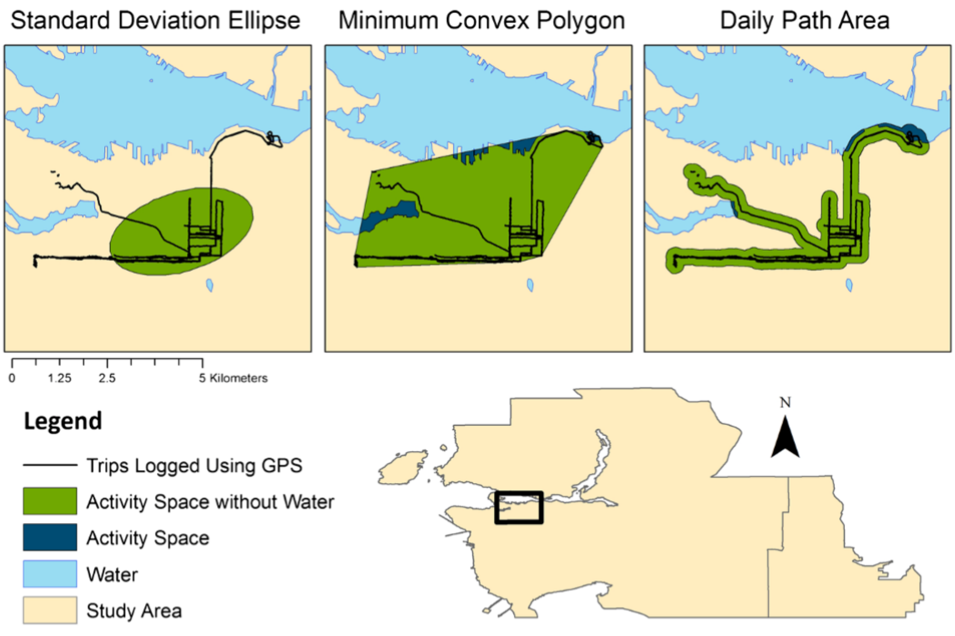

Figure 3: Different types of activity spaces (Hirsch et al., 2014).

Map tools in health science and public participation planning

GPS is a technology measuring geographic positions which can be used to generate activity-space and life-space measures in the health sciences. Generally, geospatial technologies offer more possibilities for generating and representing health-related constructs, such as the activity space. Such technologies or tools have already been used in different fields such as health research and urban planning to support decision-making and data collection, exploration and visualization (Cinnamon et al., 2009; Sherman et al., 2005).

Health sciences. In this field, to date, GPS is the most commonly-used geospatial technology, but there are earlier studies which examined interactive map tools for collecting and exploring health-related data. Only two exemplary studies could be found, which are subsequently described.

Visualizing and exploring data becomes even more important as the complexity of the data used for decision-making increases. The increased complexity of data has been observed, for example, in public health datasets. Therefore, Cinnamon et al. (2009) published a paper in which they evaluated three different types of maps—static, animated and interactive—allowing injury prevention stakeholders and other public health officials to analyze and explore their spatial injury-related data. The maps used showed different injury rates and socio-demographic determinants in Toronto, Canada. The purpose of the conducted study was to compare injury patterns with socio-demographic risk factors. For this, the interactive map was the most preferred by the study participants. But these results have to be considered with caution, as the outcome of such usability studies is always related to the user group and the specific purpose of an application (Cinnamon et al., 2009). Similarly, Mennis et al. (2013) used a GIS for exploring activity spaces in the context of health-related environmental exposure.

Chaix et al. (2012) developed an interactive map-based tool for collecting mobility data. As most health-related studies focus on mobility in people's neighborhood and on data collection over limited time periods, their aim was to assess individual mobility by asking for regular destinations. This means that locations are collected which are regularly visited but are not of necessity in a specific period (no temporal limitation). To this end, they developed the VERITAS application, which is a web-based mapping tool where spatial information, such as visited locations (points), the perceived neighborhood (polygons), and trips (lines), about participants can be recorded, including additional attribute data. The application is presented in the form of a questionnaire which should stimulate recall so that participants remember several visited locations. As the tool is map-based, it allows generating more accurate geographical information than, e.g., paper-based questionnaires. The participants' information is entered by a trained technician. Consequently, the tool has not been tested regarding its usability for untrained users.

Based on the data entered in the application, Chaix et al. (2012) generated different indicators for individuals' spatial behavior, such as convex polygons, standard deviational ellipse, number of regular destinations or extent of perceived neighborhood (Chaix et al., 2012). These measures are similar to the above-mentioned activity-space measures derived from GPS data (Hirsch et al., 2014).

Urban and environmental planning. In this field, similar tools have been developed for collecting public data and supporting decision-making. These tools are rooted in the development of GIS and its use for planning purposes. As the developers of GIS were working with academic and governmental institutions, GIS was not accessible to the broad public for a long time. With rising concerns that there are many different groups in society which are poorly represented in public policy-making, partly because of the use of GIS in decision-making, the attempt to develop public participation GIS (PPGIS) arose (Obermeyer, 1998). PPGIS can be defined as a "field within geographic information science that focuses on ways the public uses various forms of geospatial technologies to participate in public processes, such as mapping and decision making" (Tulloch, 2008, In: Brown & Kyttä, 2014). The aim of PPGIS is to engage "[...] non-experts to identify spatial dimensions of social and cultural landscapes [...]" (Brown & Kyttä, 2014:122).

Carver et al. (2001) developed web-based approaches to evaluate the usability of PPGIS. Their evaluation revealed fundamental problems such as access to the internet, the use of computers and poor understanding of spatial problems by laypersons (Carver et al., 2001). Later, the role of web-based mapping and the use of PPGIS for the regeneration of inner city neighborhoods was examined by Kingston (2007). Kahila & Kyttä (2009) published a comprehensive discussion on the so-called softGIS method, a term that seems popular in the Finnish literature and which is similar to PPGIS. SoftGIS may be understood as an internet-based participatory mapping tool which is used predominantly in collaborative urban planning. The aim of this tool is to find relationships between environmental factors and the knowledge of residents. Locals can share their experiential knowledge, which then can be accessed by researchers and urban planners. Through this exchange of knowledge, a bridge between policy makers and residents can be created. In their paper, Kahila & Kyttä (2009) present different softGIS methods which capture the quality of environments and information on different topics, as well as methods which are developed for specific user groups.

A review of environmental and urban-based studies using PPGIS is provided by Brown & Kyttä (2014). In different tables, they list studies that have been conducted and different spatial attributes mapped with PPGIS. The authors highlight the diversity of approaches regarding map attributes, sampling strategy, purpose, technology and location of participatory mapping.

Finally, they propose future research priorities. One of these research goals is the evaluation of the effectiveness of PPGIS, as "governments are reluctant to spend funds on evaluation" of a tool or its effectiveness (Brown & Kyttä, 2014:134). Moreover, when academics conduct an evaluation, they neither focus on the effectiveness of PPGIS, because they are more interested in the usability of tools and technologies (e.g. Andrienko et al., 2002; Gottwald et al., 2016; Meng & Malczewski, 2009).

2.2.5 The special role of older adults in today's technology generation

When evaluating the usability of computer-based tools and technologies, important differences exist between various user groups. Higher usability scores have been related to users with, e.g., a higher level of education, affinity for technology or experience in GIS (Meng & Malczewski, 2009). Accordingly, as not all persons have these qualifications, research has had to focus on usability improvements for individuals with lower technical experience, such as older adults. There are several studies which evaluated the usability of travel aids, user interfaces, websites, mobile maps and PPGIS applications for older people (Becker, 2004; Docampo Rama et al., 2001; Gottwald et al., 2016; Kovanen et al., 2012; Petrie et al., 1996; Rice & Alm, 2008). These studies do not only try to tackle the lack of technical affinity that causes difficulties for older adults in handling websites or devices, but also cognitive, sensory, motoric and emotional challenges which can affect their experience with such tools (Gottwald et al., 2016). So, when developing a tool or a website that should be user-friendly for older adults, all these challenges must be considered. As our population is aging and older adults are increasingly using the internet, guidelines and suggestions have been developed and studies have been conducted for improving and evaluating the design of websites and maps for older people (Kovanen et al., 2012; Zaphiris et al., 2006). But even if guidelines exist, such recommendations are often not implemented in real applications such as websites. As Becker (2004) showed, only a few websites have a design, performance and reading complexity that is appropriate for older adults. Hence, there is a general need to take into account the requirements of older adults. Therefore, insight into the challenges and corresponding design recommendations for using map-based web applications among older adults must be given.

With increasing age, study participants need more time for solving tasks with electronic devices and for accessing websites (e.g. Docampo Rama et al., 2001). This effect is influenced by different cognitive, motoric, sensory and emotional challenges.

Cognitive challenges in older age include concentration and memory deficiencies, and a lack of experience and spatial abilities. The lack of experience with computers, the internet and online maps may lead to confusion and disorientation when using a web application with an integrated map such as a PPGIS tool (Gottwald et al., 2016). This inexperience concurs with the inconsistency of functions in web applications and with the fact that people mostly rely on previous experiences (Righi et al., 2011). Accordingly, unexperienced map tool users already have difficulties with zooming in and out and finding targets on the map, and they require support even for simple map handling tasks. Such handling difficulties cannot be fully avoided, but guidelines recommend to keep websites and applications as simple and consistent as possible and to use plain language (Gottwald et al., 2016; Xie & Pearson, 2010).

Motoric challenges impose further potential difficulties, and are mostly related to tasks that include the handling of the mouse, such as scrolling down the page or pull-down menus. Motoric challenges in older age can be caused by arthritis or tremors. Accordingly, scrolling and pull-down menus should be avoided. But, especially, scrolling cannot be completely avoided as websites are mostly responsive to a computer's screen size. So, the main recommendations given in usability guidelines are to reduce scrolling tasks and to enlarge the size of buttons (Gottwald et al., 2016; Vrenko & Petrovič, 2015; Xie & Pearson, 2010).

Sensory challenges include changes in vision with aging, as well as color vision deficiencies. Hence, older adults are sensitive to text with small font sizes, as well as low color contrast and brightness. Improvements in the usability of map-based applications can be achieved with colors that are also distinguishable by people with color vision deficiencies, clearly understandable symbols, a large area for the map and a simple design (Gottwald et al., 2016; Kovanen et al., 2012).

Emotional challenges are related to negative user experience when getting lost on a website or when getting stuck performing a task. Some older adults are quite self-conscious when using web applications because they worry about their performance and about making mistakes. Accordingly, participants ask many questions which can be answered by the instructor in a study situation. To tackle this insecurity, it may be helpful to provide additional materials, such as a user guide, a video tutorial or a help function, which can be accessed by the user at all times (Gottwald et al., 2016).

2.3 Identification of the research gap and research questions

Different studies have shown that age-related functional limitations and impairments are related to mobility behavior. Accordingly, a major concern of public health is the decreased mobility of older adults and the influence on their health. In order to approximate life space or activity space, researchers, mainly from the spatial and health sciences, have elaborated and tested different mobility measurement approaches in the past decades.

Self-reported questionnaires, such as the LSA, are time- and cost-efficient, and provide, on top of an approximation of an individual's activity space, additional semantic information concerning the frequency of movement and the need for assistance. However, the information collected is not explicitly spatially locatable, and, especially, cognitively-impaired people might not remember all their movements.

Recently, sensor-based measurement approaches, such as GPS, have become more popular for measuring life-space mobility and the environmental exposure in health-related studies (Hirsch et al., 2014). This approach is more objective, because participants do not report on their mobility themselves. The data is continuously and digitally assessed. Furthermore, spatially-explicit measures such as home location, area, compactness and perimeter of a life space, average distance from home and time away from home can be derived (Hirsch et al., 2014; Tung et al., 2013). However, study participants need to continuously carry a GPS-enabled device over a long enough period to be representative. As mentioned by Kerr et al. (2011), when using GPS data, problems, such as data accuracy or even a lack of data, can arise through the influence of, e.g., interference from buildings and atmospheric conditions. Further challenges associated with sensor-based measures include the battery life and the restricted memory of a device, as well as not being able to assess semantic information.

Several researchers in the health sciences claim that new solutions for individually measuring and evaluating older adults' activity spaces are needed (e.g. Hirsch et al., 2014; Perchoux et al., 2013). Chaix et al. (2012) proposed an interactive map-based tool for assessing people's mobility data. This tool has multiple functions in collecting spatial mobility data and additional semantic information, but it has not been evaluated regarding its usability for study participants. In the field of urban and environmental planning, different approaches of PPGIS have been developed and tested for their usability. PPGIS aims to engage non-experts to identify knowledge about spatial planning issues in local and regional environments and to collect spatial data for identifying relevant planning issues (Brown & Kyttä, 2014). The design and the functioning of map-based tools have to be adjusted for non-expert users, especially for older adults who face several challenges when using different technologies. Accordingly, Gottwald et al. (2016) presented a PPGIS approach which has been evaluated and adjusted regarding its usability for older adults.

Research gap. The findings established through the review of the related literature allow to identify a research gap for this thesis. The advantages of self-reported and sensor-based life-space mobility assessment are the spatially-locatable data and the additional semantic information, respectively. However, neither of these two measurement approaches manages to provide both types of information. Consequently, the research gap here is that the current state of the art does not provide a measurement approach which allows to assess spatially-locatable and semantically-enriched data on older adults' life-space mobility. In my MSc thesis, I propose a map-based tool (MBT), as such tools offer the capability to assess both spatially-referenced data and the relevant semantic information. Furthermore, a map-based tool may reduce the effort which is needed for sensor-based measures, and it may provide a higher data accuracy compared to self-reported questionnaires. To date, no health-related study was reported in the literature that specifically assesses the life-space mobility of older adults with a map-based tool.

The **overall research objective** of this thesis can be summarized as follows: By combining the findings of Chaix et al. (2012) and Gottwald et al. (2016), and by including further geographic concepts, this thesis aims to close the research gap regarding map-based tools for older adults in the health sciences.

Research questions. Responding to the research gap described above, the following research questions have been identified and formulated for this thesis:

RQ1: What are the requirements for a map-based tool (MBT) aiming at measuring older adults' life-space mobility as an alternative to the LSA and GPS-based indicators in health and aging research?

RQ2: How usable is the newly-developed MBT for assessing the life-space mobility of older adults in general as well as compared to the usability of the LSA and the GPS-based measurements?

RQ3: How do the MBT, GPS and LSA methods compare with respect to derived spatial and semantically-enriched life-space indicators?

3 The "MapSpace" experiment

"MapSpace" is an experiment which has been conducted by the GIS Unit at the Department of Geography at the University of Zurich (UZH) and the Department of Sport, Exercise and Health (DSBG) at the University of Basel (UniBas). The aim was to evaluate the usability, validity and reliability of a new map-based tool (MBT) for measuring older adults' life-space mobility. Therefore, the experiment was made up of three parts: the tool development, a study with older adults and the evaluation (Figure 4).

The development of the MBT has been elaborated within this MSc thesis by identifying tool and user-oriented requirements. A description of the development process and the implemented MBT is given in Chapter 5.

The study assessed life-space mobility with three different measurement approaches, namely the life-space assessment (LSA), global positioning system (GPS) and the newly-developed MBT. Additionally, complementary measures of health and everyday functioning were obtained, such as physical performance and activity, instrumental activities of daily living (IADLs), cognition status and other measures (Section 3.5). A detailed description of the study structure is given in Section 3.4.

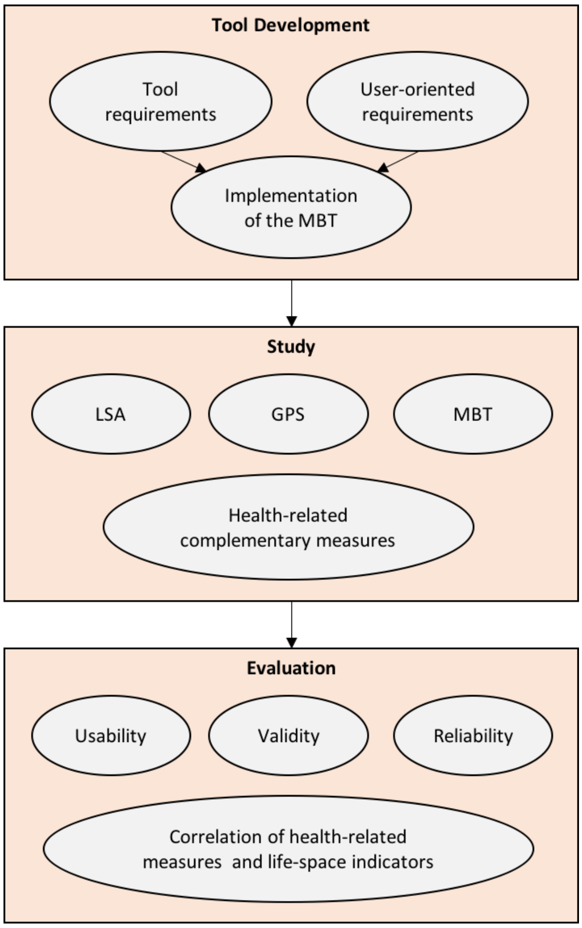

Figure 4: Workflow of the „MapSpace" experiment.

The evaluation focuses on the usability (Chapter 6), validity (Chapter 7) and reliability of the MBT, and the correlation between the health-related complementary measures and life-space indicators derived from the MBT (examined in two other theses; Section 3.1).

The driver for conducting this experiment is that epidemiological research on life-space mobility could greatly benefit from this new tool, reducing the burden on participants compared to GPS, and, at the same time, obtain higher accuracy compared to questionnaires.

3.1 The schedule and the contributors of the "MapSpace" experiment

The MBT was developed in the period of June to August 2016. The recruitment process started in the middle of August 2016 (Section 3.3) and the measurements were conducted in the period from September to December 2016. The aim was to achieve a sample size of 56 study participants. This includes 47 participants plus a dropout rate of 10%. The sample size was based on the Bland-Altman analysis, which is used to assess the agreement between two methods in clinical measurements (Bland & Altman, 1986).

As each of the approximately 60 study participants partook in three appointments (Section 3.4), several contributors were involved: A Master's student from the UZH (the author of this thesis, Adriana Zanda), as well as a Master's student (Jennifer Schmid), a Bachelor student (Sophie Sutter), and a research assistant (Sandra Baumann) from UniBas. Each of them was given the same instructions regarding the recruitment and the measurements. In the end, each student wrote an autonomous thesis which focuses on specific aspects of the "MapSpace" experiment. In the scope of this thesis, the different life-space measurement approaches will be elaborated, compared and evaluated (development, usability and validity of the MBT). The MSc thesis by Schmid (2017) examines the reliability of the MBT, and correlations between life-space indicators and several of the health-related measures collected through the "MapSpace" study. The remaining physical measures will be correlated to participants' life spaces and evaluated in the BSc thesis by Sutter (2017).

For recognizing the general context of the "MapSpace" experiment, the following sections of Chapter 3 give an overview of the inclusion criteria, the recruitment process, the structure and different measures assessed within the study and the characteristics of the study participants.

3.2 Inclusion criteria

The inclusion criteria for participating in the study were defined as follows:

- Participants must be 65 years or older.
- Participants must have an ambulatory ability (with or without a walking aid) over at least short distances.
- Participants must leave the home regularly, at least three times a week.
- Participants must be able to visit the outpatient clinic of the DSGB at least three times, located in the St. Jakob ice stadium in Basel, where the measurements were conducted.

3.3 Recruitment process

For the recruitment, several general practitioners (GPs) in the city of Basel and its nearby municipalities were contacted with an information letter, inviting them to contact the DSGB if they were interested in supporting the study participant recruitment. GPs could benefit from their support as they would be informed about their patients' mobility and physical and cognitive performance in the study. Further, they would receive a report on the summarized findings of the study. By talking to patients in the GPs' practices personally and by placing flyers in the waiting rooms, older adults were informed about the study. Moreover, flyers were distributed in gym classes for older adults and in other studies which were conducted concurrently at the DSBG. Further study participants were recruited via personal connections or by contacting participants from previous studies via e-mail or telephone. If a person was interested in participating in the study, a first appointment was fixed and the prospective participant received a more detailed information sheet including a declaration of consent which had to be signed before participating in the study.

3.4 Structure of the "MapSpace" study

Overview. The study consisted of three appointments and a 7-day GPS assessment period (Figure 5). The first appointment was used to hand out the GPS device subsequently used for measuring participants' mobility over 7 days. The second was used to collect the device and to measure the life-space mobility of the identical 7 days (retrospectively) with the other two life-space mobility measurement approaches, LSA and MBT, and assess further physical functioning and cognition measures. Finally, the third appointment intended to assess the life-space mobility over another week to evaluate the reliability of the MBT. Accordingly, participants' life-space mobility was measured twice for 7 days, where the first period was assessed with all three measurement methods and the second period only with MBT and LSA. Table 1 summarizes the structure and elements of the "MapSpace" study. A detailed description of each appointment is given subsequently.

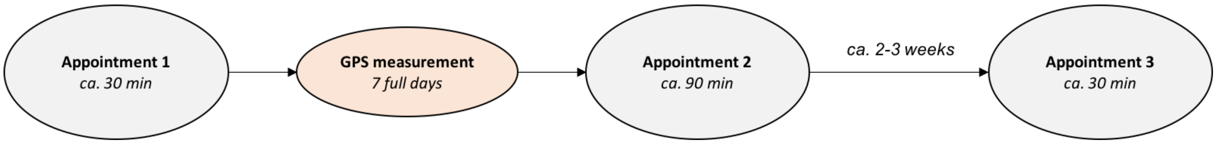

Figure 5: Overview of the structure of the "MapSpace" experiment.

Table 1: Structure and elements of the "MapSpace" study.

	Elements of each appointment
Appointment 1	- Information about the study - Instructions regarding GPS device - Assessments: • personal characteristics • chronic conditions • activities of daily living • general mobility • housing situation • technical experience and related confidence • spatial ability
Wearing the GPS device	- Assessing participants' mobility behavior (GPS) and physical activity (integrated accelerometer)
Appointment 2	- Assessments: • usability and wearing comfort of the GPS device • measuring participants' mobility over the past 7 days with the map-based tool (MBT) • system usability of the MBT • life-space assessment (LSA) over the past 7 days • anthropometric measures • hand grip strength • physical performance • physical activity • fall-related self-efficacy • health-related quality of life • cognition
Appointment 3	- Assessments: • measuring participants' mobility over the past 7 days with the MBT • system usability of the MBT • LSA over the past 7 days

First appointment. During the first appointment, it was verified that participants were informed about the study and that they fulfill the inclusion criteria. Further, participants had to consent to participating in the study by signing the participation agreement. After the organizational aspects, personal characteristics (sex, age), chronic conditions (diseases that had been diagnosed at least once) and physical functioning based on difficulties involved when performing instrumental activities of daily living (IADLs) were assessed. Further, participants were asked to answer several questions regarding their general mobility behavior (modes of transport used, areas of movement and neighborhood restrictions), housing situation, technical experience with different devices, and confidence in using each of them. Moreover, their spatial ability was assessed with the Santa Barbara Sense of Direction Scale (SBSOD) developed by Hegarty et al. (2002). Finally, the study participants received verbal instructions regarding the handling of the GPS device as well as written instructions (Appendix B, CRF 1 and written instruction sheet).

After the first appointment, study participants had to wear the GPS device for a full 7 days whereby they had to report in a paper-form questionnaire every evening if they had worn the device the whole day and if they had been outside their home (Appendix B, CRF 2). To verify that the device worked properly and that the participants did not have any handling problems with the device, a control phone call was made by an examiner within the first three days of the GPS mobility observation period.

Second appointment. The second appointment took place about 8-10 days after the first. Participants had to hand in the GPS devices and undergo several assessments. Firstly, they had to answer some questions regarding the usability and the wearing comfort of the GPS device. Then, they had to report their movements over the last seven days by using the newly-developed map-based tool (MBT) under supervision (further descriptions about the tool are given in Chapter 4). Meanwhile, the examiner marked down the time used for completing the MBT, whether the participant could complete the MBT by him-/herself, and whether any questions were asked and, if so, regarding which aspects of the tool (e.g. handling or navigational or map elements, comprehension of descriptions or asked questions, reading the map and localizing points). Furthermore, the usability of the tool was assessed by a usability questionnaire, the System Usability Scale (SUS) by Brooke (1996), and with a question asking about difficulties encountered when using the tool (Appendix B, CRF 3). Afterwards, several health-related measures were assessed, such as anthropometric measures (height, weight and waist circumference), hand grip strength with a Jamar dynamometer (Sammons Preston, Bolingbrook, IL) as evaluated for example by Desrosiers et al. (1995), physical performance of the Short Physical Performance Battery (SPPB) by Guralnik et al. (1994), physical activity with the International Physical Activity Questionnaire (IPAQ) by Craig et al. (2003), history of falls over the past 12 months with the Falls Efficacy Scale – International Version (FES-I) by Dias et al. (2006) and health-related quality of life with the Short Form-36 Health Survey (SF-36) by Bullinger (2000) (Appendix B, CRF 4 and 5). As the aim of this thesis was to compare the new MBT to already known life-space mobility measures, participants had to fill out an adjusted LSA questionnaire after the MBT towards the end of the appointment (Appendix B, CRF 6). By following this order, it could, on the one hand, prevent participants from being influenced by the LSA when using the MBT for the first time. On the other hand, there was a time gap between the two measures which is big enough to slightly reduce the effect of the MBT on the LSA. The last measure of this appointment aimed to assess participants' cognition. For this, the Mini-Mental State Examination (MMSE) was used (Appendix B, CRF 7).

Third appointment. Finally, the third appointment took place approximately 3 weeks later. Again, participants had to report on their mobility during the preceding 7 days by completing the MBT and the LSA (Appendix B, CRF 8). The aim of this appointment was to assess the reliability of the newly-developed MBT. The following Section 3.5 now describes in detail the above-mentioned spatial and additional complementary measures.

3.5 Experiment measures

3.5.1 Spatial measures

GPS — sensor-based approach

For sensor-based life-space and activity measurements, participants had to wear the *uTrail* device, which is a small portable tracking device developed by CDD in Greece (www.cdd.gr) featuring three sensors: global positioning system (GPS), accelerometer and microphone. Figure 6 illustrates the size and features of the *uTrail*. The device has a power and microphone mute button, whereas the latter was not used as this study as we did not collect audio data from the participants. Further, the status LED in the center of the device indicates if there is GPS reception and accelerometer measurement (blue flashing light), no GPS reception but accelerometer measurement (flashing green), a low battery status or if it is charging during which no assessments are taken (flashing red). The participants were instructed to charge the device every evening by plugging it into an electric socket or by connecting the device to a computer via the USB interface. A USB charging cable was provided to the participants. Two versions of the device were available for this study, one with a cord which can be worn around the neck, and one with a clip for wearing the device on the waistband or the belt. Both types were used in this study, 30 participants (51.7%) used the one with a cord and 28 (48.3%) the one with a clip. The sampling rate of the *uTrails* was set to 1 second. Accordingly, the GPS coordinates (if satellite signal was available) and a physical activity count (similar to a step count, but not as accurate) were stored each second.

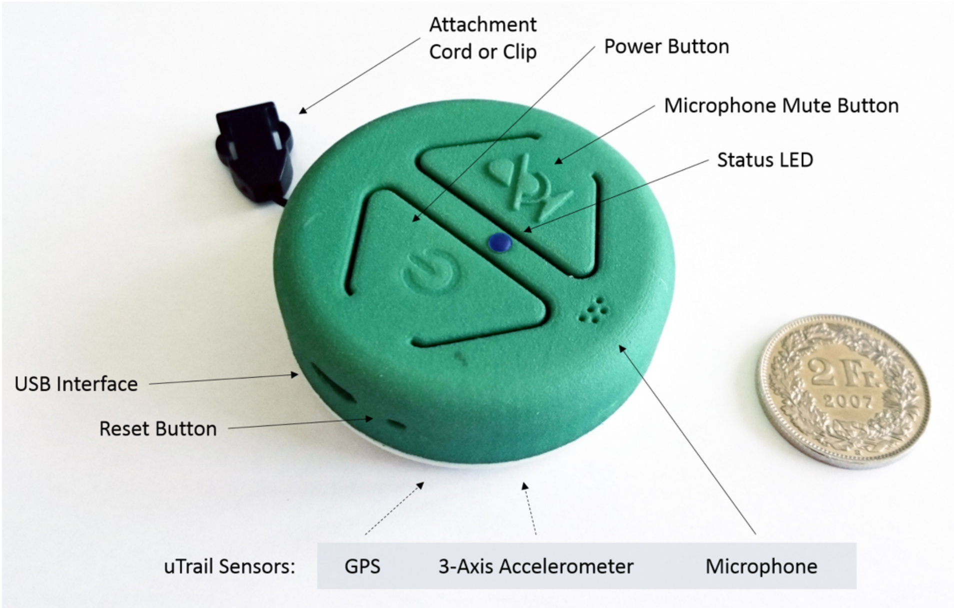

Figure 6: Illustration of the size of the uTrail compared to a Swiss 2Fr. coin.

Modified LSA — self-reported questionnaire

As it is not possible to distinguish between in-home and close-to home (surrounding/garden) locations based on GPS only because of possible signal wandering (Kerr et al., 2011), the focus was set on outdoor mobility. Furthermore, an inclusion criterion required that study participants frequently go outdoors. Hence, it can be assumed that there are no indoor mobility limitations among the study participants. Accordingly, the original LSA life-space levels, as illustrated in Figure 2 in Section 2.2.4 (Peel et al., 2005), were restricted and the level numbers were adjusted (Table 2). The original Levels 0, 1 and 2 were summarized as Level 0 (home). Accordingly, the original LSA Levels 1 and 2 concerning places in participants' home and the near surroundings (e.g. yard, porch, patio) were excluded. The remaining levels were assigned as follows: Level 1—in the neighborhood, Level 2—places outside the neighborhood, but in town and Level 3—places outside one's town. These designations will be used in the remainder of the thesis.

Table 2: Assigning the life-space levels of the modified LSA to the original life-space levels.

Type of LSA	**Assignment of life-space levels**					
Life-space levels of the modified LSA	**0**			**1**	**2**	**3**
Life-space levels of the original LSA	0	1	2	3	4	5

Moreover, the LSA was adapted for measuring mobility over the past 7 days, instead of four weeks. Yet, the modified LSA questionnaire still asked for the frequency with which the different levels were visited and if assistance was needed. Additionally, the questionnaire was translated from English to German, as the study was conducted in German and it could not be expected that all study participants were able to understand an English questionnaire (Appendix B, CRF 6 and CRF8_Q17-19).

Map-based tool (MBT)

In order to be comparable to the measures collected by the LSA and the GPS, a map-based tool (MBT) should at least be able to capture spatially-locatable places that were visited by the participants within a period of 7 consecutive days. Further, the life-space level, the frequency of visiting and the need for assistance to reach these places should be assessed. The development and implementation of the MBT and the resulting tool are described in Chapter 4.

3.5.2 Complementary measures

Spatial ability

The Santa Barbara Sense of Direction Scale (SBSOD) is a self-reported questionnaire which allows assessing participants' environmental spatial ability. It consists of 15 statements which are formulated positively or negatively and which can be rated with a Likert scale ranging from 1 to 7. The SBSOD was developed by Hegarty et al. (2002) and it has been used for several studies which intended to reveal correlations between people's spatial ability and space-related tasks, such as performance in different mapping tasks or the ability of older adults to drive to certain areas (Liben et al., 2010; Turano et al., 2009). In this study, the spatial ability measure was used as a variable to help understand participants' MBT performance. Accordingly, based on the questionnaire provided in Appendix B (CRF1_Q24) in Hegarty et al. (2002), the SBSOD was translated from English to German.

System Usability

The system usability scale (SUS) was developed by Brooke (1996) and it can be used as a low cost, broad, quick and simple system usability evaluation method. The SUS is organized according to 10 questions, which assess a user's subjective opinion of a system's usability. Moreover, the questions are formulated as statements, whereas the answers are given in the form of a Likert scale (1-5) representing a respondent's degree of agreement or disagreement with the statement (Brooke, 1996). Again, based on the provided SUS by Brooke (1996), the statements of the questionnaire were translated for German-speaking participants (Appendix B, CRF3_Q9 and CRF8_Q8).

Instrumental activities of daily living

Older adults’ ability to conduct instrumental activities of daily living (IADLs) was assessed by self-report based on the concept of Lawton & Brody (1969). In this study, participants were asked questions based on the health survey from 2012 in Switzerland (Appendix B, CRF1_Q7) regarding the degree of difficulty to prepare food, make a phone call, shop for groceries, do the laundry, manage light or difficult household work, take care of their finances and use public transport (Bundesamt für Statistik, 2014). According to their answers, a score from 0 to 8 is generated where 0 means that a participant has no difficulty in performing any of the mentioned IADLs, and the score of 8 would indicate difficulties with all IADLs.

Physical performance

For assessing physical performance of older adults, Guralnik et al. (1994) developed the Short Physical Performance Battery (SPPB). This includes an assessment of people’s balance with a side-by-side stand, a semi-tandem and a tandem stand, measuring the balance based on three different feet positions. Further, the gait speed over four meters, the ability to rise from a chair and the hand grip strength are measured (Appendix B, CRF 4).

Physical activity

The International Physical Activity Questionnaire (IPAQ) is a standardized self-reported measure of habitual physical activity (Appendix B, CRF5_Q1-7). The short version was used for the present study. Participants were asked about the number of days, over a period of 7 days, and the average time spent on each of these days performing exhausting and moderate physical activities, as well as walking and sitting. The IPAQ allows to determine a person’s activity level among one of three categories, low, medium or high (Craig et al., 2003).

Fall-related self-efficacy

The fall-related self-efficacy–international version (FES-I) assesses history of falls within the past 12 months. Furthermore, it asks for the degree of concern of falling when performing different activities, e.g. taking a bath or walking on slippery surfaces. A German version of the FES-I provided by Dias et al. (2006) was used (Appendix B, CRF5_Q8-10).

Health-related quality of life

The short form-36 health survey (SF-36) is a self-reported questionnaire which assesses a person’s health-related quality of life (Appendix B, CRF5_Q11-21). The SF-36 comprises questions regarding social, mental, physical and everyday aspects of well-being and functionality (Bullinger, 2000).

Cognition

Participants' cognitive condition was assessed with the Mini-Mental State Examination (MMSE). The MMSE allows to differentiate between people with or without cognitive impairment (Folstein et al., 1975). In this test, older adults were asked questions regarding temporal and spatial orientation. Additionally, they had to repeat words, solve simple maths problems and perform several other cognitive tasks (Appendix B, CRF 7). For each successfully solved question or task, they received a score of 1. This results in a scoring range from 0 to 30, whereby a score of 30 indicates that a person does not show any cognitive impairment.

3.6 The study participants

For the "MapSpace" study, 58 older adults (IDs: 10-67) were recruited, whereby one participant terminated the study after Appointment 2. As all the recruitment attempts were focused on the area of Basel, most of the participants lived in the city of Basel or in nearby municipalities. Their characteristics are summarized in Table 3, which is an excerpt from the MSc thesis by Schmid (2017). The average age among study participants was 74 years ranging from 65 to 87. Furthermore, 23 (out of 58; 39.7%) participants were female. All the participants went to school or completed occupational training for at least 8 years, 24 had an educational career of 13 to 16 years and 14 participants were in training for more than 17 years. An education of 8 to 12 years would encompass, e.g., elementary school, and high school or an apprenticeship. And more than 17 years of education is comparable to, e.g., a Master's degree at a university.

Considering the modes of transport, most of the participants used public transportation (55.2% at least once a week and 37.9% less frequent), and more than three-quarters (77.6%) had the option of using a private car. Furthermore, focusing on health-related aspects, most of the participants (77.6%) had no difficulties in performing instrumental activities of daily living (IADL). Almost half of the participants had arthritis (48.3%) and one third had visual problems (34.5%). Additionally, almost none of them used any walking aid (98.3%). The overall cognitive condition assessed with the MMSE shows a mean count of 27.6. However, 3 participants had an MMSE count of 23 (of 30) or lower, which is usually considered as being indicative of cognitive impairment (Lezak, 2004). The final characteristic assessed with the IPAQ represents the self-reported physical activity which shows that almost half of participants had high (46.6%) and a further half had a medium activity level (48.3%). However, two participants had a low activity level.

Table 3: Characteristics of the "MapSpace" study participants based on Schmid (2017).

Characteristic	N (missing)		Min.; Max
Sociodemographic and –economic data			
Age, mean ± SD	58	74.0 ± 5.5	65; 87
Female, n (%)	58	23 (39.7)	
Years of school or occupational training, n (%)	58		
8-12 years		20 (34.5)	
13-16 years		24 (41.5)	
≥ 17 years		14 (24.1)	
Use of modes of transportation			
Use of public transport, n (%)	58		
Never		4 (6.9)	
Less than once a week		22 (37.9)	
At least once a week		32 (55.2)	
Possibility to use a private car, n (%)	58	45 (77.6)	
Health-related aspects			
IADL count (0-8), n (%)	58		
0		45 (77.6)	
1		9 (15.5)	
≥ 2		4 (6.9)	
Arthritis, n (%)	58	28 (48.3)	
Visual problems, n (%)	58	20 (34.5)	
Aids for walking, n (%)	58		
No aids		57 (98.3)	
Walking stick		1 (1.7)	
Rollator		0 (0)	
MMSE Count (0-30), mean ± SD	58	27.6 ± 2.3	17; 30
Physical activity			
IPAQ Activity Level, n (%)	57 (1)		
High		27 (46.6)	
Medium		28 (48.3)	
Low		2 (3.4)	

N/n = number of participants; SD = standard deviation; IADL = Instrumental Activities of Daily Living; MMSE = Mini-Mental State Examination; IPAQ = International Physical Activity Questionnaire

4 Workflow of this thesis

In order to answer the research questions of this thesis, as given in Section 2.3, this thesis consists of four parts (Figure 7). First, a map-based tool (MBT) to measure life-space mobility of older adults in the "MapSpace" experiment was developed (described in Chapter 5; **RQ1**). Tool requirements were derived from the analysis of the pre-study in which geographers were asked to sketch their life space and the literature review of papers in which similar tools were examined (Section 5.1). Afterwards, based on the tool requirements, the user-oriented requirements can be identified by considering research papers which elaborated design guidelines for older adults by focusing on other technologies, such as websites, maps and TV services (Section 5.2).

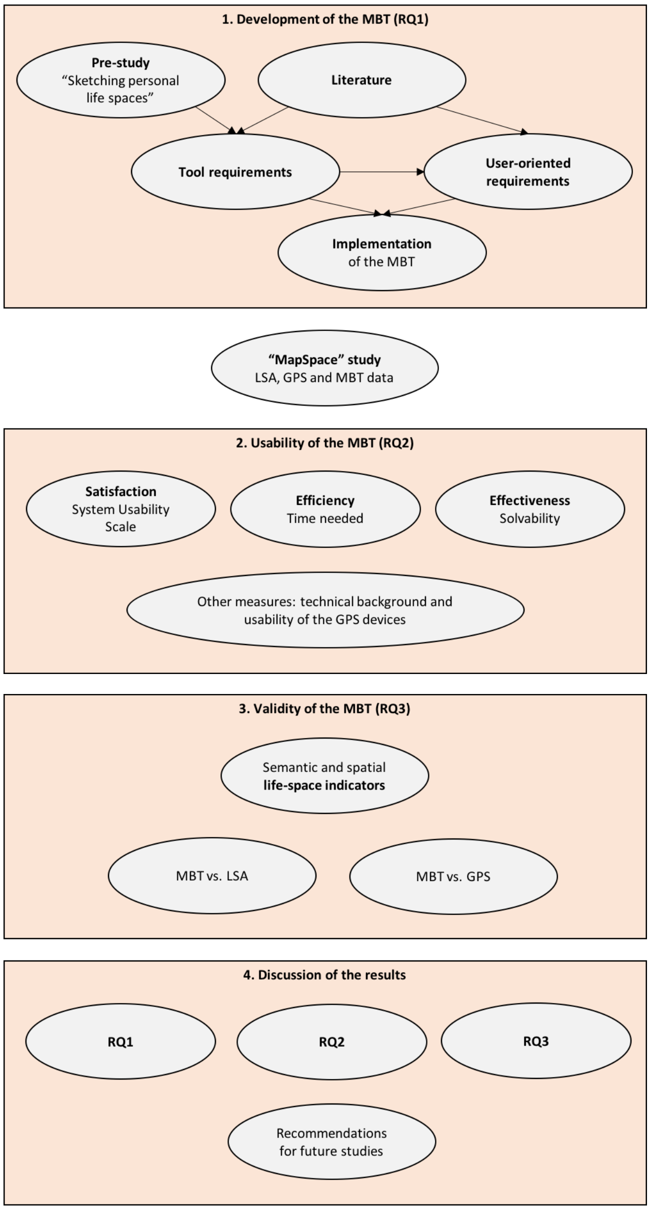

Figure 7: Workflow of this thesis.

The data as assessed within the "MapSpace" experiment forms the basis for the following workflow steps of this thesis: the comparison and evaluation of the newly-developed MBT with the frequently-used life-space measures LSA and GPS.

Accordingly, the second step of the workflow evaluates the usability of the MBT with a system usability evaluation method and by comparing against other criteria such as time efficiency, older adults' technical background and other measures (Chapter 6; **RQ2**).

Third, the focus is set on the validity of the MBT by investigating older adults' life-space areas in the context of the spatial extent and the distribution of visited locations measured with the three different measurement approaches. Therefore, different spatial and semantic life-space indicators are elaborated to correlate the results of the MBT with that generated from the LSA and the GPS data (Chapter 7; **RQ3**).

In the fourth and final step, the results of the preceding steps were discussed to give recommendations concerning the feasibility of the MBT in assessing older adults' life-space mobility regarding future studies (Chapter 8).

5 Development of a map-based tool

Defining the purpose is essential for the development of a usable and appropriate tool or application (Brooke, 1996). As highlighted in the preceding chapters, there is a need for new approaches to assess older adults' life-space mobility, which is addressed with the aim of this thesis—the development of a map-based tool (MBT) for older adults as a new approach in life-space mobility research. Consequently, the general purpose of the herein described MBT is to assess older adults' self-reported life-space mobility. To meet this goal, the requirements for such a tool must be identified.

In Section 5.1, the tool requirements are identified. These build a framework for the identification of the user-oriented requirements, described in Section 5.2. Subsequently, in Section 5.3, a framework is chosen in which the MBT can be developed. And finally, Section 5.4 illustrates the development process and the implementation of an MBT which aims at measuring older adults' life-space mobility.

5.1 Tool requirements

Section 5.1.1 elaborates the fundaments to identifying tool requirements by describing the concept of place and how it could enhance understanding of individuals' mobility, the pre-study "Sketching personal life spaces", which should incorporate the advantages of the place concept, and by elaborating which type of mapping approach and which output device will be used for the new MBT. Subsequently, first tool requirements are derived from the results of the pre-study (Section 5.1.2). Then, technical tool requirements are identified by reviewing literature (Section 5.1.3). Firstly, the focus is on aspects of the design and interactivity of web-mapping applications. Secondly, the conceptual aspect is determined, namely the relevant geographic primitives (point, line and/or polygon) to sketch life spaces on a map. And, finally, Section 5.1.4, summarizes the identified tool requirements.

5.1.1 Elaboration of the fundamentals to identify tool requirements

As mentioned in the state of the art, definitions of life space or activity space and the already-known measurement approaches GPS and LSA rely mostly on the spatial components of people's mobility and only to a small degree on additional semantic information related to space. However, the mostly spatial approaches of life space are extended with the concept of place, which is a familiar but contested concept in the field of human geography (Cresswell, 2014). More concretely, Tuan (2013) argues that spaces are delineated by boundaries and consist only of physical attributes. The concept of place assumes that a space can be transformed into a place when local knowledge or personal experience are annotated to a location (Moore et al., 2013;

Purves & Derungs, 2015). Further, attaching personal information to a space has also been examined in PPGIS-related research (Brown et al., 2015). Accordingly, the concept of life-space mobility, when measured with an MBT, could be enhanced by associating more personal semantic information with visited locations. Consequently, personal experience and place attachments could be gathered to examine a person's connection to a place which could support a better understanding of mobility.

To evaluate which further semantic attributes could be of interest in the context of measuring life-space mobility with an MBT, we have conducted a small pre-study involving geographers at the University of Zurich and some of their friends. The aim of this pre-study was to examine how different people sketch their personal life space without searching for any definition of the term. For this, a two-sided questionnaire was elaborated whereas, on the first page, subjects were asked about their geographic education and, on the second page, they could freely sketch their life space. This approach is based on the idea of mental mapping which is mostly used to assess subjective representations of environments (Kahila & Kyttä, 2009; Perchoux et al., 2013). By looking at the resultant sketches, several elements could be identified which were represented in participants' sketches. These elements and the resulting output of this pre-study are presented in the following Section 5.1.2.

Before the technical tool requirements for the MBT can be identified in Section 5.1.3, we had to decide between the following two types of mapping approaches: a paper-based or a web-based approach. The purpose of the tool is that older adults can sketch locations on a map and assign attributes to each of them. As already mentioned, older adults demonstrate unequal technological experience induced by cultural and generational differences (Rice & Alm, 2008). Since their technological knowledge can be very high or very low, the question of whether the MBT should be in paper form or if a web-based application would be more effective was raised. It was decided the outputs of the latter would be easier to analyze because the data would already be in a digital form and the map extent could be adjusted for each participant.

Several studies have focused on the evaluation of paper-based versus web-based surveys. Commonly, as revealed, for example, by Pocewicz et al. (2012) in the context of PPGIS, it is assumed that paper-based surveys show a higher response rate than internet-based questionnaires. Pocewicz et al. (2012) highlight that people mapped more places when paper-based questionnaires were provided instead of internet-based ones. Furthermore, they found out that younger participants tended to use the web-based survey (Pocewicz et al., 2012). Further, Manfreda et al. (2008) conducted a meta-analysis of response rates with different survey modes. Again, the response rate with web surveys was lower, but the following explanations for this trend were given: the sample recruitment base, the solicitation mode and the number of contacts (Manfreda et al., 2008). As these studies mostly focused on the response rate of the different survey types, the preference of survey modes in study examinations had to be taken into account. Shiffman et al. (2008) found that study participants, including older adults, prefer electronic devices to paper-based applications. Based on these findings, it can be assumed that older adults prefer to use a web-based application to mark visited locations, instead of drawing them on a paper map. Consequently, the technical tool requirements for the MBT will be identified for a web-based mapping application.

Thus, it had to be decided which output device, such as a computer or a tablet, was going to be used for the web-based mapping tool in the “MapSpace” study. Unfortunately, there were no tablets available at the University of Zurich or at the University of Basel, so the MBT had to be implemented on a computer. Subsequently, a mouse and a keyboard were fixed as the input devices.

5.1.2 Evaluation of the pre-study “Sketching personal life spaces”

The pre-study which aimed to investigate the elements of sketches of personal life spaces included 20 participants. Thereof, 18 were geographers from the Department of Geography at UZH whereas their actual positions were BSc (1), MSc (8) or PhD (9). The focus of their research was in the fields of remote sensing (3), geovisualization and analysis (6), GIScience (7) and geocomputation (2). Here, it must be highlighted that the study group was not very representative, especially not compared to older adults. However, it seems reasonable to rely on the geographers’ sketches in order to get an impression of which elements could be important when using the concept of life spaces. Nonetheless, the following results should be handled with caution.

The life-space sketches differed in several ways (Figure 8): upper left—designed with circles to which several attributes or activities had been added such as mind maps; lower left—almost no text and location names, most similar to an image; upper right—many explanations regarding the frequency of visiting and the activities at a place, seasonal references and used mode of transportation (MOT); lower right—highlights the relations between places and used MOTs to reach a place.

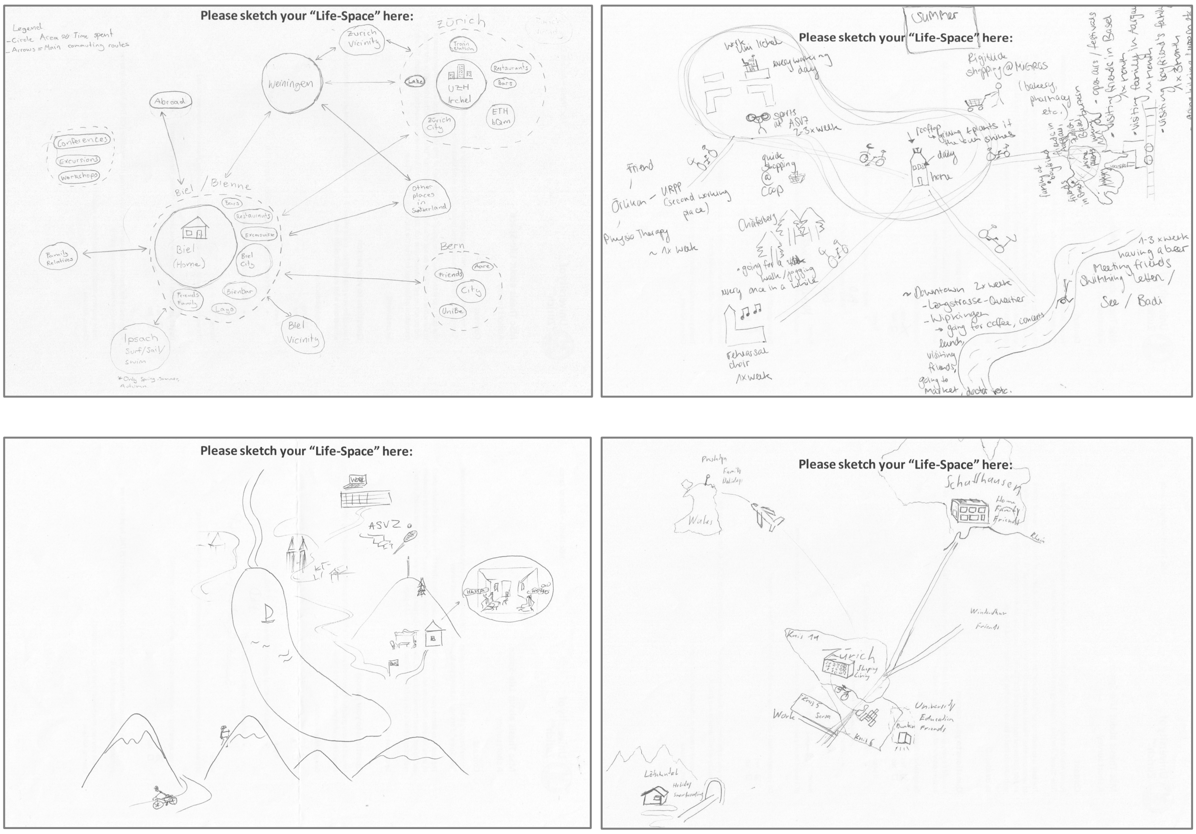

Figure 8: Examples of different life-space sketches.

By looking at all the life-space sketches, different categories and inherent elements could be identified, such as that summarized in Table 4. Almost all pre-study participants—19 out of 20—mentioned their home and added semantic information to sketched places. The semantic information mostly concerns modes of transportation (MOTs) between different activities at the mentioned places. Sketched MOTs were bicycles, trains and planes. Additionally, several public transportation stops were sketched. All these elements belonging to the category "transportation" could be found four or five times in the different life-space sketches. Furthermore, the most frequently-assigned activities were work, meeting people, sports, family, going for a drink or shopping (mostly groceries). Some of these activities were mentioned by almost all the participants and others were sketched only a few times. Accordingly, the frequency of sketching different activities varied more than the frequency of sketching MOTs which were all almost equally represented. Moreover, some temporal aspects were mentioned, such as the frequency of visiting places and the season dependency of the life space in general. Finally, the life-space sketches allowed to identify further sketching elements which were assigned to two additional categories, namely map elements and conceptual aspects. The most commonly-mentioned map elements were city names and water bodies. Regarding the conceptual aspects, connections between places and the representation of places with points were used.

Table 4: Identified categories and elements in the personal life-space sketches.

Categories	Elements	Participants who sketched the inherent element (n = 20)
Home	Home	19
Semantic information	Add information to place	19
Modes of transportation (MOTs)	Public transportation stop	5
	Bike	5
	Train	5
	Plane	4
Activities	Work	19
	Meeting people	13
	Sports	13
	Family	10
	Drink	7
	Shopping	6
	Holidays	3
	Climbing	1
Temporal aspects	Time/ Frequency	4
	Seasons	2
Map elements	City names	17
	Water bodies	13
	Mountain	8
	Abroad	8
	Trees	7
	Streets	2
	Buildings	2
	Terrain	1
Conceptual aspects	Connection between places	13
	Points	4

Firstly, the results in Table 4 suggest that home and additional semantic information, such as modes of transportation (MOTs), activities and temporal aspects, are essential for defining a person's life space. The use of a certain MOT can give indications to the physical capabilities of the moving person, as well as to the effective physical activity or the mobility lifestyle of a person. Active commuting has the potential to largely contribute to an individual's overall physical activity. For example, a person who uses the car everyday could be constrained in his/her physical functioning or the person is just used to driving the car. Independently, this person shows a low physical activity during commuting. By contrast, a person who regularly moves around by bike or by foot might have better physical functioning and is more physically active during commuting. Others might commute inactively (by car or public transport) but engage in physical activity or exercise at the visited location (and thereby compensate for the inactive commute).

Moreover, knowing the activities helps to understand what a person does and experiences at a specific place. Furthermore, whether a person visits a place voluntarily or not could be determined. In the context of measuring older adults' mobility, this aspect could be essential. As an example, if a person is sick and goes regularly to a doctor, the life space represents a forced form of mobility and not necessarily a person's general mobility. Accordingly, by including the activity or the purpose of visiting a place, the life space of a person could be evaluated with respect to the voluntariness and the necessity of movements. These findings emphasize the activity-based approach described by McNally & Rindt (2008). This approach also assumes that mobility behavior is "related to and derived from differences in lifestyles and activity participation among the population" (Jones et al., 1990, In: McNally & Rindt, 2008). Consequently, the purpose of visiting a place and the used MOT could enhance the evaluation of older adults' life-space mobility. So, these aspects should be integrated into tool requirements.

Finally, temporal aspects were raised in a few sketches. Time- and frequency-related elements have already been examined in the already known life-space measurement approaches, directly with the LSA and indirectly with sensor-based measures such as GPS. But the mentioned seasonal element suggests that places which belong to a personal life space can be visited once, only during a specific season or regularly, independently from other influencing factors. As an example, Mount Everest is most probably only ascended once in a lifetime, public swimming pools are only visited in summer, but a person would go to work every day regardless of the season. Accordingly, it may be of interest to distinguish between regular and exceptional places. So, a general frequency of visiting a place during the period of a year could be included as a tool requirement.

Secondly, the pre-study emphasizes the importance of several map elements. Generally, city names, water bodies, streets and buildings are essential for orienting on a map (e.g. Kovanen et al., 2012). Furthermore, the relevance of going abroad has been highlighted. Consequently, the technical tool requirements should consider a map which includes at least city names, water bodies, streets and buildings, and which allows to mark locations outside of Switzerland.

And, thirdly, the conceptual aspects highlight the importance of relations between places and that places are often visualized as points. Accordingly, they will be further discussed in the context of technical tool requirements (Section 5.1.3).

5.1.3 Literature review regarding technical tool requirements of an MBT

As described in Section 5.1.1, the framework of the MBT has been defined as an interactive web-mapping tool which will be operated on a computer with a mouse and a keyboard. It is almost impossible to create a definitive list of interactive web-mapping guidelines (Meng & Malczewski, 2009), but an approach to summarizing at least some recommendations to identify technical tool requirements can be stated. The list below provides principles of general web design and recommendations regarding the layout, design and interactivity of mapping applications, which could be relevant for the development of an MBT (Kraak, 2004; Meng & Malczewski, 2009; Nielsen, 1999; Nielsen & Pernice, 2010; Nivala, Brewster, & Sarjakoski, 2008):

General

- (T5.1) The web-mapping application should be clearly structured
- (T5.2) Highlight important information, the most important elements should stand out
- (T5.3) Support simple navigation
- (T5.4) Provide a tutorial and/or a help button which describes the use of the map and other functionalities of the application
- (T5.5) Consider the trade-off between introducing a new tool and maintaining consistency with existing tools

Website design

- (T5.6) Buttons should look clickable
- (T5.7) A page design in bright colors
- (T5.8) Harmonious color concept

Map interactivity

- (T5.9) Allow zooming in and out
- (T5.10) Allow panning with a continuous click-and-drag option
- (T5.11) Provide search functionality
    - Search box in which it is clarified what type of searching criteria can be entered
    - Center the map according to the search results

After providing general technical guidelines for the development of an interactive web-mapping tool, the conceptual aspects of such a tool need to be determined. This means that the relevant geographic primitives (point, line and/or polygon) to sketch life spaces on a map need to be identified. A first approach for this evaluation is to have a look at three commonly-used life-space representations generated from GPS data by Hirsch et al. (2014) shown in Figure 3 (Section 2.2.4). The first picture shows a standard deviational ellipse (SDE), which does not cover the whole extent of the person's movement, but it is a compact area. The second is a minimum convex polygon (MCP). The area includes all the GPS points, but it is susceptible to outliers, which could easily originate from GPS measurements. The third shows a daily path area (DPA), which is seen as a buffered line. As we can see, a clear definition of how a life space should be represented does not exist. The representation which is the most useful for life-space mobility studies still has to be examined. Furthermore, the outcomes and the accordant interpretations may vary; e.g., the SDE highlights the directional distribution of a person's mobility, the MCP can be used to encompass home ranges and the DPA is ideal for analyzing trips. All these representations aim to evaluate life-space mobility. Consequently, the focus should be on allowing as many different representations as possible.

Accordingly, the relevance of each geographic primitive needs to be evaluated. In the context of examining an individual's mobility, a line is mostly seen as a trip which connects points in the correct sequence of a movement. A polygon covers an area, as for example the perceived neighborhood (Chaix et al., 2012). But the foundation of lines and areas are points, because both can be generated by connecting points or by analyzing their distribution. As an example, the three representations in Figure 3 have been generated out of GPS tracking data, which is also based on the measurement of points. Additionally, the evaluation of the pre-study where personal life spaces were sketched relied on the use of points and connections between places. Consequently, the geographic primitive "point" is essential for evaluating a person's life-space mobility. However, directly collecting lines as connections between places or perceived areas which are relevant for individual's movement behavior can be a plus, but it is not essential for evaluating a person's life space.

5.1.4 List of tool requirements

This section combines the findings of Sections 5.1.2 and 5.1.3 with the literature cited in the state of the art. Based on these approaches, the following tool requirements for a map-based tool (MBT) aiming at measuring older adults' life-space mobility can be identified:

- (T1) Based on the definitions of life space and based on the advantages of GPS measurements, the MBT should allow capturing spatially-referenced data of visited locations for measuring the spatial extent of movements.
- (T2) The MBT should at least be able to collect visited locations with the geographic primitive "point". Lines and areas would be a plus, but they are not essential.
- (T3) Based on the results of the "life-space sketches" pre-study, the MBT should examine a person's home location.
- (T4) Relying on the LSA approach, the concept of place and the evaluation of the pre-study, the MBT should gather the following semantic information:
  - (T4.1) the life-space level of each visited location
  - (T4.2) the frequency of visiting the location during a measurement period
  - (T4.3) the need of assistance to visit a location
  - (T4.4) the modes of transportation to reach a place
  - (T4.5) the purpose of visiting a place, respectively the activity at a location
  - (T4.6) the regular frequency of visiting a place (independently of the life-space measurement period)
  - (T4.7) the name or a description of the place
- (T5) The MBT should consider the technical requirements listed in Section 5.1.3, which employ general web-design principles and recommendations for map interactivity.
- (T6) In the pre-study, different map elements have been mentioned, city names, water bodies, streets and buildings. These elements should at least be integrated in the map design of the new tool.
- (T7) Based on the aim of this thesis of reducing the burden of time compared with GPS measurements, entering data through the MBT should be able to be done within a reasonable amount of time.

For comparing the MBT data to the data measured with a GPS device, the attributes "time spent at a location" and the date a place was visited would be needed. But as people visit places multiple times and do not stay there for the same amount of time, it would be inefficient to let them mark a place multiple times in order to adequately meet date and time requirements. Accordingly, these two attributes are not included in the above tool requirements list.

5.2 User-oriented requirements

Kraak (2004) stated that map providers must consider the development of technologies and the user-oriented requirements. As the first has been considered in the sections above, this section focuses on the latter, the user-oriented requirements. Additionally, ISO 13407 states a need for a user-centered design (UCD) when developing interactive applications (ISO, 1999). UCD is the key to developing a useful and usable tool (Mao et al., 2005). As the MBT will be used by older adults who may have a low technical affinity and encounter physical and cognitive impairment when aging, the MBT should be adapted to the specific needs of this user group. Yet, there is almost no literature focusing on the usability of interactive maps for older adults. Accordingly, it is necessary to consider research papers which gave design guidelines for older adults by focusing on other technologies, such as websites, maps and TV services. By reviewing this literature, user-oriented requirements can be defined and later adapted for the development of the MBT in the context of this thesis.

One of the first papers focusing on design guidelines for older adults was presented by Carmichael (1999). He elaborated a style guide which deals with the design of interactive television services for older adults. Further research has been conducted in this field as television technologies have advanced. For example, Rice & Alm (2008) developed four different designs for digital interactive television interfaces and examined their usability among older adults.

But also in the context of website usability for older adults, several studies have been conducted. The U.S. National Institute on Aging (NIA) and the U.S. National Library of Medicine (NLM) provided guidelines for designing websites such that they are usable for older adults. The objective of these guidelines was to eliminate barriers based on older adults' impairments in vision, cognition, motor skills and literacy (NIA & NLM, 2002). Based on these guidelines, Becker (2004) evaluated 125 web pages offering health resources according to their usability for older adults and found that many of the sites were not senior-friendly. Further, Kurniawan & Zaphiris (2005) and Zaphiris et al. (2006) elaborated research-derived web guidelines for older people by collecting already stated ones, removing overlaps and grouping them into 11 distinct categories. Gottwald et al. (2016) extended the approach of website usability for older adults by examining the use of PPGIS among this user group. After conducting a qualitative and descriptive study, they could identify several aspects which would improve the usability of PPGIS for older people. The results support the findings of previous studies, which only focused on more general Internet-related usability (Gottwald et al., 2016). Accordingly, the guidelines of the latter can also be used for the identification of user-oriented requirements for the MBT developed in this thesis.

Another research field focuses on the design of mobile maps for older adults. Kovanen et al. (2012) present an approach of plain cartography to provide simple maps which have been tested with older adults on mobile devices. Their focus is on simplifying map design and improving readability of maps for visually-impaired users. Accordingly, they highlight the most important map elements which are necessary to read a map and removed redundant information.

Based on the findings of the authors mentioned in the section above, a list of user-oriented requirements and guidelines for the MBT was derived. The findings are summarized in the following list (Becker, 2004; Carmichael, 1999; Gottwald et al., 2016; Kovanen et al., 2012; Kurniawan & Zaphiris, 2005; Rice & Alm, 2008; Zaphiris et al., 2006):

Language and functionalities

- (U1) Use simple language, and a familiar and positive writing style
- (U2) Provide clearly-defined and descriptive labels, annotate them with additional explanations and provide clear and unambiguous instructions
- (U3) Avoid double mouse clicks
- (U4) Avoid the drawing of lines
- (U5) Avoid the use of mouse wheel functionalities or scroll-down tasks
- (U6) Do not use drop-down menus or other features which hide information
- (U7) Reduce the functionality of an application to a minimum

Website design

- (U8) Provide clear, large headings
- (U9) Reduce the number of buttons on the screen and provide large buttons
- (U10) Text should be aligned to the left and text lines should not be too long
- (U11) Use large font sizes and sans serif font styles, and enlarge line spacing reasonably
- (U12) Choose highly contrasting foreground and background colors (no patterned background)

Map design

- (U13) Remove redundant information and labels
- (U14) Labels should be in black with halo
- (U15) Simplify symbols of map features
- (U16) Combine road classes
- (U17) Show fewer details on buildings

Guidelines which have already been identified in the tool requirements part are not listed again (Sections 5.1.3 and 5.1.4). But a major trend that can be revealed by considering this list of user-oriented requirements is that an MBT for older adults should simplify use as much as possible. Accordingly, the tool requirements which could present major difficulties, e.g. asking older adults to draw lines or polygons on the maps, should be reduced to a minimum. Accordingly, an adapted list of all the tool and user-oriented requirements can be found in Appendix A.

5.3 Choosing an appropriate framework for developing the MBT

Once all the requirements had been defined, we had to decide which framework would be the most appropriate for implementing an MBT which meets the tool and user-oriented requirements. There are two principal options: relying on an existing map tool or developing a new MBT from scratch. Among the possible existing tools are Maptionnaire[2] (fee-based), mark-a-spot[3] (open source), Geoform[4] (ArcGIS Online Template) or ArcPad[5] (mobile field mapping and data collection software). The first three are structured like a questionnaire including a map and the last is more like a desktop GIS. Accordingly, the latter could be too complicated for older adults. By contrast, a map-based questionnaire could be a good approach as it is assumable that questionnaires are a more familiar tool among older adults. This familiarity with questionnaires would support the requirement which highlights that parallels should be built to known applications. The only problem is that Maptionnaire and mark-a-spot have been designed for supporting PPGIS and it could be difficult to adapt those tools to the requirements of an MBT which aims to measure life-space mobility. And, finally, there is reason to fear that Geoform is too much oriented towards a questionnaire form than representing a map, so that the interactivity with the map could get lost. Consequently, it was decided that the best approach for developing an MBT for assessing older adults' life-space mobility was to implement it from scratch. The implementation is based on the *mappysurv* code[6] which has been adapted and extended to take into account the tool requirements defined for the MBT aiming to assess older adults life-space mobility (Section 5.4).

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[2] Maptionnaire (n.d.). Available at: https://maptionnaire.com [Accessed May 22, 2016].

[3] Mark A Spot (n.d.). Available at: http://www.markaspot.de [Accessed May 22, 2016].

[4] Esri (n.d.). Rate the Geoform. Available at: https://www.arcgis.com/apps/GeoForm/index.html [Accessed May 22, 2016].

[5] Esri (n.d.). ArcPad. Available at: http://www.esri.com/software/arcgis/arcpad [Accessed March 13, 2017]

[6] The *mappysurv* code has been implemented by Julian Kissling with HTML, JavaScript and CSS.

5.4 Implementation of the MBT

Firstly, this section gives an overview of the technical framework used to implement the MBT. Then, the resulting MBT is described by considering the above-defined tool and user-oriented requirements. And, finally, the database in which the collected data is saved is described.

5.4.1 The technical framework of the MBT

For implementing an interactive web-mapping tool, a web server is needed. The basis for this was a virtual machine with Ubuntu Server 16.04 LTS (Xenial Xerus). On this server, LAMP[7] was installed for building dynamic websites or web applications. LAMP consists of four components: Linux, Apache, MySQL and PHP. Linux is a server operating system; Apache HTTP server is used as a web server; MySQL is a relational database management system (RDBMS) and Hypertext Preprocessor (PHP) is a server-side scripting language. The versions of the four components used for the implementation of the MBT are shown in Table 5. Furthermore, phpMyAdmin was installed to directly access the MySQL database with a web browser.

The MBT was implemented with HTML (Hypertext Markup Language), JS (JavaScript) and CSS (Cascading Style Sheets). Furthermore, the jQuery library (version 2.2.4) was included which allows for HTML document traversal and manipulation, event handling and asynchronous JS (https://jquery.com). For creating a coherent design, the Bootstrap framework (version 3.3.6) was used which provides several features such as dialog prompts (modals), navigation bars or buttons (http://getbootstrap.com). For providing a map and several map functionalities in the MBT, the Google Maps JavaScript API and its Drawing library were used. Icons and symbols in the MBT were created with toolkits from Map Icons (http://map-icons.com) and Font Awesome (http://fontawesome.io) to simplify the symbols on the map (U15). The resulting MBT was implemented exclusively for use in a Chrome browser and was not further improved or tested in other browsers. Furthermore, the responsiveness of the website is not given for each screen resolution.

Table 5: Versions of LAMP components on the server.

Component	Version
Linux operating system	Ubuntu 16.04 LTS
Apache HTTP server	Apache 2.4.18
MySQL RDBMS	MySQL 5.7.17
PHP	PHP 7.0.15

[7] Wikipedia (2017). LAMP (software bundle). Available at: https://en.wikipedia.org/wiki/LAMP_(software_bundle) [Accessed March 20, 2017]

5.4.2 Structure of the MBT

The main purpose of the MBT is to assess older adults' life-space mobility as spatially referenced data (T1). Therefore, the MBT consists of two elements: an application (a) and a database (b). Furthermore, requirement (T5.1) states that a web application should be clearly structured. Hence, (a) is built up in three parts: (1) a start page for correctly saving the entered data at the end of part (3), (2) a welcome and instructions part for the study participants (T5.4), and (3) a map part in which participants can report on their life-space mobility. When participants completed (a) from (1) to (3), participants' entries were stored in (b).

Next, the aim and the functionalities of the two MBT elements (a) and (b), and the three parts of (a) are described.

(a) Application

The parts (1) and (2) are built as Bootstrap modals which overlay part (3) of the application. The buttons on each screen invite the user to show the next and hide the current modal. This allows storing the entries of part (1) in the background until they are used at the end of part (3). However, this leads to short disruptions which show the map part in the background.

(1) The start page. When the MBT application is opened in a Chrome browser, the start page shows two fields in which a project name and a participant's identifier must be entered (Figure 9). This is meant to be filled out by the study examiner so that the data collected in the final map part (3) is saved correctly in the database (b) after fully completing the MBT application. The project name should correspond to the name of a table in (b) and the participant's identifier is used as ID of the new entry in the database table.

Once the two fields are filled out, the button on the lower right can be clicked. Thereupon, an alert is invoked which shows the entries of the fields so that the examiner must double check if those are correct. After confirming this alert, the participant's welcome page appears.

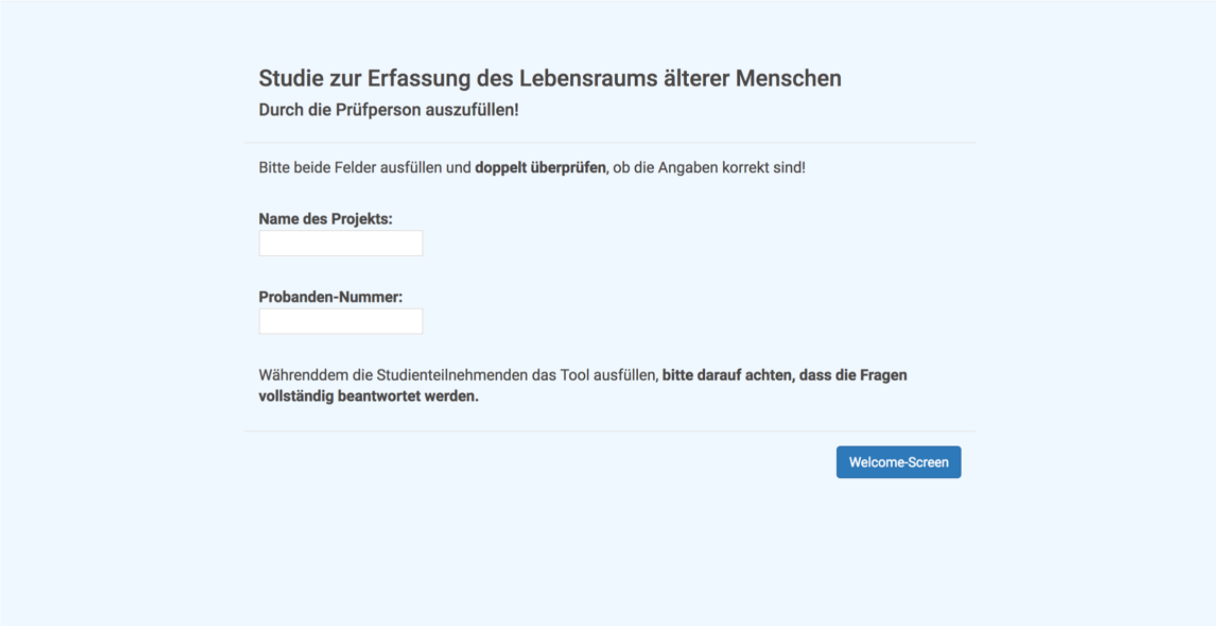

Figure 9: The start page of the MBT.

(2) Welcome page and tutorial (T5.4). This part of the MBT application aims to introduce participants to the navigation of the application and the functionalities of the map part (3). It consists of a welcome page and a tutorial. The welcome page informs participant that they can always ask the examiner if they have any questions. Additionally, it gives a short instruction on how to navigate with the blue buttons within the application. In the whole application, those navigation buttons always look the same and they always contain a text element which indicates what comes next.

The entire tutorial consists of five pages, which address several aspects of the map application (3). Firstly, an introduction to the structure of (3) and the according tasks is given. The structure is illustrated with an image showing the segmentation of (3) and an example of how to solve a task is presented (Figure 10). The second tutorial page explains how the life-space mobility will be measured with different life-space levels (more details are given in part (3) below). The page describes and highlights those levels with different colors in the text and with an image of part (3) which shows the different symbols on the map. Furthermore, it is stated whether a location should be marked on the map or not. Thirdly, the tutorial shows how to find a location on the map by using the search box on the map, or by panning the map and zooming in and out. Again, a screenshot of the map is provided which indicates the position of the described functionalities. The fourth page of the tutorial explains how to set a marker on the map and how to provide additional information on each location. Lastly, a written description and an illustrative image elucidate how wrongly-placed points can be deleted. By clicking the blue button in the lower right corner of this page, the map application (3) appears.

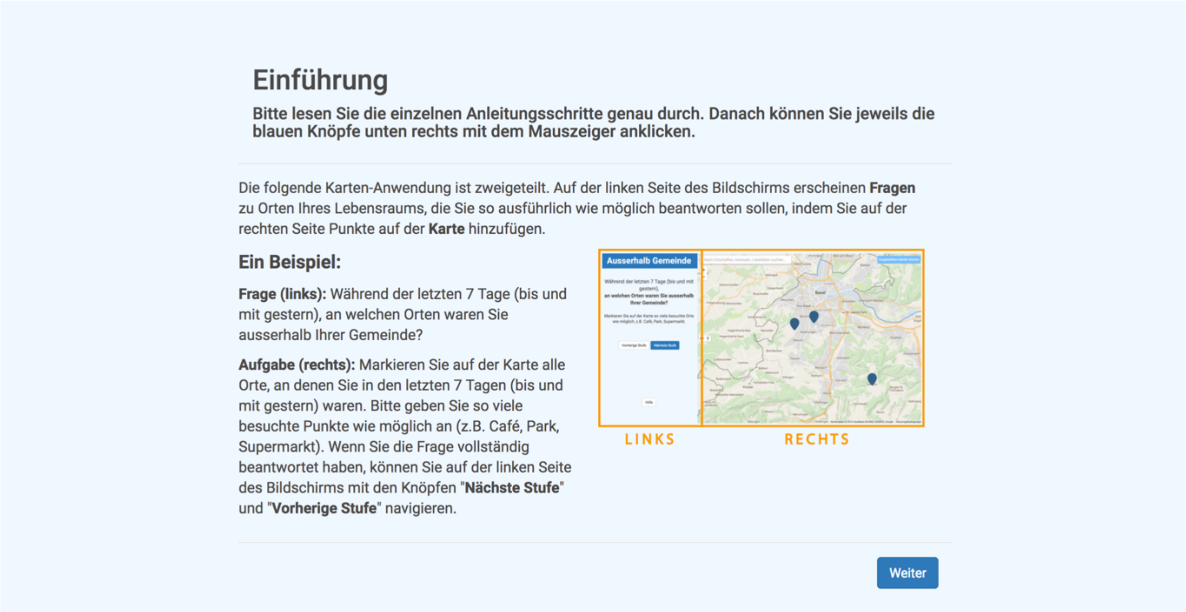

Figure 10: As an example, page 1 of the tutorial—introduction to the map application.

(3) Map application. This part aims to collect data on participants' life-space mobility during a specific measurement period, in this case the past 7 days. Figure 11 is the enlarged version of the graphic in Figure 10, showing more detail. It illustrates that the map application splits the screen into a left and right pane. The left side states questions, in the style of the following: "During the past 7 days (until yesterday), which places did you visit in your neighborhood?". The questions are supposed to be answered by marking points on the map on the right-hand side of the screen.

The left screen has been conceived as a questionnaire which is inspired by the requirement (T5.5) ensuring the consistency of a new tool with existing tools. Furthermore, the idea was to ask questions stepwise in order to stimulate participants' memory in recalling places visited. There were two possible approaches to building the questionnaire in a stepwise fashion: first, by asking for different activities and, second, by asking for life-space levels. The first was discarded as it would be too onerous to ask for all possible types of activities which are conducted in people's everyday life. Accordingly, the questions on the left side of the screen ask participants about visited places in the different life-space levels, as predefined by the LSA. However, different to the LSA, the MBT allows to firstly assess the home location (T3), followed by a question for each of the three LSA life-space levels: "within neighborhood", "outside neighborhood but within the municipality", and "outside a person's municipality" (T4.1). The questions regarding the different levels ask for visited places within the past 7 days as defined for the "MapSpace" experiment. Furthermore, these questions were formulated in the same way as the questions in the LSA. After the question to the last life-space level, the left screen highlights that the participants have arrived at the end of the test and a saving button is provided. The column on the left states the current level in the header (dark blue). The field below (light blue) contains the question which should currently be answered, a short description of the current life-space level area, and a hint regarding different types of locations that could be marked on the map. Underneath this text section, two buttons are placed, which allow navigating to the next or the previous question. Those are followed by the "help" button which again opens the tutorial (2).

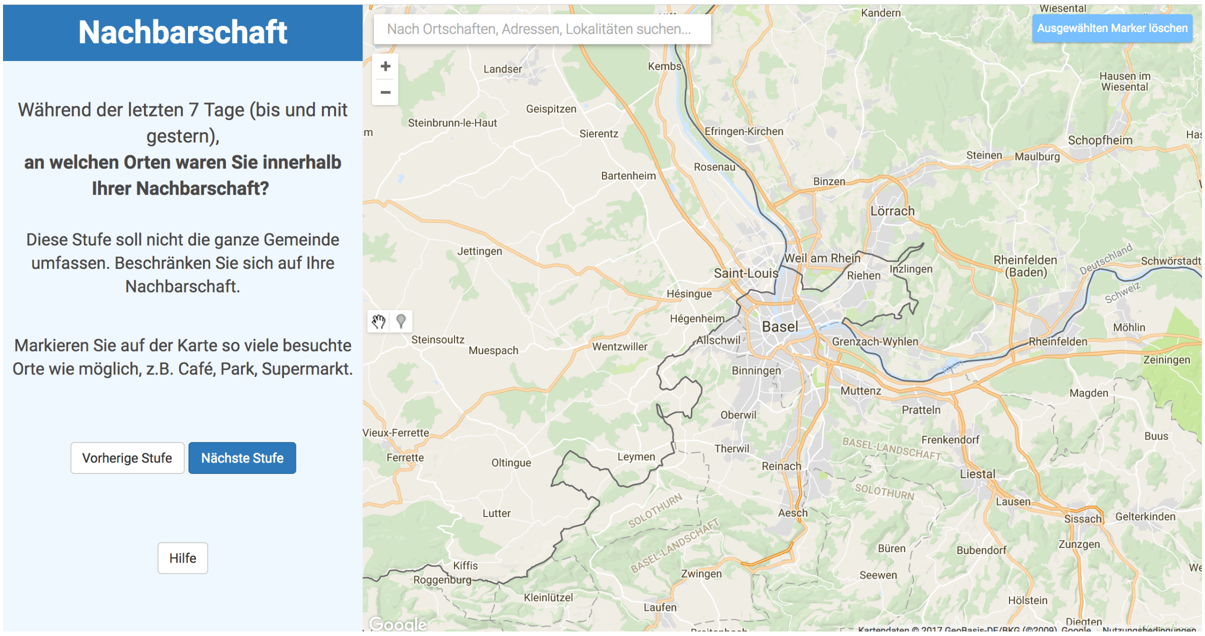

Figure 11: Illustration of the map part (3) which asks for visited places in a person's neighborhood.

The right hand-side of the screen represents the map with different functionalities. The map design is a modified version of the Google Maps map, based on the Gowalla design from Snazzy Maps[8] and adapted to the user-oriented requirements of the MBT. The map shows the city names, water bodies and streets as stated in the tool requirement (T6). The buildings are not represented because the polygons provided by Google Maps intersect with the streets which would disturb the general map design. Consequently, the user-oriented requirement (U17) becomes redundant as it is intended to show fewer details on buildings. Furthermore, the map shows man-made landscapes such as larger settlements, as well as rural areas and forests with meaningful colors. The road classes have been combined and simplified (U16). Highways and smaller roads are shown in light orange and white, respectively. Redundant information and labels have been removed, e.g. the numbers and names of the highways (U13). The remaining text is visualized in dark gray with a white halo to set off the text from the background map (U14).

[8] Snazzy Maps (2013). Gowalla. Available at: https://snazzymaps.com/style/20/gowalla [Accessed March 23, 2017]

The map functionalities can be described by considering Figure 12. The map can be panned (T5.10) and it is possible to zoom in and out with the + / - symbol on the upper left (T5.9). Furthermore, the white box, also placed in the upper left area of the map, allows to search for locations included in the Google Maps Places library. If a search criterion is identified, the map is focused on this particular location (T5.11).

The most essential map functionality is to mark locations on the map. On the middle left side of the map is an icon (highlighted in Figure 12 below) which can be activated (indicated with a thick border) to set a marker on a desired location (T2). However, line or polygon drawing was disabled, as the user-oriented requirements (U4 & U7) claim to reduce a tool's functionality to a minimum and to avoid the drawing of lines when developing a tool for older adults.

When marking a location on the map, this event directly adds the life-space level to the database entry according to the current question stated on the left side of the screen (T4.1), and an info window pops up (illustrated in Figure 12) in which several place-related questions must be answered (T4). There are two versions of info windows, one for the home location and another for all the other visited locations. Considering the first, it asks if the user slept at home every night over the past 7 days. Considering the info window for all the other locations, the questions concern several semantic attributes which will also be attached to the place entry, such as a name or a description (T4.7), the purpose of visiting or the activity done at a place (T4.5), the mode of transport used (T4.4) or the need for assistance (T4.3) to reach this place, the frequency of visiting this place during the preceding 7 days (T4.2) and the frequency independent of the study period (T4.6). Afterwards, the marked locations are represented with icons in different colors (depending on the life-space level) on the map (Figure 13).

Additionally, when a marker has been set to a wrong location on the map, it is possible to activate it by clicking on it (indicated with a thick border) and then drag it to another place. If the user accidentally entered erroneous place-related information to a location, the marker can be reselected and deleted by clicking on the button on the upper right area of the map.

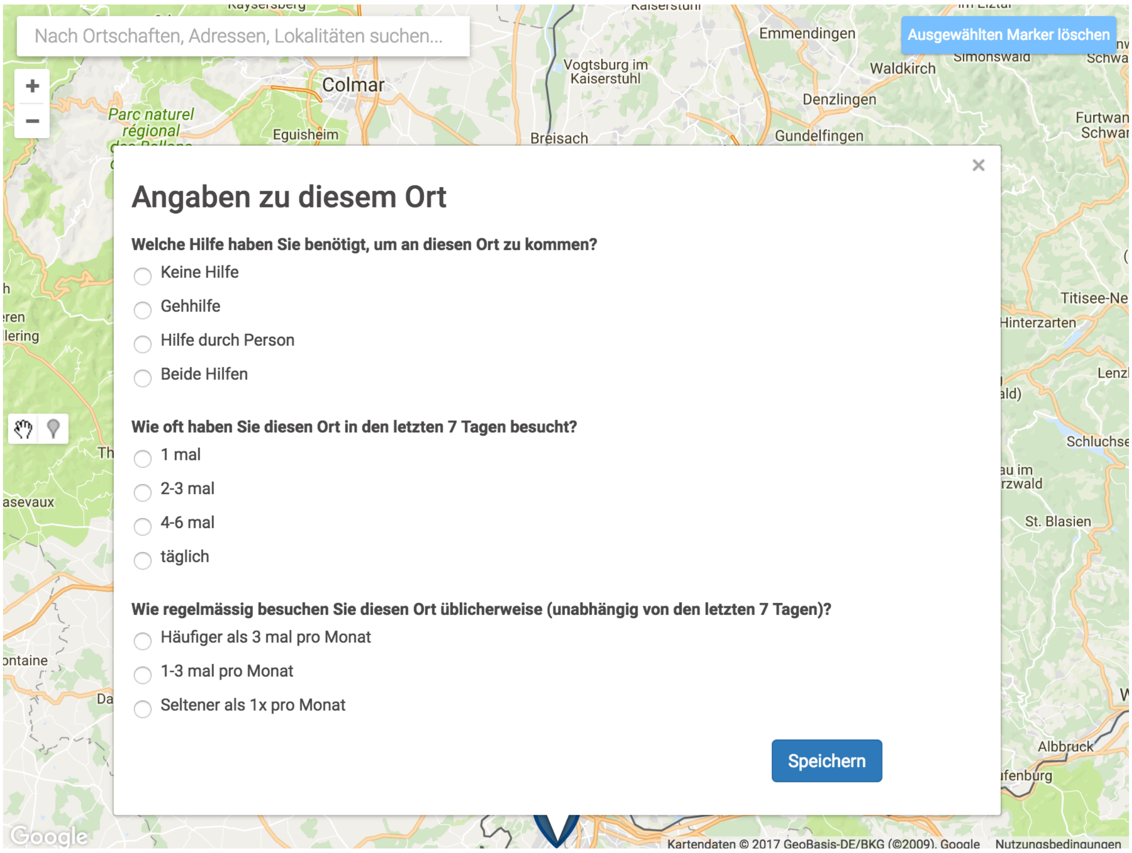

Figure 12: An illustration of the map with all its functionalities.

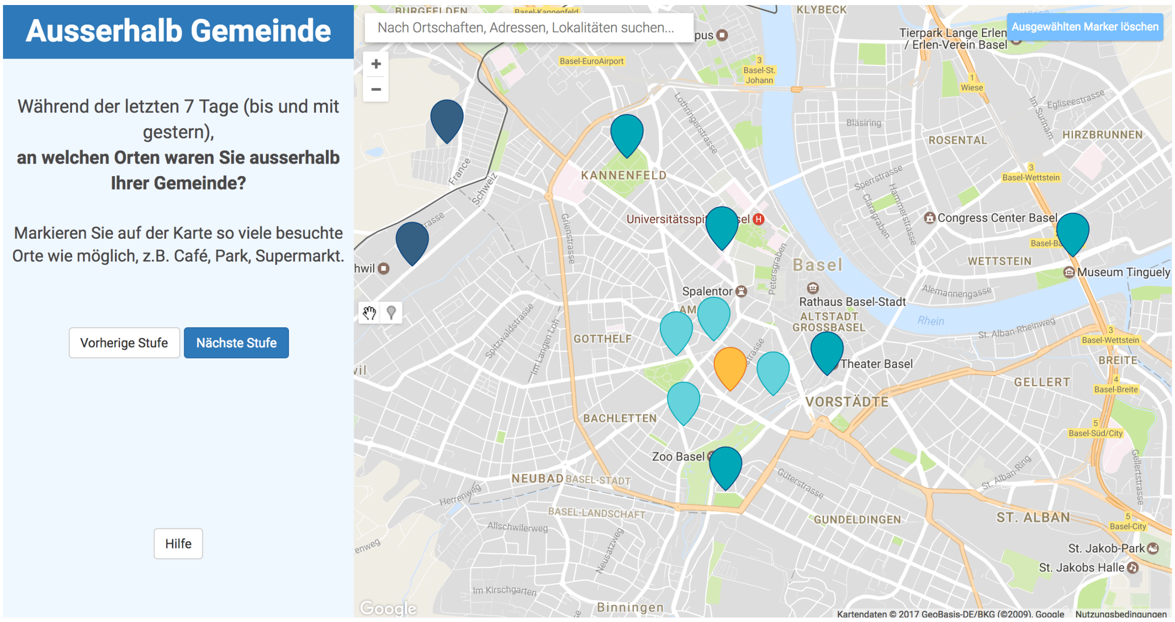

Figure 13: Illustration of the map application with markers indicating different life-space levels (orange: home location; light blue: locations the neighborhood; mid-blue: locations outside neighborhood but within town; dark blue: locations outside a person's home town).

Once all the visited locations have been added to the map, the user can continue to navigate to the last question on the left side of the screen which provides a button to save the entries. This button stores all the data directly in the database. Considering that, all markers which were placed on the map were added to a JS object *shapes*. When saving the data, each element of the object *shapes* is added as feature to an object *geojson*, which stores the participant's spatial mobility data as text in GeoJSON format in the database. Additionally, the GeoJSON text is written in the Chrome browser's console so that a study examiner can copy the text and paste it in a separate file. This file is used as data backup in case any problems with the database occur.

(b) Database

To save the data entered in the application (a), an *mbt* database (b) was created in MySQL to which the data was inserted with a PHP script. (b) must contain a table with the same name as the entered project name in part (1) of (a). As this procedure could be error-prone, the manually saved backup file, mentioned in the last section, is used. However, the mentioned database table consists of four columns which are named *uid*, *timestamp*, *date* and *json*. *uid* is the participant's identifier, *timestamp* stores the time of saving the mobility data in (b) as Unix time[9] in seconds, *date* saves the date of saving as an immediately readable format and *geojson* contains the participant's life-space mobility data as text in GeoJSON format.

5.4.3 The general design of the MBT application

The color concept of the MBT uses a bluey color scheme and further colors which fit harmoniously with blue, such as gray, white, orange and green (T5.8). A light blue was chosen as the background color, as (T5.7) suggests having a page design in bright colors. The text color was always chosen in a way to maximize the contrast with the background (U12), a dark grey on light backgrounds and white on darker backgrounds (e.g. forwarding buttons or headers of the life-space level sections; see below).

Headers are large and concise (U8). Continuous text was restricted to only a part of the screen and is aligned to the left (U10). Furthermore, the font sizes were chosen such that they are easily readable for older adults (mostly >16px) and the font style is Roboto (sans serif) (U11). The most important information is highlighted by using a bold text style (T5.2). For formulating labels, headers and longer text sections, a simple language was used to provide clear and unambiguous instructions (U1 & U2). As the study participants were recruited around Basel

[9] Unix time is a time reference which tracks time in seconds starting from the Unix epoch on the 1st January 1970 00:00:00 (UTC).

which belongs to the German-speaking part of Switzerland, all the text elements of the MBT were formulated in German.

For the navigation, forward buttons are in a more prominent darker blue and backward button are in a subtle light grey (T5.3). All the buttons were created as Bootstrap features, so they are large and look clickable (T5.6). Also, the number of buttons was kept to a minimum, only as needed to enable the functionalities of the application (U9). Additionally, they are always placed at the end of a text section, so the workflow is predefined: first read the text, then click to reach the next page.

Regarding the functionalities and older adults' motor skills, it was ensured that participants would not need to double click or scroll (U3 & U5). Furthermore, drop-down menus were avoided such that no information is hidden (U6).

6 Usability of the MBT compared to GPS and LSA

6.1 Methods

To evaluate the usability of the developed MBT, the principles of usability—the satisfaction, effectiveness and efficiency of using the tool as proposed by ISO (1999)—and further measures were applied. In Section 6.1.1, the system usability scale (SUS) by Brooke (1996) is presented which assesses a user's satisfaction (Bangor et al., 2008). Then, its effectiveness is described in Section 6.1.2, by considering the solvability of the MBT by older adults including an analysis of their reported difficulties and aspects of the MBT about which they asked questions. Furthermore, in Section 6.1.3, their use of specific technologies is examined and a technical background score is generated, as this could have an influence on their tool performance. Then, the usability of the *uTrails* is evaluated in Section 6.1.4. Finally, in Section 6.1.5, the criterion time efficiency is examined for all three life-space measurement approaches.

6.1.1 Evaluation of the MBT's general usability

The system usability scale (SUS) by Brooke (1996) is used to evaluate the general usability of the MBT which represents a subjective measure of a user's satisfaction. It is a questionnaire with which a user's subjective opinion regarding a system's usability can be assessed and quickly and simply evaluated (Section 3.5.2). The "MapSpace" study participants completed the questionnaire twice, in the second (Appendix B, CRF3_Q9) and third appointment (Appendix B, CRF8_Q8), directly after the use of the MBT and before any discussion of the MBT could take place, as proposed by Brooke (1996). Hence, a usability score, " […] a single number representing a composite measure of the overall usability of the system […]" (Brooke, 1996:194), for each of the appointments and any change between the two scores could be examined.

The SUS scores were calculated based on the instructions by Brooke (1996). For items a, c, e, g and i of the questionnaire, the score contribution was calculated as *Likert-scale position – 1*. The formula for the other items (b, d, f, h, j) was *5 – Likert-scale position*. The sum of all the items' score contributions, ranging from 0 to 4, was generated and multiplied by 2.5, which resulted in the final SUS scores ranging from 0 to 100. The higher the final score, the better the system's usability. As Brooke (1996) stated, a single item's score is not meaningful, the scores will not be evaluated individually. In Section 6.2.1, the corresponding results are presented.

6.1.2 Different aspects of the solvability of the MBT

The effectiveness of the MBT is evaluated based on the solvability by older adults and several questions asked during the "MapSpace" study. Some of them were answered by the participants, others are observations made by the study examiners while participants filled out the MBT. Again, all the aspects were evaluated for both Appointments 2 and 3 (Ap. 2 respectively Ap. 3) to be able to examine any differences in using the MBT for the first and the second time.

As a first step, the number of participants that could solve the MBT by themselves was noted[10] (Appendix B, CRF3_Q8 and CRF8_Q7). In a second step, their self-reported difficulties were evaluated, irrespective of whether or not they solved the MBT by themselves. In Ap. 2, they had the option of rating their difficulties according to the following three levels: yes, a bit and no (Appendix B, CRF3_Q10). In contrast, Ap. 3 asked for their difficulties in relationship to Ap. 2 (distinctively more, a bit more, equally, a bit less and distinctively less difficulties; Appendix B, CRF8_Q9). Subsequently, the self-reported measure of possible reasons for the participants' difficulties was evaluated. These were asked only once in Ap. 2 (Appendix B, CRF3_Q11). Moreover, only participants who indicated "yes" or "a bit" in the question regarding the difficulties (Ap. 2) had to give possible reasons for their difficulties. Accordingly, only the answers given by those with any difficulties were analyzed. Finally, it is examined to which aspects of the tool (e.g. navigation, understanding the content, etc.) questions were asked, documented by the study examiners (Appendix B, CRF3_Q3 and CRF8_Q2). The results corresponding to this section are shown in Section 6.2.2.

6.1.3 Examination of the participants' technical background

A person's technical background can be used to examine its relevance to a participant's MBT performance. As an example, a person who has a low technical affinity would have more difficulties in solving tasks with the MBT than a person with more experience with different technologies. Accordingly, technical background is evaluated in three ways, first, by considering the number of participants who use a specific technology, second, the mean of used technologies per participant and, third, a general technical background score (TBS). Furthermore, the latter is tested if it correlates with the above-mentioned usability and solvability measures.

The assessment of technical background was based on asking participants if they use 10 specific technologies, such as a smartphone, a computer or the internet, and how confident they are in using these tools (Appendix B, CRF1_Q22-23). The usage of a technology could be answered with "yes" (value = 1) or "no" (value = 0), and the confidence with "very unconfident" (value = 1), "rather unconfident" (value = 2), "rather confident" (value = 3), "very confident" (value = 4) or "not specified" (value = 0.5).

[10] Documented by the study examiners.

The values were used to calculate a TBS among all the specified technologies which takes into account a person's confidence when using a technology. The calculation of such a score is defined as follows: the values of the answers "yes" or "no" are multiplied with the confidence values for each technology, and then these 10 technology-specific scores are summed up. The resulting scores were in the range of 0 and 40.

Confidence was rated linearly, whereas the rating "not specific" received the value 0.5. The reason for this decision is that a value = 0 would exclude the technology from the final score, even if the inherent answer is "yes", and the value 1 would be equivalent to "very unconfident", which would falsify the resulting scores.

6.1.4 Wearing comfort and handling of the *uTrails*

For comparing the usability of the developed MBT to the usability of the other life-space measurement approaches, questions regarding the wearing comfort and handling of the *uTrails*, the used GPS devices, were included in the "MapSpace" study. Participants had to rate the usability of those in the beginning of the second appointment, whereas this assessment was the first after the GPS measurement period.

The questionnaire was based on 10 questions (Appendix B, CRF3_Q1) regarding, e.g., the awareness of the device in everyday life or the disturbance of the flashing status LED. The answers were given with a Likert scale ranging from 1 (very likely) to 5 (very unlikely). For evaluating these questions, the frequency of marking a Likert-scale position among the study participants was analyzed (Section 6.2.4).

6.1.5 Assessment of the overall time need and time efficiency

An aim of this thesis is encountering the disadvantages of the commonly used life-space measurement approaches. One of these disadvantages is the high time need for GPS measurements. Accordingly, the time efficiency of the MBT, LSA and GPS is evaluated and compared to each other. As the time needed for GPS measures is fixed, namely to 7 days, the time needed to fill out the MBT and the LSA had to be assessed in the "MapSpace" study. In Appointment 2, the time was stopped for both, MBT and LSA (Appendix B, CRF3_Q2 and CRF 6), and, in Appointment 3, only the time needed for the MBT was assessed again (Appendix B, CRF8_Q1). Thus, the overall time need and the time efficiency of each of the three measurement approaches can be analyzed.

The overall time need considers the total time used to collect the data with each approach. Hereby, the evaluation of the MBT constitutes an exception. As not all the participants filled out the tool by themselves, a further measure "effective time need" was calculated for the MBT which only regards the data of participants who filled out the MBT by themselves.

The time efficiency is a relative measure which evaluates the time need for each single data entry of the three approaches. This relativizes the overall time need and helps to better understand the efficiency of each measurement approach. As an example, GPS measurements last 7 days in total but, during this period, lots of location points can be assessed. However, the LSA mostly takes only a few minutes, but the data consists of only 12 values. Accordingly, for calculating the time efficiency of life-space assessment, the time need of the LSA (in minutes) was divided by 12 (the number of crosses which were used to fill out the LSA). Furthermore, the time used to assess life-space mobility with the MBT (in minutes) was divided by the number of marked locations. Again, the dataset was reduced to participants who solved the tool by themselves. And finally, for the GPS the total time of measurement (7 days * 24 * 60 = 10,080 minutes) was divided by the number of collected GPS points.

6.2 Results

6.2.1 The MBT's usability score

The results of the evaluation of the SUS questionnaires are summarized in Table 6. During Appointment 2 (Ap. 2), all the study participants completed the SUS in its entirety. However, Appointment 3 (Ap. 3) shows three missing scores. One can be explained by a participant who did not take part in Ap. 3. The other two *missings* are due to two participants who did not fill out the SUS completely. Accordingly, the three cases were excluded from the evaluation of Ap. 3. The means of the SUS scores are 33.66 for Ap. 2 and 31.68 for Ap. 3. Other studies which used the SUS have mean scores of around 70.14 (Bangor et al., 2008). Accordingly, the mean SUS scores of the MBT seem to be very low. Furthermore, a decline of the SUS scores between Ap. 2 and Ap. 3 can be observed. The minimum and maximum values of the SUS scores range from 0 to 90 and from 0 to 87.5 (in Ap. 2 and Ap. 3, respectively). Similar to the mean, also the maximum score declined from Ap. 2 to Ap. 3.

Table 6: Summary statistics for the SUS scores of the MBT in study Appointments 2 and 3.

	Appointment 2	**Appointment 3**
N (missing)	58	55 (3)
SUS scores, mean ± SD	33.66 ±21.82	31.68 ± 20.63
Min; max	0; 90	0; 87.5

N = number of participants; SD = standard deviation

Figure 14 (on the left) shows a scatterplot which contrasts the SUS scores of Ap. 2 and 3. The points are mostly placed near the linear regression line which indicates that a participant has almost the same SUS scores in the two appointments. A Pearson correlation proved that the SUS scores of both appointments correlated positively with each other (*r = 0.700 and p = 0.000*). Furthermore, the scatterplot shows a noticeable outlier in the lower right corner which represents highly different scores for one participant: more than 80 in Ap.2 and around 20 in Ap. 3. This can also be recognized in the boxplot in Figure 14 (right). The same outlier states a difference of 56 between Ap. 2 and 3. The other differences of usability evaluation per participant show residuals between -25 and 25, whereas the mean is around 0 (Figure 15).

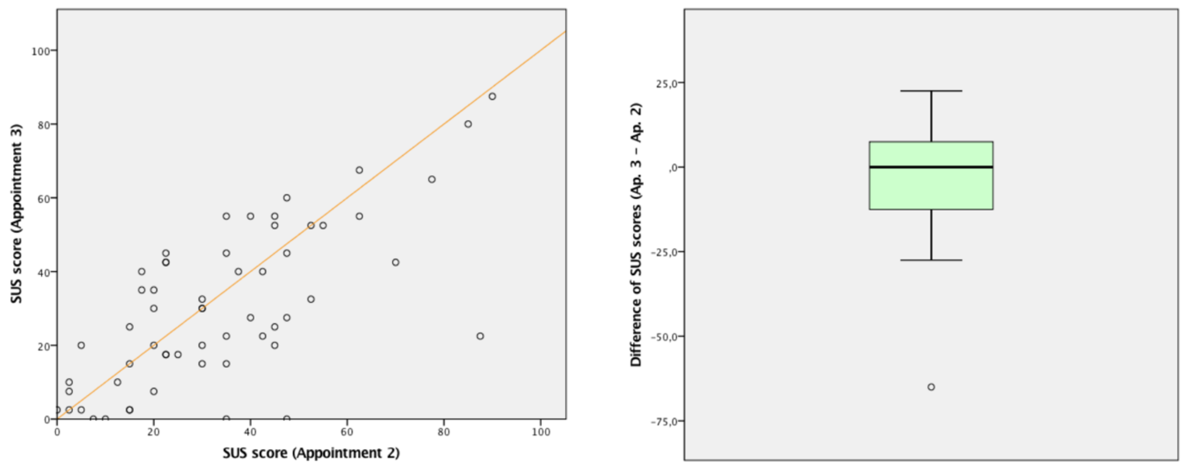

Figure 14: Left - Scatterplot of the SUS scores of Appointments 2 and 3 with a linear regression line (orange). Right - Boxplot of the differences between Appointments 2 and 3 (SUS score Ap. 3 - SUS score Ap. 2).

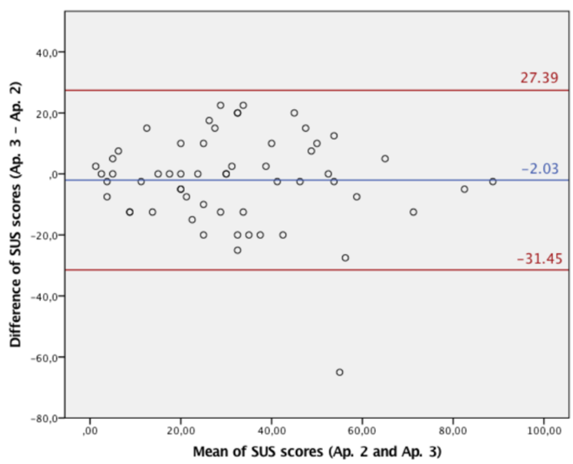

Figure 15: Bland-Altman plot of the differences of the SUS scores of Appointments 2 and 3.

6.2.2 The solvability of the MBT

The results regarding the solvability of the MBT are summarized in Table 7. In Ap. 2, 82.8% of the participants filled out the MBT by themselves. However, in Ap. 3, there are two missing values, one of these is the participant who did not complete the study, and a slightly smaller number of older adults solved the tool by themselves (80.4%).

Regarding the difficulties encountered with the MBT, more than half of the participants (n =30) stated that they had no difficulties, 18 had only a few, and 10 had difficulties when solving the MBT the first time. The second time, 91.2% of the participants reported having equal or less difficulty compared to the first attempt. However, 4 had slightly more, and 1 had distinctly more difficulty. Furthermore, the 28 participants who stated "yes" or "a bit" considering the difficulty in Ap. 2 had to report on possible reasons, but only 16 answered these questions (12 are missing). Thereby, it could be found that 8 never used and 12 have general difficulty using a computer. Similar results emerge when considering the internet as a reason for participants' difficulty, 9 never used it and 8 have general difficulty with it. To explain the 12 missing values, it is possible that all the mentioned reasons for difficulty did not apply or the participants simply forgot to answer those questions.

As the participants were invited to ask the study examiner for help when encountering problems in understanding or handling parts of the MBT, questions were raised about several aspects of the tool. Those have only been analyzed for participants who filled out the tool by themselves (n=48 and n=45, in Ap. 2 and 3, respectively). In Appointment 2, only a few participants asked for help regarding the handling of the mouse or the keyboard (n = 6) or the map search function (n = 6), the navigation through the tutorial (n = 5) or the left screen of the map application (n = 7). Furthermore, only 9 older adults asked questions regarding the content of the information window which pops up when a marker is set on the map, 8 did not know how to select or move a marker on the map and 4 encountered problems in reading or finding specific locations on the map. Slightly more problems emerged when considering the definitions of the life-space levels (n = 10). However, more problematic aspects of the MBT seemed to be the content of the tutorial (50.0%), the zooming and panning of the map (60.4%), the handling of the information window on the markers (41.7%) and the procedure to delete a marker from the map (35.4 %). But the most prominent result concerns the aspect of setting a marker on the map as 87.5% of the participants on at least one occasion did not know how to mark a visited location on the map.

Generally, in Appointment 3, less questions were asked about almost all aspects of the MBT. The only exceptions were the navigation through the questions on the life-space levels in the left screen of the map application (+14.3%) and questions regarding the definitions of the life-space levels (+28.1%). There notably fewer questions asked about the handling of the map (– 24.8%) and the information window (–12.8%) or how to set or delete a marker on the map (– 16.4% and –15.4%).

On average, the number of aspects about which a participant asked questions (maximum = 13) was 3.81 when using the MBT the first time (Ap. 2) with a slightly lower value during Appointment 3 (mean = 3.33).

Table 7: Summary statistics for the solvability of the MBT in study Appointments 2 and 3.

Characteristic	Appointment 2 N (missing)		Appointment 3 N (missing)	
Solvability				
Solved the MBT by themselves, n (%)	58	48 (82.8)	56 (2)	45 (80.4)
Difficulties				
Yes, n (%)	58	10 (17.2)		
A bit, n (%)	58	18 (31.1)		
No, n (%)	58	30 (51.7)		
Distinctly more, n (%)			57 (1)	1 (1.8)
A bit more, n (%)			57 (1)	4 (7.0)
Equally, n (%)			57 (1)	21 (36.8)
A bit less, n (%)			57 (1)	15 (26.3)
Distinctly less, n (%)			57 (1)	16 (28.1)
Reasons for difficulties[11]	16 (12)			
Never used a computer, n (%)		8 (50.0)		
General difficulties using a computer, n (%)		12 (75.0)		
Never used the internet, n (%)		9 (56.3)		
General difficulties using the internet, n (%)		8 (50.0)		
Questions asked during the use of the MBT[12]				
Aspects of the MBT				
Use of mouse and keyboard, n (%)	48	6 (12.5)	45	4 (8.9)
Navigation through the tutorial, n (%)	48	5 (10.4)	45	2 (4.4)
Understanding of the content of the tutorial, n (%)	48	24 (50.0)	45	19 (42.2)

[11] Only participants who checked “yes“ or “a bit” regarding their difficulties in Ap. 2 had to answer this question.

[12] These questions are only evaluated for participants who filled out the tool by themselves (n = 48, resp. n = 45).

Navigation through the left screen of the map application, n (%)	48	7 (14.6)	45	13 (28.9)
Definitions of the life-space levels, n (%)	48	10 (20.8)	45	22 (48.9)
Handling of the map search function, n (%)	48	6 (12.5)	45	4 (8.9)
Handling of the map (zoom and pan), n (%)	48	29 (60.4)	45	16 (35.6)
Understanding content of IW, n (%)	48	9 (18.8)	45	6 (13.3)
Handling the IW, n (%)	48	20 (41.7)	45	13 (28.9)
Set a marker on the map, n (%)	48	42 (87.5)	45	32 (71.1)
Select or move a marker, n (%)	48	8 (16.7)	45	6 (13.3)
Delete a marker, n (%)	48	17 (35.4)	45	9 (20.0)
Map reading and finding locations, n (%)	47 (1)	4 (8.5)	45	4 (8.9)
Number of aspects to which a participant asked questions (0-13), mean ± SD (min; max)	47 (1)	3.81 ± 2.11 (0; 8)	45	3.33 ± 2.48 (0; 10)

N/n = number of participants; SD = standard deviation; IW = information window which pops up when a marker is set on the map

6.2.3 Participants' technical background

The technical background of the study participants was examined by analyzing the number of participants who use specific technologies, the mean of used technologies and a technical background score (TBS) per participant. The results are summarized in Table 8. The use of different technologies varies greatly. A normal phone is used by almost all study participants, with only 1 exception. Mobile phones are still used a lot (87.7%), but less than phones. Remarkably less participants stated they used a smartphone, slightly more than half of them (n = 32). A computer or a laptop is used by a large majority (81.0%), however, iPads or other tablets do not prove to be so popular (34.5%). Navigation devices are used by almost half of the group (46.6%), but activity trackers only by 10 participants. Furthermore, the internet and map applications on the internet are used by many older adults (84.5% and 74.1%, respectively). In contrast, only a smaller part of the study participants (34.5%) have used a geographic information system (GIS).

On average, a study participant uses 6.07 of 10 mentioned technologies (Table 8). Figure 16 (on the left) shows that there are two cases with a very limited technical background which use only one technology, namely a phone. As opposed to this, there are three technically affine participants which use all the mentioned technologies. Most of the participants use 5 different technologies.

The generated TBS, which integrates the number of used technologies and confidence in using them, shows a mean of 21.34 (Table 8). The maximum would be 40, which was reached by two participants (Figure 16 on the right). When comparing the TBS to the number of used technologies, it can be observed that the newly-generated TBS allows to examine a participant's technical background in more detail.

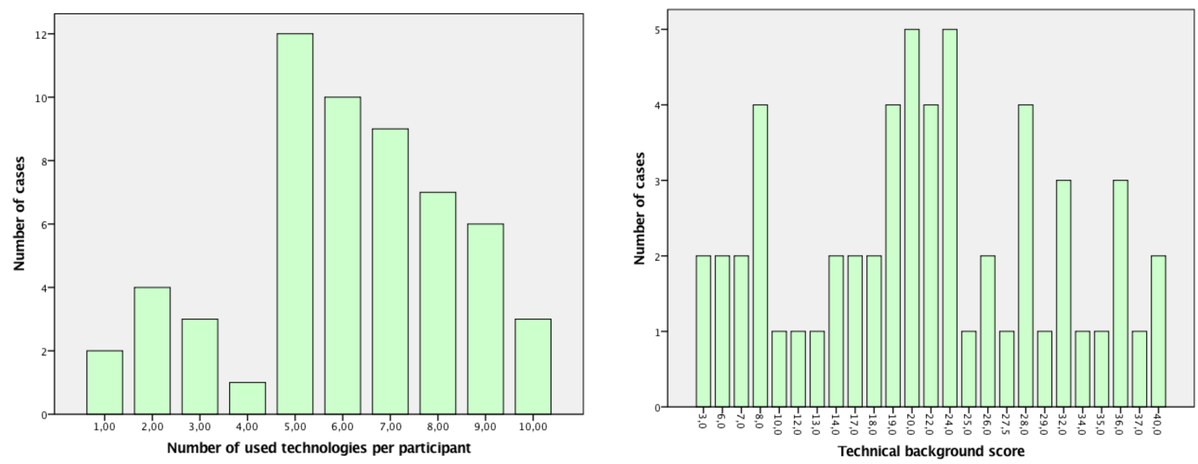

Figure 16: Left – Histogram of the numbers of used technologies among "MapSpace" study participants (n = 57; ID = 63 is missing). Right – Histogram of the technical background scores (n = 57; ID = 63 is missing).

Table 8: Summary statistics regarding study participants' technical background.

Technical background characteristic	N (missing)		Min.; Max
Use of different technologies			
Phone, n (%)	58	57 (98.3)	
Mobile phone, n (%)	57 (1)	50 (87.7)	
Smartphone, n (%)	58	32 (55.2)	
Computer / laptop, n (%)	58	47 (81.0)	
iPad / tablet, n (%)	58	20 (34.5)	
Navigation device, n (%)	58	27 (46.6)	
Activity tracker, n (%)	58	10 (17.2)	
Internet, n (%)	58	49 (84.5)	
Map applications on the internet, n (%)	58	43 (74.1)	
GIS, n (%)	58	20 (34.5)	
Number of used technologies (0-10), mean ± SD	57(1)	6.07 ± 2.30	1; 10
Technical background score (0-40), mean ± SD	57 (1)	21.34 ± 9.81	3; 40

N/n = number of participants; SD = standard deviation; GIS = Geographic Information System

Furthermore, a Pearson correlation has been run to examine the relation of the TBS with the SUS scores of the MBT (Section 6.2.1) and the number of aspects of the MBT to which participants asked questions (Section 6.2.2). The correlation coefficients show a significant negative correlation between the TBS and the SUS scores of Appointments 2 and 3 ($r = -0.529$ and $p = 0.000$, and $r = -0.452$ and $p = 0.000$, respectively). Additionally, the TBS negatively correlates with the number of asked aspects in Appointment 2 ($r = -0.359$), but not with the one of Appointment 3 ($r = -0.066$).

6.2.4 Usability of the *uTrail*

The answers given by the study participants regarding the usability of the *uTrail* is summarized in Table 9. Most of the participants were aware of the devices in their everyday life. However, 65.5% testified to the convenience of wearing the *uTrail* in terms of its size and weight. According to the majority of the study participants (70.7%), the handling of the *uTrail* was very intuitive. Furthermore, 74.1% stated that the on-/off-button responded when applying pressure to it. The flashing status LED in the middle of the *uTrail* did not disturb most of the users (70.7%) and the material and the construction of the *uTrail* seemed to appear robust (62.1%). The appeal of the overall design tended to be satisfactory, whereby most of the ratings are located in the middle of the Likert scale (34.5%). A large part of the participants did not feel restricted in their everyday activities (79.3%) and did not change their regular behavior (75.9%) due to the *uTrail*. Regarding the last aspect which concerns talking to people within a person's environment about wearing the *uTrail*, opinions were dispersed from one end to the other on the Likert scale.

Table 9: Summary statistics regarding the usability of the uTrail.

Characteristic	**N** (missing)	very likely **1**	**2**	**3**	**4**	very unlikely **5**
Awareness of the *uTrail* in everyday life (in %)	58	37.9	20.7	15.5	17.2	8.6
Inconvenience of wearing due to the size and weight of the *uTrail* (in %)	58	-	12.1	10.3	12.1	65.5
Intuitive understanding of the handling of the *uTrail* (in %)	58	70.7	10.3	10.3	5.2	3.4
Respondence of the on-/off-button when pressure was applied (in %)	57 (1)	74.1	6.9	5.2	3.4	8.6
Disturbance of the status LED (in %)	58	8.6	8.6	8.6	3.4	70.7
Robustness of the material / construction of the *uTrail* (in %)	58	62.1	25.9	5.2	-	6.9

Liking the overall design of the *uTrail* (in %)	58	29.3	24.1	34.5	8.6	3.4
Restrictions of everyday activities due to the *uTrail* (in %)	58	1.7	5.2	3.4	10.3	79.3
Change of regular behavior due to the *uTrail* (in %)	58	1.7	1.7	3.4	17.2	75.9
Talked to people in your environment about the *uTrail* (in %)	58	27.6	22.4	17.2	8.6	24.1

N = number of participants; miss. = number of missing answers

6.2.5 The overall time need and time efficiency of the three measurement approaches

The overall time need and time efficiency of the three measurement approaches differ greatly (Table 10). During the second appointment, the mean of the overall time need, which all participants needed to indicate in the MBT, was 30.03 minutes whereas the minimum time need was 10.5 and the maximum 58.17 minutes. Only for the participants who filled out the MBT by themselves (n = 48 in Ap. 2) could the effective time need be calculated. Compared to the overall time need, the mean (= 31.79 minutes) and the minimum of the effective time need (= 11.55 minutes) were a bit higher. In Appointment 3, all the values for the overall and the effective time need were lower.

The overall time need of the LSA and GPS was assessed only once. Regarding the time used to complete the LSA questionnaire, the mean was 2.81 minutes, whereas the minimum was around 1 minute and the maximum slightly more than 5 minutes. However, these values were all noticeably lower than the used time need measures for the MBT. However, the overall time need for the GPS measurements was for all participants the same, namely 7 days which is much higher than the time need for the other two measurement approaches.

The time efficiency of all the three life-space measurement approaches is less varied than the overall time need because the values were relativized by generating the time needed to mark a point on the map, to answer the questionnaire or to collect a pair of coordinates. In Appointment 2, participants used on average 2.81 minutes to mark a point. The minimum was 1.01 and the maximum 5.56 minutes. Again, the time efficiency of the MBT in Appointment 3 was lower when regarding the mean and the minimum, but not when regarding the maximum. However, the mean time efficiency of the LSA and the GPS measurements was significantly lower, namely 0.18 and 0.15 minutes, respectively. But the maximum time efficiency of the GPS is almost within range of the MBT (max. time efficiency GPS = 1.63 minutes).

Table 10: Summary statistics of the time need and efficiency of the MBT, LSA and GPS.

Characteristic	Appointment 2 N (missing)		Appointment 3 N (missing)	
MBT				
Overall time need (in minutes), mean ± SD (min; max)	58	30.03 ± 12.00 (10.5; 58.17)	57 (1)	20.77 ± 9.76 (5.57; 49.02)
Effective time need[13] (in minutes), mean ± SD (min; max)	48	31.79 ± 11.29 (11.55; 58.17)	45	21.67 ± 9.06 (7.80; 47.53)
Time efficiency[4] (per marked point; in minutes), mean ± SD (min; max)	48	2.81 ± 1.00 (1.01; 5.56)	45	2.18 ± 1.05 (0.87; 5.94)
LSA				
Overall time need for the LSA (in minutes), mean ± SD (min; max)	58	2.17 ± 0.98 (0.75; 4.80)		
Time efficiency (per marked answer; in minutes), mean ± SD (min; max)	58	0.18 ± 0.08 (0.06; 0.40)		
GPS				
Overall time need (in days), n	58	7		
Time efficiency (per assessed coordinate pair; in minutes), mean ± SD (min; max)	58	0.15 ± 0.24 (0.03; 1.63)		

N/n = number of participants; SD = standard deviation

Figure 17 (on the left) shows the boxplots of the time efficiency of the MBT in Appointments 2 and 3. Both boxplots show outliers between 5 and 6 minutes for marking a point. The green boxes represent the interquartile distance which contains 50% of the measurements. The box for Appointment 2 ranges from approximately 2.2 to 3.4 minutes. And the box for Appointment 3 is lower, between 1.3 and 2.7 minutes. Again, a time reduction can be recognized when using the MBT the second time.

On the right side of Figure 17, the time efficiency of the LSA and GPS measurements are represented as boxplots. The range on the y-axis is noticeably smaller than in the left plot. The GPS boxplot shows several outliers between 0.5 and 1.7 minutes for collecting a GPS point. The LSA measures seem to be distributed similarly as there are no outliers. The interquartile distances on the right are both in the range of 0.1 to 0.3 minutes, which again is distinctly lower than the time efficiency values for the MBT.

[13] Measure is based only on participants who filled out the tool by themselves.

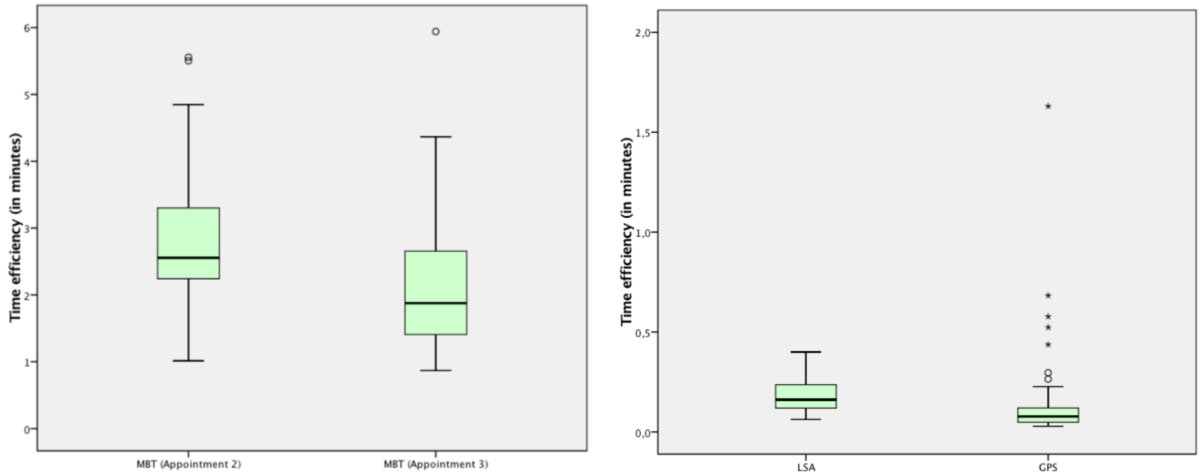

Figure 17: Left - Boxplots of the time efficiency of the MBT measurements in Appointments 2 and 3. Right - Boxplots of the time efficiency of the LSA and GPS measurements.

7 Evaluation of the validity of the MBT

The aim of Chapter 7 is to evaluate the validity of the MBT by comparing different life-space indicators derived from the MBT to indicators generated from the LSA and GPS, respectively. Therefore, this chapter first gives an overview of the properties of the spatially-referenced life-space datasets in order to get a better feeling for the data and to be able to contextualize the subsequent evaluation (Section 7.1). In the methods section (7.2), several life-space indicators are elaborated in order to compare the MBT and the LSA, and the MBT and the GPS, respectively. The indicators used for evaluating the MBT's validity against the LSA have a more semantic character, and the ones for comparing the GPS can be summarized as purer spatial measures. Finally, in Section 7.3, the results of these life-space indicators are described and evaluated.

The methods and results of Chapter 7 are only applied to the data collected within the first 7 days (up until Appointment 2 inclusive). The reason for this is that the datasets of all three measurement approaches are available only for this period.

7.1 Data

For giving an overview of the data used for the following Sections 7.2 and 7.3, the structure, several preprocessing steps and the possibilities of deriving semantic information of the MBT and GPS data are described in this section.

7.1.1 MBT data

As already mentioned in Section 5.4.2, the MBT data was saved as GeoJSON[14] which is a format for saving geographic data structures. It represents a feature collection in which each feature is composed of a geometry and properties (Figure 18). As an example, in the MBT, the geometry would be the marked location on the map, a point with Longitude and Latitude coordinates, and the properties would be the semantic information entered in the info window of a set marker. As shown in Figure 18, the properties of MBT features are *id*, *zoom*, *stufe*, *name*, *purpose*, *mot*, *assistance*, *sleep*, *frequency* and *frequencyYear*. The attributes *id*, *zoom* and

```
{
  "type": "Feature",
  "geometry": {
    "type": "Point",
    "coordinates": [
      7.588231086338055,
      47.54837787649766
    ]
  },
  "properties": {
    "id": 7,
    "zoom": 16,
    "stufe": 1,
    "name": "",
    "purpose": "einkauf",
    "mot": "zuFuss",
    "assistance": "keine",
    "sleep": "",
    "frequency": "1",
    "frequencyYear": "1-3/m"
  }
},
```

Figure 18: GeoJSON structure of a feature from the MBT.

[14] GeoJSON (n.d.). GeoJSON. Available at: http://geojson.org [Accessed April 4, 2017]

stufe are added directly for each marked location in the MBT, e.g. based on the current zoom level of the map or the question in the left screen of the map application. Further, when the question about participants' homes is open in the left screen, the tag "wohnort" is directly added to the attribute *name*. Additionally, the "home markers" incorporate only semantic information regarding the attributes *id*, *zoom*, *stufe*, *name* and *sleep*, and all the other attributes remain empty (""). However, semantic information about locations representing life-space levels should have a tag for each attribute, depending on the participants' entries in the info window. The only exception is the attribute *sleep* which is only assessed for "home markers". Based on these attributes, the MBT would e.g. allow to identify locations which were visited voluntarily or involuntarily based on the stated purpose of visiting a particular place. Additionally, the general frequency of visiting a place (independently of the period of measurement) or the MOTs could be evaluated. However, this semantic information will not be further analyzed because it would go beyond the scope of this thesis.

The preprocessing of the MBT data consists of several parts. First, as each MBT assessment has been saved twice, namely directly from the tool in the database and manually by copying the GeoJSON code from the console of the browser in a separate file, the database table entries had to be compared to the manually-saved files. Some of the MBT assessments were not saved in the database, most probably due to spelling the project name on the start page of the MBT incorrectly. Furthermore, when a participant saved an MBT session twice, it could arise that not all sessions were saved manually. In such a case, study examiners had to report why a participant had to save multiple MBT sessions, and which of them were valid (Appendix B, CRF3_Q4-7 and CRF8_Q3-6). In Appointment 2, which is the focus of Chapter 7, two MBT datasets of one participant (ID = 10) had to be combined because he/she wanted to add further points to the first saved entry.

The second part of the preprocessing focused on eliminating duplicate or multiple home locations. This was necessary because the part of the MBT in which participants had to mark their home allowed setting multiple points, but the following life-space indicators work only with one home location (Sections 7.2.1 and 7.2.2). In Appointment 2, there was one participant who marked two locations as his/her home (ID = 10). By looking up this participant's home address in a separately saved "MapSpace" study code book, the data could be adjusted in order to have only one home location. Hence, the tag "wohnort" has been deleted for the wrong home location but, as for home locations where most of the semantic information is not available, it is also missing for this adjusted location.

Thirdly, the functionality of setting points on the map was not restricted to when the end of the test was indicated in the left screen of the application (Section 5.4.2). Accordingly, locations were marked and saved with a life-space Level 4 (*stufe = 4*) which is not defined for this thesis. This problem occurred for one participant (ID = 42) in Appointment 2. Hence, all the marked locations with a life-space Level 4 have been adjusted to Level 3.

Finally, for enabling the calculation of metric measures, the Longitude and Latitude coordinates had to be projected in a metric coordinate system, namely the Swiss coordinate system LV03.

7.1.2 GPS data

The *uTrails*, which were used in the "MapSpace" study to assess sensor-based mobility data, provide several files which can be downloaded after a measurement period, namely a configuration file, different accelerometer files (a raw IMU—Inertial Measurement Unit—file and a thereof derived activity file), and location files in different formats such as CSV—Comma-separated values—or KML—Keyhole Markup Language. For the evaluation of the spatial information measured with the GPS trackers, the location files in the CSV format are used. The structure of such a CSV file is illustrated in Figure 19. Each entry is stored in an interval of approximately one second in which the date and time of measurement, the longitude and latitude of the current location, the number of satellites which were available at that time and a recording attribute are stored (lines 1, 6-23). When no GPS reception is available, *NA* values (missing) are stored (lines 2-5). Additionally, when the device is charging, this is stored with the tag "charging" in the longitude attribute (lines 24-29). From this GPS data, it would be possible to extract the mode of transportation (MOT), making it possible to distinguish between active and passive transportation, or a spatio-temporal stop detection could be applied in order to ascertain the number of outdoor activities. Furthermore, GPS allows to create daily path areas as proposed by Hirsch et al. (2014). However, again, these aspects will not be further analyzed because it would go beyond the scope of this thesis.

```
1  Date, Time, Longitude, Latitude, Satellites, Recording
2  29/08/2016, 11:27:53, NA, NA, NA, NA
3  29/08/2016, 11:27:54, NA, NA, NA, NA
4  29/08/2016, 11:27:55, NA, NA, NA, NA
5  29/08/2016, 11:27:56, NA, NA, NA, NA
6  29/08/2016, 11:27:58, 008.550053, 047.396565, 4, 0
7  29/08/2016, 11:27:59, 008.550067, 047.396562, 4, 0
8  29/08/2016, 11:28:00, 008.550040, 047.396572, 4, 0
9  29/08/2016, 11:28:01, 008.550037, 047.396577, 4, 0
10 29/08/2016, 11:28:02, 008.550010, 047.396590, 4, 0
11 29/08/2016, 11:28:03, 008.550007, 047.396593, 4, 0
12 29/08/2016, 11:28:04, 008.549960, 047.396615, 4, 0
13 29/08/2016, 11:28:05, 008.549950, 047.396617, 4, 0
14 29/08/2016, 11:28:06, 008.549938, 047.396622, 4, 0
15 29/08/2016, 11:28:07, 008.549878, 047.396647, 4, 0
16 29/08/2016, 11:28:08, 008.549877, 047.396647, 4, 0
17 29/08/2016, 11:28:09, 008.549870, 047.396647, 4, 0
18 29/08/2016, 11:28:10, 008.549865, 047.396647, 4, 0
19 29/08/2016, 11:28:11, 008.549858, 047.396648, 4, 0
20 29/08/2016, 11:28:12, 008.549855, 047.396653, 4, 0
21 29/08/2016, 11:28:13, 008.549823, 047.396670, 4, 0
22 29/08/2016, 11:28:14, 008.549815, 047.396675, 4, 0
23 29/08/2016, 11:28:15, 008.549807, 047.396680, 4, 0
24 29/08/2016, 11:28:16, Charging, NA, NA, 0
25 29/08/2016, 11:28:17, Charging, NA, NA, 0
26 29/08/2016, 11:28:18, Charging, NA, NA, 0
27 29/08/2016, 11:28:19, Charging, NA, NA, 0
28 29/08/2016, 11:28:20, Charging, NA, NA, 0
29 29/08/2016, 11:28:21, Charging, NA, NA, 0
```

Figure 19: Structure of a CSV file containing GPS data.

The GPS data had to be preprocessed in order to obtain a dataset which only includes the relevant entries for performing spatial analyses (Section 7.2). For preprocessing the GPS files, several steps were needed (Figure 20).

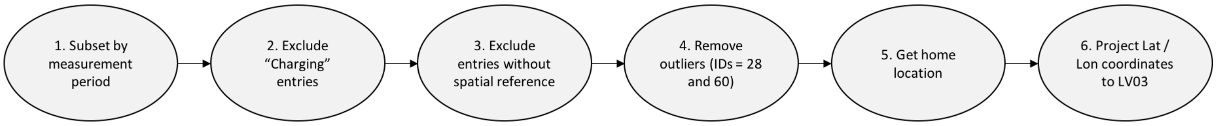

Figure 20: Preprocessing steps of the GPS data.

First, a subset of the GPS data was created which only included entries within the measurement period of each participant. Second, the "charging" entries were excluded. Third, the entries were reduced to those which store a pair of coordinates. Then, extreme outliers were removed. The only ones which could be identified by visually inspecting the GPS data were from two participants (IDs = 28 and 60). For each of them, a single point was located in France and Nigeria, respectively. Steps 2-4 reduced the data on average by ca. 312,500 entries per participant (minimum = -ca. 21,600 and maximum = - ca. 544,400 entries). The fifth step, in order to have a home location in the GPS data, was to get the median latitude and longitude of the daily first GPS fixes (function *getHome()* from the *moasis* package[15]). And, finally, the last step was to project the Longitude and Latitude coordinates in a metric coordinate system, in this case the Swiss coordinate system LV03.

The spatial data from one participant (ID = 64) had to be excluded from the subsequent analysis because this person's *uTrail* was broken and the collected GPS data showed massive errors (Figure 21).

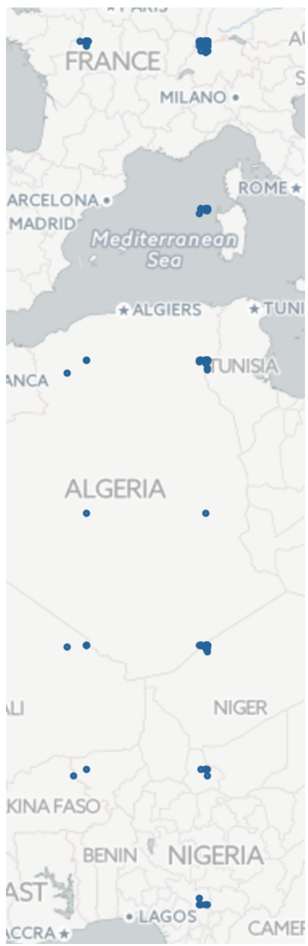

Figure 21: Erroneous GPS data (ID = 64).

[15] *moasis* is an R package which is not publically available. The used version was moasis_0.3 [Received October 7, 2016].

7.2 Methods

The aim of the current chapter is to evaluate the validity of the MBT by comparing life-space indicators derived from the spatial and semantic data assessed with the MBT, LSA and GPS. Therefore, this Section 7.2 presents the methods for generating and evaluating life-space indicators which can be compared first between the MBT and LSA (Section 7.2.1) and second between the MBT and GPS (Section 7.2.2). The first comparison, MBT versus LSA, focuses on semantic, and the second, MBT versus GPS, on spatial indicators. The reason for this is that extracting semantic information from GPS data, e.g. the number of outdoor activities, is cumbersome and would go beyond the scope of this thesis. And, finally, Section 7.2.3 presents a spatial ability test which is used to evaluate the accuracy of the MBT data.

7.2.1 MBT versus LSA

Based on the measures which can be derived from the LSA, the following semantic life-space indicators are defined for evaluating the validity of the MBT to the LSA: visited life-space levels (Level 1—neighborhood, Level 2—outside neighborhood, but within a municipality and Level 3—outside a municipality) according to the definition of the modified LSA mentioned in Section 3.5.1, the frequency of visits and the assistance needed to visit locations in a specific level, and a composite measure, the LSA score, which represents a person's life-space mobility with one value. As the aim is evaluating the validity of the MBT, comparable measures should be derived from the two measurement approaches.

Life-space levels. Information on whether a life-space level has been visited can be extracted easily from the LSA as participants directly answered this question with "yes" or "no". In the MBT, visited life-space levels can be extracted by looking at the attribute *stufe*. If a level (1-3) appears as tag in at least one marked location, it can be assumed that the person visited this specific life-space level.

Frequency. Obtaining a comparable frequency measure from the MBT and the LSA is a bit more difficult. In the LSA, the frequency is represented with one value which refers to a specific level. However, the MBT gathers a frequency for each visited location separately. Accordingly, a solution is needed to reduce multiple frequency values per level to one. Therefore, different possibilities could be identified, namely building the sum of all the frequency values, summing up the number of visited locations per level or finding the maximum frequency per level. When all the frequencies per level are summed up, the sum would most probably overestimate the level-specific frequency values and go beyond the maximum frequency (7 = daily). Summing up the number of marked locations per level could lead to an over- as well as an underestimation of a level's frequency. For example, an overestimation is possible when a person visited 10 places in a life-space level, but all within one day (frequency = 1; locations = 10). And an underestimation could be made when a person visited only one location within a level but daily (frequency = 7; locations = 1). Accordingly, it was decided to compare the frequencies of all places within one level and extract the maximum frequency. By this, it is assumed that the most comparable of the presented solutions to extract a frequency value for each level was chosen.

Assistance. The need for assistance was assessed differently between the two measurement approaches. In the LSA, participants had to answer two questions per life-space level with "yes" or "no", namely "Did you need a walking aid?" and "Did you need the assistance of another person?". In respect to the following calculation of a LSA score based on the instructions by Peel et al. (2005), the answers to these two questions had to be combined. If both answers were "no" (no help), an assistance value of 2 was assigned; if only a walking aid was needed, the resulting assistance value was 1.5; otherwise a value of 1 was assigned. Again, these assistance values of the LSA refer to a level. But in the MBT, these values are assigned to a specific location. However, in the MBT, participants were directly asked which assistance they needed (no help, walking aid, or assistance from a person). Accordingly, the assistance values were again compared per level and the "worst" value was extracted. As an example, in level 1 of the MBT, a person stated 5 times that he/she did not need any assistance to visit a place, but for visiting one location, he/she stated they used a walking aid. Hence, the specification of using a walking aid is assumed to be the most representative assistance value for level 1.

LSA score. When the three above-mentioned indicators are derived from the LSA and the MBT, a life-space mobility score can be calculated. An instruction for generating a LSA score based on the five LSA levels is provided by Peel et al. (2005). A score per level is calculated which multiplies the level by a frequency and an assistance value (e.g. level = 2, frequency = 4-6, assistance = walking aid; formula = 2 * 3 * 1.5). Then, the level scores are summed up. In this thesis, this LSA score was calculated for the LSA and MBT data following the indications of Peel et al. (2005), but with a restriction to three LSA levels (Level 1, 2 and 3), as outlined in Section 3.5.1. As such, the formula for the LSA score had to be adapted as follows:

$$(3(L1) * \mathbf{freq}\ (L1) * \mathbf{assist}\ (L1)) + (4\ (L2) * \mathbf{freq}\ (L2) * \mathbf{assist}\ (L2)) + (5\ (L3) * \mathbf{freq}\ (L3) * \mathbf{assist}\ (L3))$$

The level values are defined linearly ascending from 1 to 3 for areas further away from a person's home and are set to 0 if a person had not visited the specific level. The frequency values range from 1 (for only once) to 4 (for daily), and the assistance values are between 1 and 2 as described above. Hence, the final life-space mobility scores of the LSA and the MBT can range from 0 to 96.

Finally, these life-space indicators derived from the MBT and the LSA are compared to each other by evaluating the total number of differences per participant between the first three life-space indicators. Furthermore, the indicators which show the most erroneous measures are identified. And, finally, the correlation between the life-space mobility scores of both measurement methods is examined.

7.2.2 MBT versus GPS

For comparing the spatial data collected with the MBT and GPS devices, several life-space indicators are defined in three categories, namely life-space level-, distance- and area-related life-space indicators (Table 11). These indicators were generated from the GPS data and the MBT by using R. Accordingly, the methods column in Table 11 states which R packages or self-implemented methods were used. Furthermore, if a method allowed it, the MBT data was weighted with the frequency of visiting a location (Buliung & Kanaroglou, 2006; Sherman et al., 2005). This was possible for the life-space indicators "mean distance to home", "distances between mean centers", "distance from mean centers to home", "standard distance deviation (SDD)", "standard deviational ellipse (SDE)", "standard deviational box (SDB)", "elongation ratio" from the SDE and SDB and the "kernel density estimation (KDE)".

As mentioned in Sections 7.1.1 and 7.1.2, the Longitude and Latitude coordinates of both assessment methods were transformed into the Swiss metric coordinate system LV03 which allows generating metric measures ((kilo)meter or square (kilo)meter) for Euclidean distances and different area calculations. Accordingly, almost all the indicators were calculated with the LV03 coordinates. Nevertheless, when the R function *spDistsN1()* from the *sp* package was used, which calculates the distances between all 2D points of a matrix to a fixed point, the input coordinates needed to be Longitude and Latitude. In this case, the Great Circle Distance was used in order to obtain metric distances as output.

After summarizing the life-space indicators in Table 11, each single indicator and the method for generating them are elucidated in more detail by considering each life-space indicator category separately. Furthermore, some of the indicators are illustrated with figures based on one participant's data (ID = 56). As a first example, Figure 22 shows the area of Basel with the MBT (orange points) and GPS data (light blue points/lines) of this specific participant.

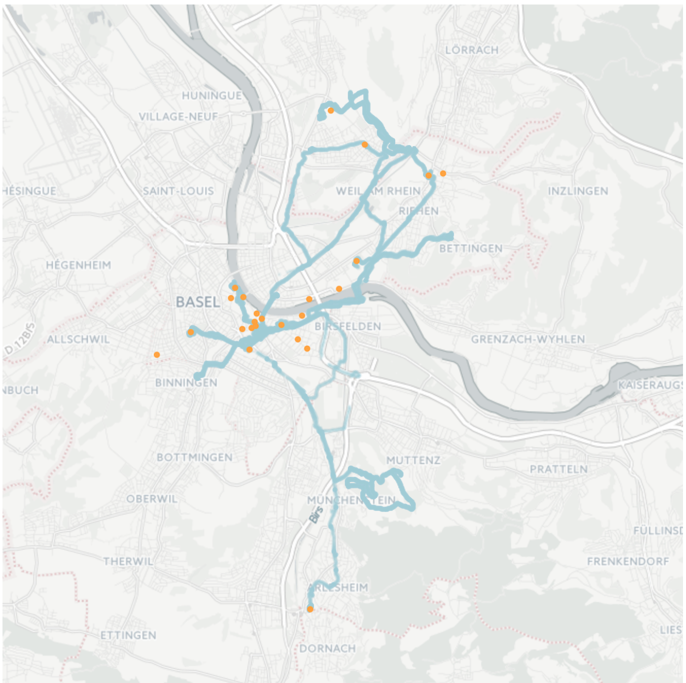

Figure 22: An example of the MBT (orange) and GPS data (light blue) of one participant (ID = 56).

Table 11: Life-space indicators for the evaluation of the MBT's validity to GPS.

Life-space indicator	Methods	Literature
Life-space level-related indicators		
Maximum life-space level	- moasis::getLifeSpaceBuffers() - moasis::getGPSLifeSpaceLevels() - base::max()	Stalvey et al. (1999), Baker et al. (2003) and Peel et al. (2005)
Maximum distance to home per life-space level	- sp::spDistsN1() - Great circle distance for each life-space level (1, 2 & 3) - base::max()	Adapted from Dijst (1999), Schönfelder & Axhausen (2003) and Setton et al. (2011)
Distance-related indicators		
Distance between homes	- Euclidean distance	
Mean distance to home	- sp::spDistsN1() - base::mean()	Tung et al. (2013)
Maximum distance to home	- sp::spDistsN1() - Great circle distance - base::max()	Boissy et al. (2011)
Distance between mean centers	- aspace::calc_sde() (resp. ::calc_sdd() or ::calc_box()) - Euclidean distance	
Distance of mean centers to home	- aspace::calc_sde() (resp. ::calc_sdd() or ::calc_box()) - Euclidean distance	Adapted from Buliung & Kanaroglou (2006), Boissy et al. (2011) and Ebdon (1985)

Standard distance deviation (SDD)	- aspace::calc_sdd()	Buliung & Kanaroglou (2006)
Area-related indicators		
Convex hull (CHull)	- grDevices::chull()	Hirsch et al. (2014) and Tung et al. (2013)
Standard deviational ellipse (SDE)	- aspace::calc_sde()	Boissy et al. (2011), Buliung & Kanaroglou (2006), Ebdon (1985), Hirsch et al. (2014), Rainham et al. (2010) and Sherman et al. (2005)
Aspect / elongation ratio (SDE)	- aspace::calc_sde() - Minor/major axis	Boissy et al. (2011), Buliung & Kanaroglou (2006), Ebdon, (1985) and Newsome et al. (1998)
Standard deviational box (SDB)	- aspace::calc_box()	
Aspect / elongation ratio (SDB)	- aspace::calc_box() - Minor/major axis	Adapted from the aspect / elongation ratio of the SDE
Axis-aligned bounding box (BBox)	- sp::bbox()	
Minimum area BBox	- getMinBox()[16]	
Minimum enclosing circle (MEC)	- raster::pointDistance() - base::max()	Skyum (1991)
Compactness	- CHull / MEC	Hirsch et al. (2014) and Tung et al. (2013)
Kernel density estimation (KDE), 95% and 50% contour area	- ks::kde() resp. - adhabitatHR::kernelUD() and ::kernel.area()	Kwan & Lee (2004), Perchoux et al. (2013), Rainham et al. (2010) and Schönfelder & Axhausen (2003)

Life-space level-related indicators. This category consists of two indicators, the maximum life-space level and the maximum distance per level. The first was proposed by Baker et al. (2003), Peel et al. (2005) and Stalvey et al. (1999) and can be directly derived from the MBT by searching for all the visited levels per participant in the attribute *stufe* and finding the maximum level, ranging from 1 to 3. For assigning a life-space level to each GPS coordinate, the functions *getLifeSpaceBuffers()* and *getGPSLifeSpaceLevels()* from the *moasis* package are used. The

[16] R Examples Repositories (2014). Convex hull, (minimum) bounding box, and minimum enclosing circle. Available at: http://www.uni-kiel.de/psychologie/rexrepos/posts/diagBounding.html [Accessed April 6, 2017].

getLifeSpaceBuffers() function needs as input radii or spatial polygons which define the different life-space areas, and the home location around which the radii are set. For the neighborhood (life-space Level 1), two different neighborhood buffers were defined, an 800-meter (= 0.5 miles) buffer as proposed in several life-space related studies (e.g. Baker et al., 2003; Hirsch et al., 2014; Zenk et al., 2011) and a buffer with the maximum distance in the neighborhood (Level 1) derived from the MBT. For the life-space Level 2, a dataset from Swisstopo containing the municipality borders of Switzerland (as of April 2015) was used. Based on these inputs, the *getLifeSpaceBuffers()* function returns a list of concentric spatial-polygons around the home. This list can be used as input for the *getGPSLifeSpaceLevels()* function which assigns to each GPS point the life-space level in which it is contained. When this assignment is completed, the maximum level can be extracted for each GPS dataset.

After the already-described implementation, a subset per level can be created for the MBT and GPS data and the distances of each point to a person's home can be calculated with the *spDistsN1()* function from the *sp* package. Then, the maximum distance to home is identified for the two datasets and assigned as maximum distance per life-space level.

Distance-related indicators. This category consists of two types of life-space indicators. The first indicator describes a person's accuracy of marking locations in the MBT. This could further be compared to a person's spatial ability (Section 7.2.3) in order to identify if there is a relationship between a low accuracy of marking points and a low spatial ability. The following distance-related indicators are used to compare the similarity of the results derived from the MBT and the GPS data. Therefore, the results are correlated and the difference between them is evaluated.

The distance between the GPS or the MBT to home, which is the first distance-related indicator, is calculated as the Euclidean distance (in LV03) between two points. The second indicator, illustrated in Figure 23 on the left, is the mean distance to home which represents the concept of circles around the home (blue circle—mean distance of the GPS data; orange circle—mean distance of the MBT data; red circle—mean distance of the weighted MBT data), adapted from Andrews et al. (2007). Therefore, the home locations had to be excluded from the calculation so as to not decrease the resulting values. The third indicator is the maximum distance to home which indicates the furthest location a person can reach (Figure 23 on the right). For calculating the mean distance as well as the maximum distance to home, the functions *spDistsN1()* (Great Circle Distance) with Longitude and Latitude coordinates, and the *mean()* were used. For the mean distance, each distance from a visited location to home was weighted with the frequency of visiting this place. And then, the mean was calculated based on the weighted distances. The fourth measure regards the distance of the mean centers generated from the (weighted) MBT and GPS locations. According to Ebdon (1985), a mean center represents the average perceived location, namely the mean of all coordinates of a dataset. The “displacement of mean center from true location is a measure of average accuracy of perception” (Ebdon, 1985:141). Accordingly, this approach is used to evaluate the fifth indicator, the distance of mean centers to home. For both indicators, the function *calc_sde()* (or *calc_sdd()* resp. *calc_box()*) from the *aspace* package can be used to generate the mean centers. Optionally, a weighting vector can be defined. When a mean center is defined, the distances to each other or to a person’s home can be calculated by using the Euclidean distance (LV03). And, finally, the last indicator is also based on the *aspace* package, the standard distance deviation (*calc_sdd()*) which provides a concise description of the spatial distribution of points around the mean center (Ebdon, 1985).

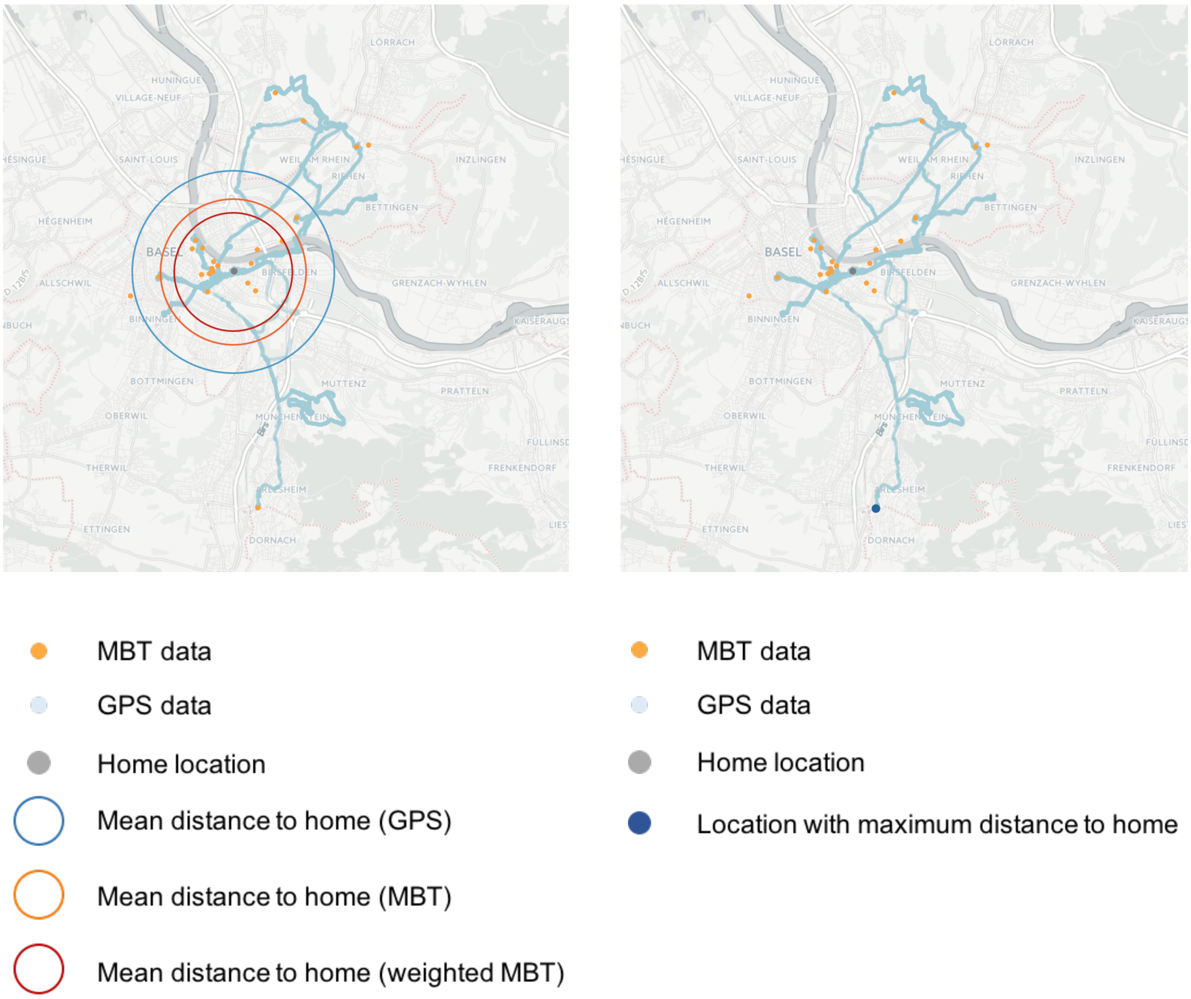

Figure 23: Upper left - mean distances to home. Upper right – location of with the maximum distance to home. Below – legends explaining the map icons.

Area-related indicators. These life-space indicators are used to evaluate the validity of the MBT compared to GPS based on different areal measures. The convex hull is a polygon which encompasses all points representing a person's mobility (Figure 24 top left). Accordingly, it is "a measure of the area covered by a participant through his/her daily travelling" (Kestens et al., 2014:5). In R, this measure can be generated e.g. with *chull()* function in the *grDevices* package. The next indicators, the standard deviational ellipse and box (Figure 24 lower left and right), and their elongation (resp. aspect) ratio could be generated with functions, *calc_sde()* resp. *calc_box()*, from the *aspace* package. From the output of these functions, the major and minor axis can be extracted whereby the elongation ratios can be calculated (formula: *length of the minor axis / length of the major axis*). The area of standard deviational ellipse (SDE) is a measure of agreement between respondents (Ebdon, 1985). However, the elongation ratio is "an indication of the degree of fullness" (Newsome et al. 1998:363) whereas the value 1 indicates a circle and the value 0 would represent a line. Other life-space indicators are the axis-aligned and the minimum area bounding box (BBox; Figure 24 mid left and right). Both are rectangles which include all points of a dataset, but the first is oriented in the direction of x- and y-axes and the second is rotated in order to minimize the size of the BBox area for more effectively encompassing a point pattern. The axis-aligned BBox has been generated with the *bbox()* function from the *sp* package, and for the minimum area BBox a function from the R Examples Repositories from the University of Kiel[15] has been used. Moreover, for the minimum enclosing circle (MEC) area, the *pointDistance()* function from the *raster* package was used which allows generating the radius of a circle cutting the two most distant points (Figure 24 top right). This approach should include all the points in a circle. Based on the MEC and the CHull, the compactness can be generated which is a measure of how circular (MEC) a polygon (CHull) is (Hirsch et al., 2014; Tung et al., 2013). Similar to the elongation ratio, the compactness values can range from 0 to 1, whereas 1 indicates that the CHull looks like a circle. And, finally, the kernel density estimation's (KDE) 50% and 95% contour areas shall be generated by using the *kde()* (*ks* package), respectively the *kernelUD()* and the *kernel.area()* (*adehabitatHR* package) functions. These would indicate the areas in which a person moves 50% and 95%, respectively (Figure 25).

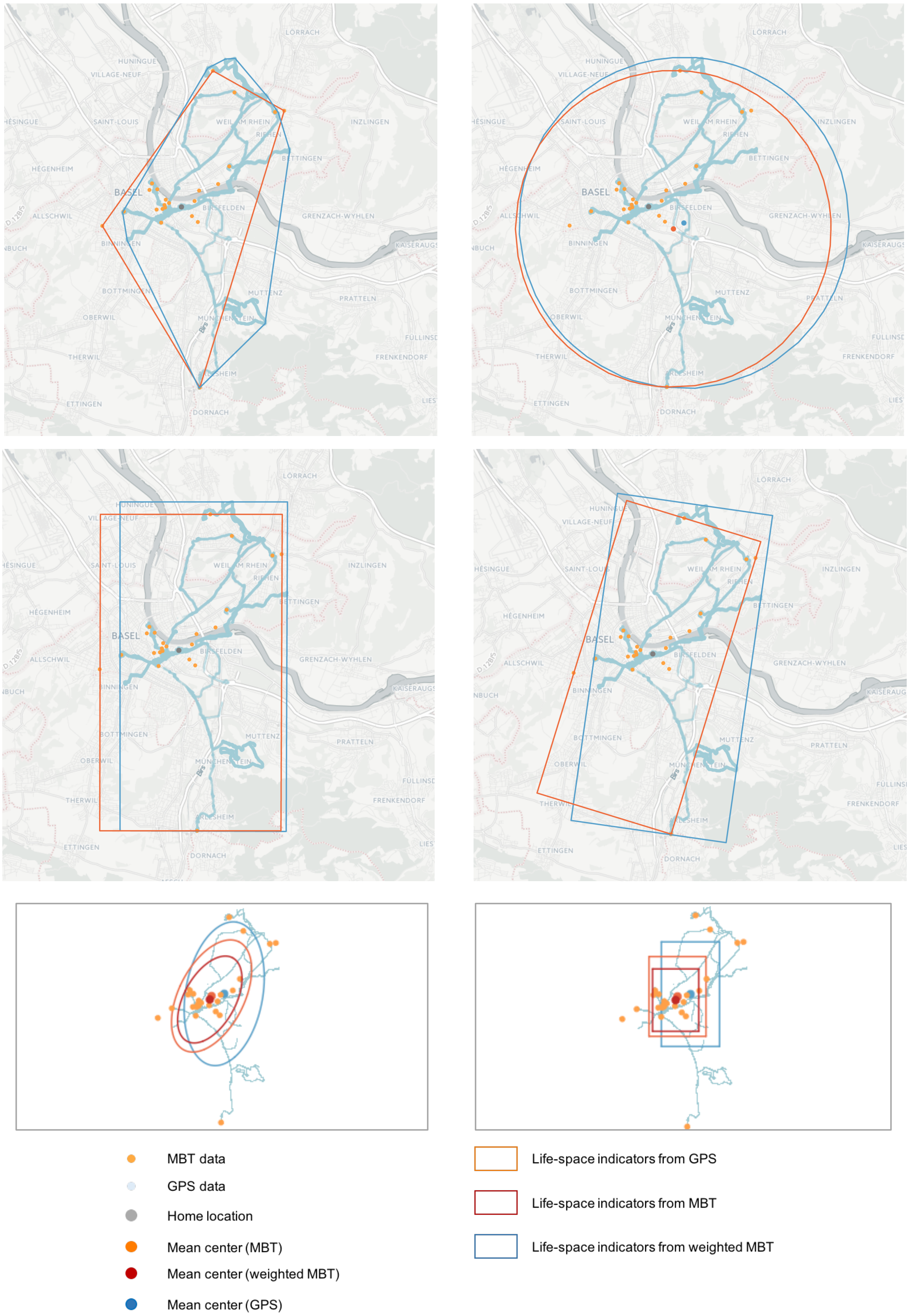

Figure 24: Upper left – convex hull. Upper right – minimum enclosing circle. Mid left – axis-aligned bounding box. Mid right – minimum area bounding box. Lower left - standard deviational ellipse. Lower right - standard deviational box.

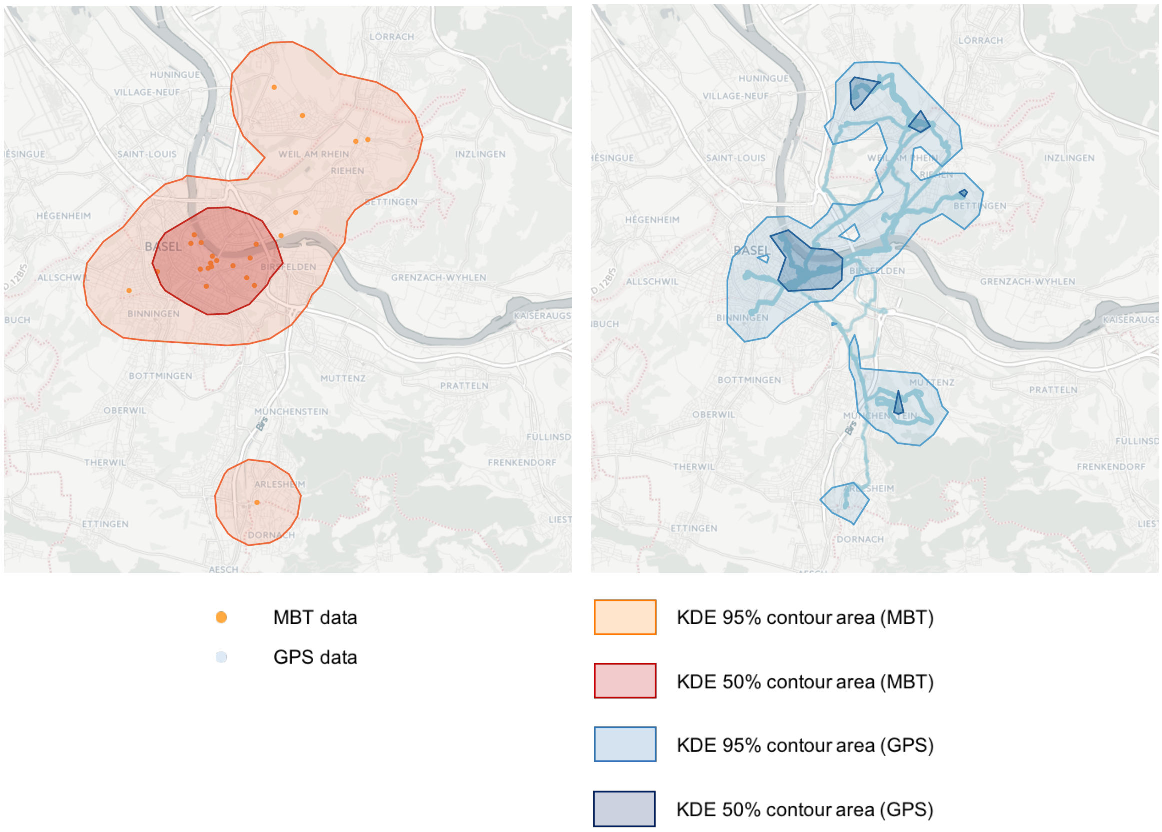

Figure 25: Illustration of possible kernel density estimation 50% and 95% contour areas of the MBT (left) and GPS (right) based on the R package adehabitatHR with an Epanechnikov kernel and a href (ad hoc) smoothing method (ID = 56).

In Section 7.3.2, these life-space indicators derived from the MBT and GPS are compared to each other by using Pearson correlation. Furthermore, the indicators which show the most erroneous measures are identified and analyzed in more detail with Bland-Altman plots. And finally, the first distance-related indicator, which describes a person's accuracy of marking locations in the MBT, is compared to a person's spatial ability, explained in Section 7.2.3.

7.2.3 Spatial ability

A person's spatial ability is a measure which could be used to evaluate the accuracy of marking locations in the MBT and to explain differences among the life-space indicators derived from the MBT and GPS. The spatial ability was surveyed by using the Santa Barbara Sense of Direction Scale (SBSOD) by Hegarty et al. (2002) (Section 3.5.2). The questionnaire consists of 15 items which were formulated positively (a, c, d, e, g, i, n) and negatively (b, f, h, j, k, l, m, o; Appendix B, CRF1_Q24). Furthermore, Hegarty et al. (2002) stated that a higher score should indicate a better spatial ability. Accordingly, as the score 1 means that a statement is true and 7 that it is not, the rating of the positively-formulated items needs to be reversed. The final spatial ability scores per person are generated by calculating the mean of all item scores. The results are shown in Table 16 (Section 7.3.2).

7.3 Results

In this section, the above-mentioned life-space indicators are analyzed with different plots visualizing the data, using Pearson correlations and Bland-Altman plots. The latter examines the agreement between two methods. As the true value of a measure is not known, the mean is meant to approximate such a value represented on the x-axis. The y-axis illustrates the difference between the two methods. Accordingly, this "plot of difference against mean [...] allows us to investigate any possible relationship between the measurement error and the true value" (Bland & Altman, 1986:308). Furthermore, a Bland-Altman plot contains a line indicating the mean of the differences (in this thesis represented by a blue line), and two lines representing the limit of agreement (in this thesis represented by red lines: *mean ± 1.96 * standard deviation*). Ideally, in a Bland-Altman plot, 95% of the differences should lie within this limit of agreement. Extreme outliers—depending on the data—a high mean difference, very distant limits of agreement and conspicuous point patterns, such as trumpet-shaped ones, are undesired.

7.3.1 Evaluation of the life-space indicators of the MBT and LSA

The first evaluation of the MBT's validity compared to the LSA considers the total number of deviations in the answers given to the visited life-space levels, the maximum frequencies of visiting these levels and details regarding assistance needed generated by determining whether the values of both measurement approaches were the same (Figure 26). Most of the participants showed only deviations of, in total, 2 single aspects among their answers (out of 9). However, there were a couple with 3 or more deviations, and a few who had less than 2. To further break down this general histogram, the deviations among participants' answers in the MBT and the LSA are analyzed in more detail in Table 12 by splitting up the deviations and aspects by level. Considering life-space Level 1, 35 deviations could be observed among all study participants. Additionally, in Levels 2 and 3, even more deviations appeared, 69 and 42, respectively. In Levels 1 and 3, the deviations regarding the visited life-space levels and the need for assistance were very few (< 4). But, in life-space Level 2, both indicators showed 14 deviations in the answers. However, most of the deviations come from the indicator "frequency of visiting a place". In all three levels, more than 30 deviations occurred.

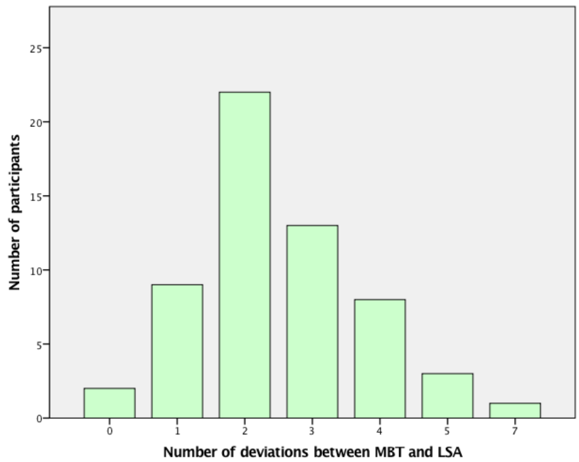

Figure 26: Number of deviations per participants between MBT and LSA.

Table 12: Comparison of total number of deviations per life-space level and the number of deviations regarding the visited life-space levels, the maximum frequency and the assistance needed between the MBT and the LSA.

	L1 visited	L1 freq.	L1 assist.*	L2 visited	L2 freq.	L2 assist.	L3 visited	L3 freq.	L3 assist.
Total number of deviations per level		35			69			42	
Number of deviations	3	30	2	14	41	14	2	36	4

freq. = maximum frequency; assist. = need for assistance; assist.* = 1 missing value

As the frequencies show such a high number of deviations, they are analyzed in more detail in Figure 27. The histogram on the left shows the difference of the maximum frequencies between the LSA and the MBT in life-space Level 1 (possible range from -4 to 4). For most of the participants, no deviations in their answers could be found (difference = 0). For more than 20 cases, the MBT underestimates the maximum frequency (difference ≥ 1). And, in almost 10 cases, the MBT overestimates the frequency. In the histogram in the middle, the maximum frequencies are compared for Level 2. Again, most of the participants showed no difference, but a high number of underestimations through the MBT can be observed. Still, a few are overestimated. On the right (life-space Level 3), the highest peak is represented with the underestimation by one frequency score (difference = 1). Here, the tendency of the MBT to underestimate the maximum frequency is indicated once more. Concluding, the three histograms in Figure 27 highlight that the MBT underestimates the frequency scores in each life-space level, but, still, approximately half of the participants showed no deviations in their answers regarding the maximum frequency scores.

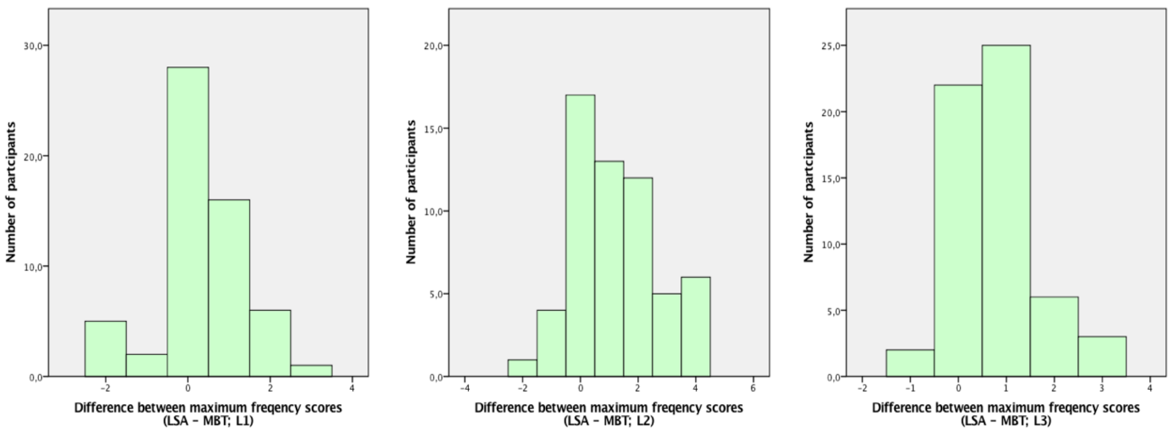

Figure 27: Number of differences between maximum frequency scores per life-space level (L1, L2 and L3; from left to right).

The second evaluation in the current section considers the composite LSA scores which were derived from both life-space measurement approaches. Figure 28 on the left shows a scatterplot which compares the LSA scores derived from the LSA on the x-axis and the ones derived from the MBT on the y-axis. The orange line represents the linear regression line. It can be observed that the same LSA score has been calculated for only two participants. Furthermore, the points are distributed over the whole plot. This fact is underlined through the Pearson correlation test which results in a correlation coefficient of $r = 0.09$ ($p = 0.503$). Accordingly, it can be assumed that the two differently generated LSA scores do not significantly correlate with each other.

This assumption is further emphasized when considering Figure 28 on the right, which shows a Bland-Altman plot indicating a considerable lack of agreement (Bland & Altman, 1986). The mean of the differences is 18.81 (blue line), which already indicates a shift when comparing the scores. The red lines show the limit of agreement, which points to high variations between the two datasets. Furthermore, the highest discrepancies can be observed on the y-axis above 0 which indicates an underestimation of the LSA score derived from the MBT compared to scores derived from the LSA. When comparing the range of differences from the mean, no particular distribution pattern can be recognized.

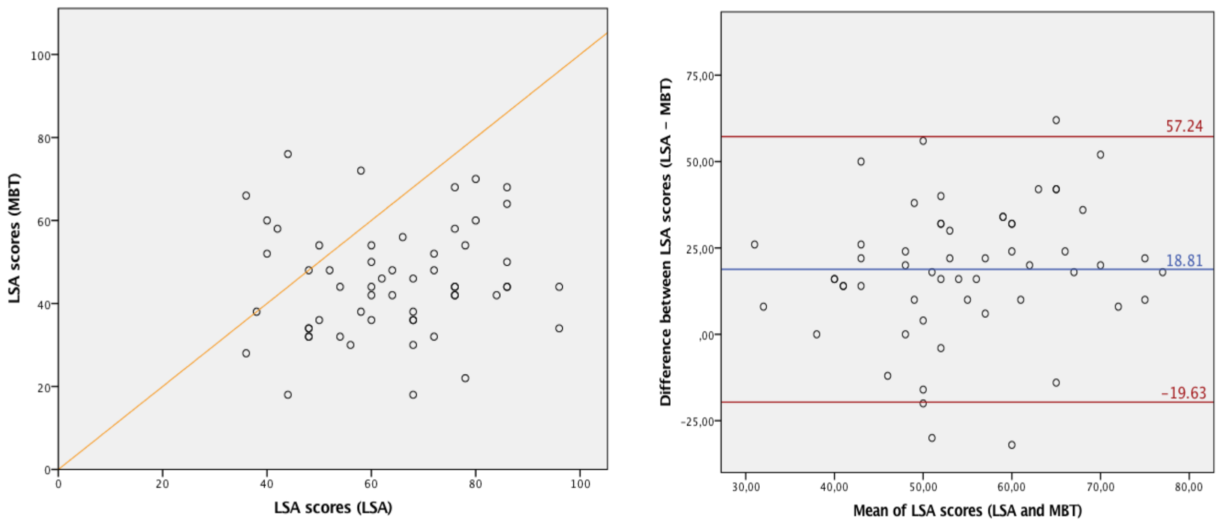

Figure 28: Left – Scatterplot of the LSA scores from the MBT and the LSA. Right – Bland-Altman plot of the differences of the LSA scores between the MBT and the LSA.

7.3.2 Evaluation of the life-space indicators of the MBT and GPS

Section 7.3.2 evaluates the validity of the MBT compared to GPS by considering first the life-space level-related, second the distance-related and third the area-related life-space indicators. As already mentioned in Section 7.1.2, the measurements from one participant are invalid and had to be excluded from the subsequent evaluation, because the *uTrail* assessed incorrect data. Accordingly, in this section, the maximum number of participants is 57, instead of 58.

Additionally, as mentioned in Section 7.2.2, all the following measures have been derived from the GPS and MBT data. If possible, a weighted MBT measure was generated. However, a pre-evaluation showed that all the normal and weighted measures generated from the MBT show high correlation coefficients ($r \geq 0.900$). Furthermore, the life-space indicators which are derived from the MBT without a weighting parameter correlate more with the GPS measures than the weighted indicators. The only exceptions are the measures from the standard deviational ellipse (SDE; area and elongation ratio). For this case, the GPS measure shows a stronger correlation with the weighted MBT than the normal MBT measures. Consequently, for the following analysis of the life-space indicators, only the GPS and normal MBT measures are compared. This decision has a further advantage, namely that it was possible to generate all the indicators for the normal MBT.

Life-space level-related indicators. When comparing the maximum life-space levels per participant assessed with GPS and the MBT, in most of the cases ($n = 53$), the same maximum level could be identified (Table 13). For three participants, the MBT underestimated the maximum level compared with the GPS measures, two participants had a deviation of one level and one participant had one of two levels. For one participant, however, the maximum level was overestimated by one. Considering the results in which the life-space levels were assigned to the GPS data based on the neighborhood buffer derived from the MBT—meaning that the maximum distance of Level 1 assessed with the MBT was used to assign the life-space levels to the GPS points—no significant differences could be observed in the assignment of the maximum life-space levels. The only exception is that no maximum life-space level could be assigned to one participant (missing = 1).

Table 13: Differences between the maximum life-space levels of the GPS and the MBT.

	N (missing)	**-1**	**0**	**1**	**2**
GPS - MBT	57	1	53	2	1
GPS* - MBT	56 (1)	1	53	2	-

N = number of participants; GPS = global positioning system; MBT = map-based tool; GPS* = the maximum life-space level has been extracted from the GPS dataset which is based on the neighborhood buffer derived from the MBT

Moreover, when regarding the results of the Pearson correlation of the maximum distances per life-space level in Table 14, we can see that the distances correlate in all three levels. However, it can be stated that, in Level 1 (generated with a fix buffer of 800 m), no significant correlation could be found ($r = 0.085$ and $p = 0.533$). As for Level 1*, the definition of the maximum distance is based on the MBT, and the maximum distances of the GPS and MBT absolutely correlate ($r = 1.000$) with each other.

Table 14: Correlation between the maximum distances to home per level generated from GPS and MBT data.

	N (missing)	r	p
Level 1	56 (1)	0.085	0.533
Level 1*	56 (1)	1.000	0.000
Level 2	43 (14)	0.388	0.010
Level 3	52 (5)	0.768	0.000

N = number of participants; r = Pearson correlation coefficient; p = p-value; Level 1* = the correlation has been executed with the maximum distance of the GPS Level 1 based on the neighborhood buffer derived from the MBT

For analyzing the maximum distances of the three correlating levels (Level 1*, 2 and 3) in more detail, Bland-Altman plots were generated. In Figure 29, the differences of Level 1 (on the y-axis) from the mean are illustrated. Most points lie on the blue line—mean of differences— which is, in this case, around 0. There is only one outlier which has a difference of -0.15 km at a mean maximum distance of ca. 2.2 km. This single point shifts the whole plot so that only one limit of agreement line can be shown (red line). But, in general, the plot absolutely underlines the results of the correlation of *r = 1.000*. In contrast, the differences of the maximum distances of life-space Level 2 show a more distributed pattern (Figure 30 on the left). Almost all differences range between 3.25 km and -2.25 km independently of the mean maximum distance. But, again, there is one outlier with a difference of -4.00 km at a mean of ca. 3 km. Finally, Figure 30 shows the Bland-Altman plot of the maximum distances of Level 3. Here, again, most of the participants show differences of around 0 which appear within the entire range of mean distance values. However, this plot shows the most outliers above and below limit of agreement lines (in red). One of these outliers reaches a 150 km difference, which indicates a high deviation.

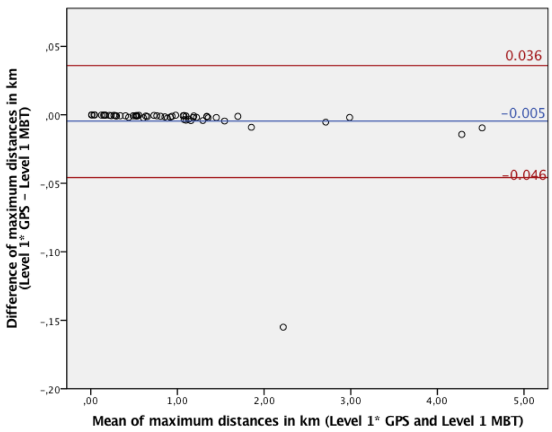

Figure 29: Bland-Altman plot of the maximum distances of life-space Level 1 derived from the GPS (MBT based neighborhood buffer) and the Level 1 from the MBT.*

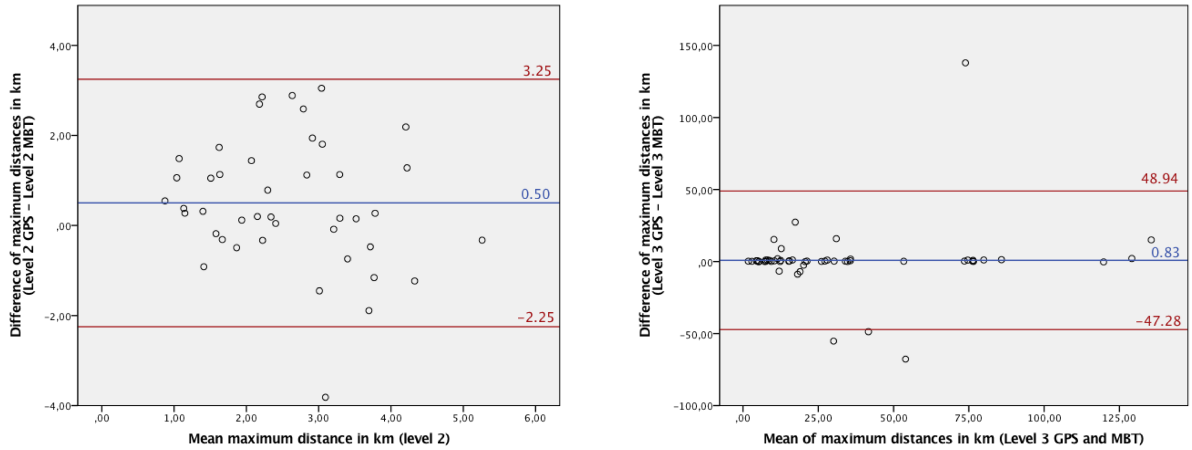

Figure 30: Bland-Altman plots of the maximum distances of life-space Level 2 (left) and Level 3 (right) derived from the GPS data and the MBT.

Distance-related life-space indicators. The results of these indicators are summarized in Table 15. The first indicator is the distance between the home locations which could be used to evaluate participants' accuracy in marking locations on the map. The mean distance between the two home locations is 161.5 meters. But the variation of this distance among study participants seems to be very high, which is indicated by a high standard deviation (= 291.3 m) and wide range of distances between home locations (min = 8.0 m; max = 1,544.4 m). This high variation could be explained by differences in participants' spatial abilities. The assumption would be that a person with a low spatial ability could have had more difficulties in correctly identifying his/her home on the map. Accordingly, the spatial ability scores based on the Santa Barbara Sense of Direction (Hegarty et al., 2002) are derived and summarized in Table 16. However, a Pearson correlation test showed no significant correlation between a person's spatial ability and the distance between his/her home locations in the GPS and MBT data ($r = -0.060$ and $p = 0.659$).

The second indicator in Table 15—the distance between mean centers—could also be used for evaluating differences in the data accuracy between GPS and MBT. However, this measure does not rely on participants' spatial abilities, but more on the spatial data basis. The mean centers of the GPS and MBT data are, on average, 4,446.2 meters apart from each other. Again, a high variation among participants is indicated by a high standard deviation and a large range between the minimum and maximum values.

The remaining four indicators could be directly compared between GPS and MBT by examining Pearson correlations and by calculating the differences between the two measurement approaches. All the four indicators correlate significantly ($p = 0.000$), but with different correlation coefficients. The mean distance to home shows the lowest, and the distance of mean centers to home show the highest correlation ($r = 0.541$ respectively 0.946). Accordingly, these two will be further analyzed below with Bland-Altman plots (Figure 31). The mean and the standard deviation of maximum distance to home is for both measurement approaches approximately the same. However, the minimum and maximum values vary a bit. Furthermore, the difference (GPS – MBT) has a mean of around 0 (no difference), but a high standard deviation, minimum and maximum values. The results of the standard distance deviation (SDD) look similar when comparing the relationship of the means, the standard deviation and minimum and maximum values. But, here, the mean of the difference between GPS and MBT is negative (-2.49 km), which indicates that GPS generally gives lower SDD values.

Table 15: Summary statistics of the distance-related life-space indicators.

Characteristic	N (missing)	Mean ± SD	Min.; Max	Correlation
Distance between homes (in m)	57	161.5 ± 291.3	8.0; 1,544.6	
Distance between mean centers (in m)	57	4,446.2 ± 6,437.8	25.1; 34,700.5	
Mean distance to home (in km)				r = 0.541 p = 0.000
GPS	57	5.84 ± 9.08	0.04; 46.51	
MBT	57	6.91 ± 6.84	0.81; 38.40	
Difference (GPS – MBT)	57	-1.07 ± 7.88	-22.14; 32.32	
Maximum distance to home (in km)				r = 0.781 p = 0.000
GPS	57	31.86 ± 36.68	1.19; 143.07	
MBT	57	31.35 ± 33.89	2.30; 128.09	
Difference (GPS – MBT)	57	0.50 ± 23.48	-67.73; 137.91	
Distance of mean center to home (in m)				r = 0.946 p = 0.000
GPS	57	497.0 ± 18.1	482.8; 583.4	
MBT	57	496.2 ± 18.1	481.2; 588.1	
Difference (GPS – MBT)	57	0.84 ± 5.98	-8.76; 32.1	
Standard distance deviation (in km)				r = 0.686 p = 0.000
GPS	57	9.67 ± 13.14	0.09; 60.4	
MBT	57	12.2 ± 12.9	0.80; 62.8	
Difference (GPS – MBT)	57	-2.49 ± 10.3	-27.5; 48.9	

N = number of participants; SD = standard deviation; r = Pearson correlation coefficient; p = p-value; GPS = global positioning system; MBT = map-based tool; m = meters; km = kilometers

Table 16: Summary statistics of the spatial ability.

Characteristic	N (missing)	Mean ± SD	Min.; Max
SBSOD mean score (1-7); ID = 64 excluded	56 (1)	5.25 ± 0.97	3.2; 7.0

N = number of participants; SD = standard deviation; SBSOD = Santa Barbara Sense of Direction Scale

As mentioned above, Figure 31 illustrates Bland-Altman plots of the life-space indicators with the lowest and highest correlation between GPS and MBT measures. On the left (*r = 0.541*), the distribution of differences of the indicator mean distance to home is shown. Most of the points are within the limit of agreement, but outliers sit above and below the red lines. These outliers seem to appear when the mean of the mean distances to home becomes higher (trumpet-shaped point pattern). In contrast, on the right (*r = 0.946*) shows only outliers with a positive difference. Furthermore, the mean ranges between 480 and 600 km whereas the differences seem to be rather low compared to the mean values.

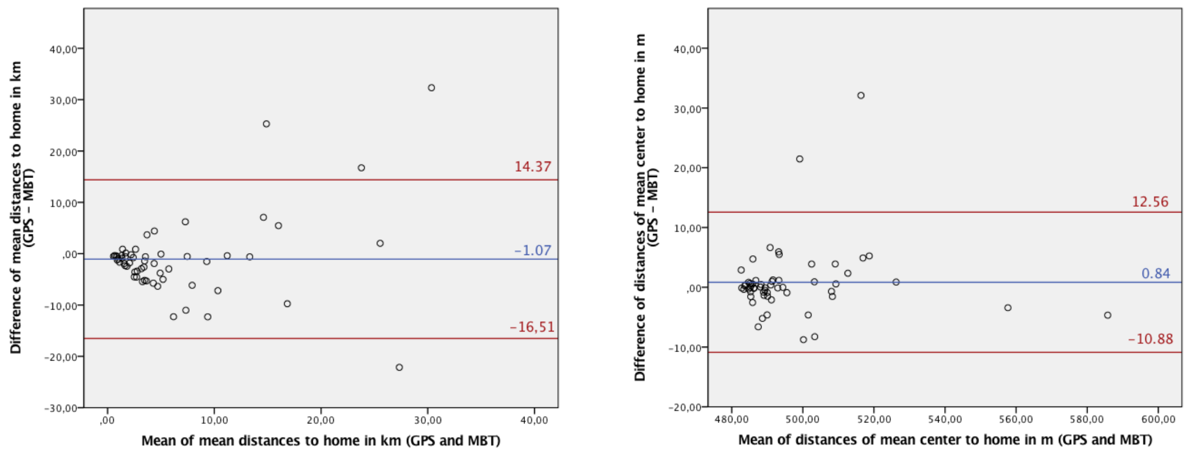

Figure 31: Bland-Altman plots of the mean distances to home (left) and the distances of mean center to home (right) derived from GPS and MBT.

Area-related life-space indicators. The results of all area-related indicators are summarized in Table 17. For all life-space indicators, results could be generated for each participant. Furthermore, all the indicators significantly correlate between the MBT and GPS. Compared to the distance-related indicators, it can be stated that the mean values of the area-related indicators differ more from each other. Moreover, it is conspicuous that the minimum and maximum values are widely dispersed. These two tendencies are also underlined by the differences between GPS and MBT measures per life-space indicator, as the means, minimums and maximums of the area-related indicators show higher values than for example in the results of distance-related indicators. As an example of a low correlation, the area of the convex hull (CHull) has two means with standard deviations that noticeably differ (GPS = 565.2 ± 1,267.4 km^2; MBT = 214.5 ± 381.1 km^2). The minimum values are approximately the same, but the maximum values are very different (GPS = 8,046.5 km^2; MBT = 1,715.9 km^2). This is also highlighted when considering the difference (GPS – MBT) where the mean and its standard deviation (350.7 ± 1,170.6 km^2) indicate an underestimation of the life-space area generated from the MBT compared to GPS.

A further example considering a higher correlation could be the area of the minimum enclosing circle (MEC). The mean values do not differ so strongly (GPS = 2,272.8 km^2; MBT = 1,979.3 km^2), and the minimum and maximum values are almost the same. However, the difference between GPS and MBT still tends to show a high mean with a high standard deviation. Furthermore, the range between the minimum and maximum values of the difference seem to be very high. Again, it could be assumed that the MBT underestimates the area compared to the GPS.

Table 17: Summary statistics of the area-related life-space indicators.

Characteristic	N (missing)	Mean ± SD	Min.; Max	Correlation
Area of CHull (in km^2)				r = 0.395 p = 0.002
GPS	57	565.2 ± 1,267.4	0.92; 8,046.5	
MBT	57	214.5 ± 381.1	0.008; 1,715.9	
Difference (GPS – MBT)	57	350.7 ± 1,170.6	-957.4; 7,511.2	
Area of MEC (in km^2)				r = 0.819 p = 0.000
GPS	57	2,272.8 ± 4,407.5	3.92; 19,027.4	
MBT	57	1,979.3 ± 3,664.7	6.41; 18'483.0	
Difference (GPS – MBT)	57	293.5 ± 2,527.0	-5,491.4; 16,968.9	
Compactness (CHull / MEC)				r = 0.338 p = 0.010
GPS	57	0.29 ± 0.12	0.04; 0.55	
MBT	57	0.20 ± 0.14	0.0007; 0.62	
Difference (GPS – MBT)	57	0.10 ± 0.15	-0.44; 0.43	
Area of SDE (in km^2)				r = 0.624 p = 0.000
GPS	57	263.9 ± 649.1	0.01; 3,619.8	
MBT	57	267.6 ± 544.7	0.06; 3,036.9	
Difference (GPS – MBT)	57	-3.65 ± 526.4	-1,357.3; 2,981.3	

Elongation ratio (SDE)				r = 0.491 p = 0.000
GPS	57	0.30 ± 0.19	0.03; 0.85	
MBT	57	0.28 ± 0.20	0.001; 0.79	
Difference (GPS – MBT)	57	0.01 ± 0.20	-0.60; 0.65	
Area of SDB (in km²)				r = 0.671 p = 0.000
GPS	57	405.2 ± 954.0	0.01; 5,617.5	
MBT	57	448.6 ± 1,044.2	1.15; 6,891.0	
Difference (GPS – MBT)	57	-43.4 ± 814.9	-4,210.7; 3,504.6	
Elongation ratio (SDB)				r = 0.520 p = 0.000
GPS	57	0.60 ± 0.23	0.14; 0.97	
MBT	57	0.61 ± 0.24	0.03; 0.97	
Difference (GPS – MBT)	57	-0.003 ± 0.23	-0.69; 0.78	
Area of axis-aligned BBox (in km²)				r = 0.879 p = 0.000
GPS	57	1,345.8 ± 2,753.1	2.19; 13,469.1	
MBT	57	1,071.5 ± 2,112.3	2.91; 11,639.2	
Difference (GPS – MBT)	57	274.2 ± 1,348.9	-4,304.1; 6,400.2	
Area of minimum area BBox (in km²)				r = 0.441 p = 0.001
GPS	57	851.7 ± 1,905.0	1.28; 12,080.9	
MBT	57	395.5 ± 714.5	0.02; 3,117.8	
Difference (GPS – MBT)	57	456.2 ± 1,714.5	-1,792.4; 11,010.3	

N = number of participants; SD = standard deviation; r = Pearson correlation coefficient; p = p-value; km² = square kilometers; CHull = convex hull; MEC = minimum enclosing circle; SDE = standard deviational ellipse; SDB = standard deviational box; BBox = bounding box

Again, Bland-Altman plots were generated for the two indicators which have the lowest and the highest correlation between MBT and GPS measures. Figure 32 on the left shows the agreement of the compactness (*r = 0.338*). The differences are mostly within the limit of agreement but the points are widely dispersed within this area. Furthermore, outliers can be identified above and below the limiting area. By contrast, the right side of Figure 32, the similarity between the areas of the axis-aligned bounding box (BBox) is illustrated (*r = 0.879*). Most of the points are clustered at a difference of around 0 and at a mean between 0 and 2,000 km^2. Single outliers can be identified; two show quite large differences and one a quite small difference. Moreover, there is one noticeable point at a mean of 12,000 km^2, but it still shows a rather small difference. Accordingly, it could be said that, independently of the mean value, the difference between GPS and MBT can be rather small for the area in the axis-aligned BBox.

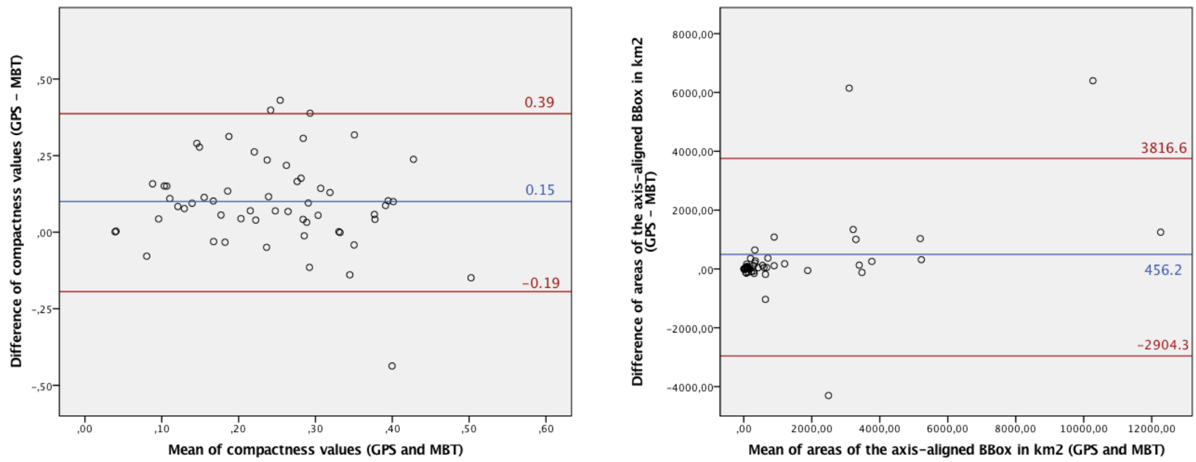

Figure 32: Bland-Altman plots of the differences of the compactness values (left) and the areas of the axis-aligned bounding box (BBox) of the MBT and GPS.

In Section 7.2.2, a further area-related life-space indicator was noted for evaluating the validity of the MBT compared to GPS, namely the Kernel density estimation (KDE) 95% and 50% contour area. This indicator is not presented in this results Section 7.3.2, because a bivariate KDE should be only generated when at least 19 points exist (Silverman, 1986). For the MBT, only 4 participants marked sufficient locations. Consequently, it would not make sense to evaluate the KDE for these 4 participants as the results would not be representative.

8 Discussion

This chapter addresses the research questions (RQs) by discussing the results of the development process, and the evaluation of the usability and validity of the map-based tool (MBT). Section 8.1 elucidates the requirements for an MBT aiming to measure older adults' life-space mobility. In Section 8.2, usability-related measures are discussed in general and compared to ratings obtained from GPS and LSA. And, finally, Section 8.3 highlights several life-space indicators derived from the three measurement approaches and provides a final assessment on the validity of the MBT in relation to the commonly-used GPS and LSA approaches.

8.1 Requirements for an MBT measuring older adults' life-space mobility

The general aim of this thesis was to develop a map-based-tool (MBT) for the determination of older adults' life-space mobility as an alternative to the commonly-used LSA and GPS measurement approaches. Accordingly, the first RQ addressed the requirements for implementing such a tool.

RQ1: What are the requirements for a map-based tool (MBT) aiming at measuring older adults' life-space mobility as an alternative to the LSA and GPS-based indicators in health and aging research?

The list of requirements

The definition of requirements was firstly based on identifying tool requirements (Section 5.1), which help to achieve the aims of the thesis. And, then, user-oriented requirements were defined which should allow implementing an MBT that is usable by older adults (Section 5.2). With this approach, a list of requirements has been elaborated. An adapted version is summarized in Appendix A whereas most of the adaptations are only new formulations compared to the listing in Sections 5.1 and 5.2. Special cases are discussed in the next section.

Problematic and special requirements, and how they have been handled

Almost all requirements could be implemented in the MBT (as described in Section 5.4). But there are still a few exceptions which need to be discussed in more detail.

The first exception is a conflict between a tool requirement (T2) and two user-oriented requirements (U4 and U7). On the one hand, T2 stated that the MBT should at least be able to collect visited locations with the geographic primitive "point", and that lines and areas would be a plus, but not essential. On the other hand, U4 and U7 express that the drawing of lines should be avoided and that the functionality of an application should be reduced to a minimum. As it is known that older adults may encounter several problems with new technologies, it seemed more important to support the user-oriented requirements U4 and U7. Consequently, in the final list of requirements (Appendix A), the requirement T2 has been adjusted.

A further exception was faced when regarding the tool requirement T6, which highlights the elements which should be represented on the map of the MBT, namely city names, water bodies, streets and buildings. The buildings have not been included in the map because the polygons provided by Google Maps intersect with the streets which would interfere with the overall map design. Furthermore, with this decision, the user-oriented requirement U17 became redundant, as it highlights buildings on maps for older adults. However, these two requirements are not withdrawn from the requirements list because it seems important to show buildings for a better orientation on the map.

And, finally, the tool requirement T7 states that entering data in the MBT should be manageable within a reasonable amount of time. This could not directly be implemented in the MBT, but, as U7 highlights the need to reduce the functionality of the MBT, it could be assumed that the time needed is also reduced to a minimum. However, this requirement will be further discussed in Section 8.2 where the time efficiency of the MBT is discussed in the context of its usability. But, at the moment, it seems that T7 is a reasonable requirement which should be stated in the final list of MBT requirements for older adults because the time needed is an important aspect when using the MBT in further health-related studies. Similar to the "MapSpace" experiment, most studies in the health sciences assess multiple measures. Accordingly, each assessment method should not require too much of a participant's time.

Summary and outlook

In conclusion, it can be said that the list in Appendix A contains the most relevant requirements for developing an MBT aiming at measuring older adults' life-space mobility. The list encompasses tool requirements which allow the MBT to achieve the aims of this thesis, as well as user-oriented requirements which should simplify the use of the MBT for older adults. However, the summary of requirements (Appendix A) should not be seen as a definitive list as there could be even more requirements which have not been taken into account within this thesis. Furthermore, the usability and validity results have to be considered in order to evaluate whether the developed MBT is really usable for older adults and if it shows similar results for life-space indicators compared to the LSA and GPS assessments.

8.2 Comparing the usability of the MBT to the GPS and LSA

This section discusses the results of the different usability measures presented in Section 6.2. First, how older adults evaluated the MBT's usability with the system usability score (SUS) is discussed.

RQ2: How usable is the newly-developed MBT for assessing the life-space mobility of older adults in general as well as compared to the usability of the LSA and the GPS-based measurements?

Results of the system usability score

As already mentioned in Section 6.2.1, the system usability scores (SUS) of the MBT have been compared to a study by Bangor et al. (2008). They state that, on average, the SUS scores of studies evaluating a system's usability are around 70. The SUS scores of our study participants are considerably lower (Appointment 2 = 33.7; Appointment 3 = 31.68). This comparison would indicate that the usability of the MBT does not seem to be very good for our study participants. However, Bangor et al. (2008) further state that the SUS values negatively correlate with participants' ages. As the SUS of the MBT is evaluated by older adults, it seems reasonable that our SUS values are lower than the mean SUS of other studies. Furthermore, the SUS scores can vary across different types of systems. For example, Bangor et al. (2008) showed that web-applications tend to have lower SUS scores than for other interfaces. Moreover, the study by Bangor et al. (2008) does not mention if the evaluated studies rely on commercial or more research-oriented systems. If their analysis is based on commercial systems, it would explain why their mean of SUS scores is so high, which could not be achieved by using a tool that is being tested for the first time, such as done within this thesis. Consequently, the SUS could indicate that the general usability of the MBT was not unsatisfactory.

In contrast, lower usability scores were found when assessing the MBT the second time (in Ap. 3) compared to the first time (in Ap. 2). Moreover, in Appointment 3, there were also 3 missing values for the SUS. A reason for the decline of the SUS could be that the missing participants in Ap. 3 had high scores in Ap. 2, and, as their scores were missing, the mean SUS decreased. Another explanation could be that participants generally rated the usability worse because they were less satisfied or annoyed with using the MBT a second time. To fully understand the reason for this loss of motivation (decrease of SUS), further evaluations would be needed.

Finally, the SUS results were correlated to the newly-developed technical background scores (TBS; Section 6.2.3), which summarize a participant's use of technologies and their confidence in using them. For both appointments, significantly negative correlations could be found. This indicates that a person with a high TBS would have rated the MBT with a low SUS, and vice versa. Based on these correlation results, it should be stated that, most probably, participants which have a higher technical affinity did not find the MBT very usable. A problem regarding these results is that no reference was provided to the participants. It is not known whether they compared the MBT to already known applications or systems, and, if so, which ones. If they compared the MBT to a simple system, such as e.g. Google Maps, it seems reasonable that the use of the MBT was unsatisfactory. However, if a person is used to using more complicated systems, such as a GIS, the MBT could be rated more satisfactorily. Accordingly, the question of to which reference they compared the tool arises.

The solvability of the MBT

Based on the results regarding solvability, difficulty and reasons for difficulty (Table 7 in Section 6.2.2), it can be concluded that the MBT was generally fairly usable for older adults. This stands in contrast to the results derived from the SUS. Accordingly, it must be highlighted that the SUS is a subjective measure which represents the satisfaction with using the tool, and the solvability is a performance measure. Around 80% were able to use the tool by themselves and experienced only a little or no difficulty in solving the MBT. However, about 10 participants stated that they have never used a computer or the internet, or that they have general difficulty in using one of the two technologies. Additionally, the same number of computer and internet users could also be found in the evaluation of technical background (Section 6.2.3). Furthermore, the technical background section stated that 15 participants had not previously used map applications on the internet. Consequently, these results could explain why some individuals needed help with using the tool.

In contrast, study participants asked several questions when using the MBT. Based on the evaluation of these questions (also in Table 7), aspects of the MBT which could be improved could be identified. Around 50% of the participants had problems with understanding the content of the tutorial. A lot of questions were asked about the illustrations in the tutorial which highlighted elements of the following map application of the MBT. A lot of participants already wanted to interact with the images and asked if they had to read the small text on the image. A second aspect of the MBT about which participants asked questions are the definitions of the life-space levels. This mostly included the question "What exactly is the range of my neighborhood?" which was answered with "the neighborhood encompasses all the places that you feel are within your neighborhood". A further problem regarding the life-space levels was that a lot of participants did not realize that they should only mark places on the map that belong to the life-space level shown on the left side of the screen. Although it was explained in the tutorial, it is possible that the tutorial contained too much information and that the older adults could not remember all the instructions until they started using the map application.

Further questions raised by participants were related to the handling of the map (zooming and panning) and the placement of markers on the map. However, the number of participants who asked for help when encountering one of these problems declined between Ap. 2 and Ap. 3. Accordingly, this suggests that older adults would learn to handle these problems when using the MBT multiple times. However, a solution should be found so that less participants encounter problems in the beginning.

Noticeably less participants asked questions about how to handle the search box, and how to select, move or delete a marker. Possible reasons for this could be that these functionalities are easy to understand or that most participants had no difficulties because they simply did not use these functionalities. These would be aspects which would have to be examined in a further study by asking more precise questions about these aspects.

Finally, the number of questions asked regarding different aspects of the MBT were correlated with the technical background score (TBS). The correlation coefficient showed a significant negative correlation between the TBS and the number of questions asked in Appointment 2. In this case, it seems reasonable that participants with a high TBS score asked less questions. However, between the TBS and the questions asked in Appointment 3, a slightly negative, though non-significant, correlation could be found. An explanation could be that participants with a high technical affinity were already used to the MBT when using it the second time, so that they scrutinized the tool more critically and more questions arose. This would indicate that some aspects questioned by this specific group of participants were not immediately obvious, but these aspects should be improved for regular usage.

Rating the uTrail

In Section 6.2.4, the results regarding the usability of the *uTrail* are examined highlighting several positive aspects of the devices. Most participant found the weight and the size of the *uTrails* rather convenient. Furthermore, the handling was found to be intuitive and the status LED did not really disturb the participants. The devices made a robust impression and the design was mostly found to be appealing. Moreover, participants stated that they were not restricted in their everyday activities and they did not change their regular behavior due to the *uTrail*. All these aspects highlight that, in general, the *uTrails* could be usable devices for assessing older adults' life-space mobility.

However, participants reported that they had a tendency of being aware of the *uTrails* in everyday life and the on-/off-button responded when pressure was applied. The latter two aspects could be interpreted negatively or positively. When a person is aware of a device in everyday life, it could constitute a disturbance. But it could also be possible that he/she is aware of the device without being disturbed by it. A similar phenomenon is the response of the on-/off-button when pressure is applied. If the application of pressure is intentional, it is a good sign when the button responds. But if pressure is applied unintentionally—e.g. by unconsciously touching the device when wearing it—it can be disadvantageous when the button immediately responds and disables the device. However, this problem was already tackled as the new generation of *uTrails* changed the design of the on-/off-button.

Comparing the overall time need and time efficiency between the MBT, GPS and LSA

For the MBT, a general reduction of the overall and effective time need, and the time efficiency could be found between Appointments 2 and 3. Consequently, it can be concluded that the burden of time can be reduced when using the MBT regularly. However, an increase between the overall time need and the effective time need of the MBT was identified. The reason for this could be that, for the calculation of overall time need, all the assessed time measurements were used, including the ones where study examiners filled out the MBT for participants who were unable to solve the MBT by themselves. In contrast, the effective time need considers only participants who filled out the MBT by themselves. Consequently, the mean time need increases but the result is more representative for the evaluation of the time need.

Comparing the effective time need of the MBT to the overall time need of GPS and LSA, the MBT requires more time than the LSA, but less time than the GPS, which takes 7 full days to assess a person's life-space mobility. Accordingly, one of the aims of this thesis—to reduce the burden on participants compared to GPS—could be achieved. However, it must be highlighted that GPS measurements are assessed passively; the user only has to wear the GPS device and does not have to actively mark visited locations.

The results considering the time efficiency (time needed per assessed entity) are higher for the MBT compared to the LSA and GPS. However, the assessed time need for the MBT includes the reading of the tutorial. Based on the assessed measures of the "MapSpace" study, it cannot be determined how much time was invested in reading the tutorial. Furthermore, it has not been considered that, for each marked location in the MBT, 6 questions had to be answered. Additionally, GPS only measures locations when a signal is available. Consequently, a location can be assessed multiple times. If a stop detection or a clustering algorithm is applied, the number of assessed locations is reduced, which would also lead to a decline in the GPS' time efficiency. Furthermore, the long processing time of GPS data is not considered in the evaluation. This has no influence on participants, but it is a relevant aspect for study examiners. Consequently, the comparability of the results is somewhat constricted and the results could give an overestimation of the MBT's time efficiency.

In conclusion, even if the MBT has a higher time efficiency than the GPS, it can be argued that the overall time need is more reflective of the overall time invested in a study and not of how much time he/she had to spend to measure one point.

Summary and outlook

Summarizing the usability of the MBT in general, it can be concluded that, based on the system usability scores (SUS) which represent a person's satisfaction, older adults tended to rate the usability poorly. However, the solvability measures—which represent a performance measure rather than a subjective usability judgment—indicate that participants with a technical affinity could solve the MBT. Interestingly, the latter rated the tool as having a low SUS. Furthermore, most of the older adults with a low TBS asked questions about various aspects of the MBT. These questions highlighted that the tutorial, the concept of asking for visited locations based on life-space levels and the manner of marking a place on the map should be reconsidered and improved. Additionally, the usability of the search box, and how to select, move or delete a marker should be further examined.

Comparing the usability of the MBT to the GPS and LSA, older adults rated the usability of the *uTrails* quite well. Regarding the evaluation of the time need, the results highlight that GPS assessments are markedly more time-consuming than that of MBT or LSA. However, the LSA remains the life-space measurement approach that is most time- and cost-efficient.

8.3 Life-space indicators for comparing the validity of the MBT with the LSA and GPS

For addressing RQ3, several life-space indicators are examined in Chapter 7 in order to evaluate the validity of the MBT with the commonly-used LSA and GPS measurement approaches. For the comparison with the LSA, only semantically-enriched indicators could be derived (Section 7.3.1). For comparing the MBT with GPS in Section 7.3.2, mostly spatial and individual semantic indicators were evaluated.

RQ3: How do the MBT, GPS and LSA methods compare with respect to derived spatial and semantically enriched life-space indicators?

Deviations in semantic life-space indicators derived from the LSA and MBT

The first evaluation of the MBT's validity compared to the LSA considered the semantic life-space indicators "visited life-space levels", "the maximum frequencies of visiting these levels" and the "specification for the assistance needed". The smallest number of deviations among the three indicators could be found for life-space Level 1 (within the neighborhood) and the highest number of deviations occurred for Level 2 (outside neighborhood, but within municipality). These results indicate that Level 1 gives the most similar results between the two measurement approaches whereas, in Level 2, the most varied statements were made when considering three life-space indicators. Accordingly, the definition of life-space Level 2 seems to be misleading for some of the participants. Several reasons might apply, including that older adults could not distinguish Level 2 from Levels 1 and 3, one of the measurement approaches was wrongly understood by the older adults or an inaccurate method was chosen to extract the indicators from the MBT.

When considering the results in Section 7.3.1 in more detail, they highlight that, in most cases, the visited life-space levels and the assistance needed were assigned correctly between the two measurement approaches. However, some deviations originated from the indicator "frequency of visiting a place". As mentioned in Section 7.2.1, for the frequency, the LSA has only one value for a specific level, while the MBT gathers a frequency for each visited location separately. Possibly, an incorrect assumption was made when defining that the maximum frequency per level in the MBT should correspond to the frequency of the LSA. However, the results in Section 7.3.1 additionally highlight that the MBT mostly underestimated the frequency. Accordingly, it appeared to be the most appropriate method for extracting the frequencies because the other methods mentioned in Section 7.2.1 would most probably have led to even greater underestimations. Consequently, the most probable reason for the noticeable deviations in Level

2 and among the frequency indicators is that older adults had difficulty in understanding the MBT or the LSA correctly.

Moreover, the LSA scores which were derived from the LSA and MBT assessments show a rather low correlation coefficient and it was shown that they do not significantly correlate. This result was underlined by further evaluations with a Bland-Altman plot.

In conclusion, the results show that the semantic life-space indicators “visiting a life-space level” and “assistance needed” could be assigned correctly. However, the indicators “frequency of visiting a level” and the LSA score show varying results. Accordingly, the validity of the MBT compared to the LSA seems to be only partially supported.

Comparing spatial and semantic indicators between the MBT and GPS

In general, it could be shown that defining life-space level-related indicators for GPS with personalized neighborhood buffers derived from the specifications in MBT results in a better validity than with a fixed neighborhood buffer. This seems reasonable as the perception of a neighborhood’s size can vary between individuals. Furthermore, higher correlations of spatial indicators were found between GPS and MBT when the MBT locations were not weighted with the frequency of visiting a place. A possible reason for this result could be that the frequency of visiting a place influences the spatial distribution of movements differently than the time spent at a place which is indirectly assessed with GPS measurements.

Regarding the life-space level-related indicators—the maximum life-space level and the maximum distance per level—in more detail, it can be stated that the validity of the MBT and GPS is given because the maximum life-space levels could be assigned correctly for more than 90% of the participants and all the maximum distances significantly correlated with each other. However, it must be highlighted that, here, the life-space Level 2 showed a lower correlation coefficient, such as mentioned in the discussion on the indicators between MBT and LSA. This again underlines the assumption that the definition of life-space Level 2 is misleading for older adults.

Furthermore, the distance-related indicators all significantly correlate between GPS and MBT. However, a special focus was set on the distance between the home locations derived from MBT and GPS, which could not be correlated to another measure. Whether this distance relates to a person’s spatial ability was tested, but no significant correlation could be found. Consequently, this difference between home locations should be further examined. Possible approaches could be to evaluate the data accuracy of GPS measurements with the number of visible satellites or the accuracy of marking a location on the map based on the stored map zoom level when a point was set.

The area-related life-space indicators showed only significant correlations between GPS and MBT measures. Especially high correlations could be found for the indicators “minimum enclosing circle”, “standard deviational ellipse and box” and the axis-aligned bounding box. However, it must be said that the differences between the area-related measures derived from the MBT and GPS were noticeably higher than in the results of e.g. distance-related indicators. A possible reason for this result is most probably that these areal indicators have generally higher values than distances or life-space levels. Accordingly, the differences also increase. Another influence on these large differences is the resolution used in assessing the data, which is illustrated below. The number of assessed GPS points reaches almost 400,000, while, in the MBT experiments, between 3 and 26 locations were marked (Figure 33). Furthermore, GPS can also assess the routes between locations and not only the visited locations, such as in the MBT (Figure 34 on the left), what can lead to higher areal measures of the GPS data. However, it is also possible that an area-related measure derived from the MBT is higher than the GPS derived indicators. But this is most probably only the case when a location in the MBT has been marked erroneously (Figure 34 on the right).

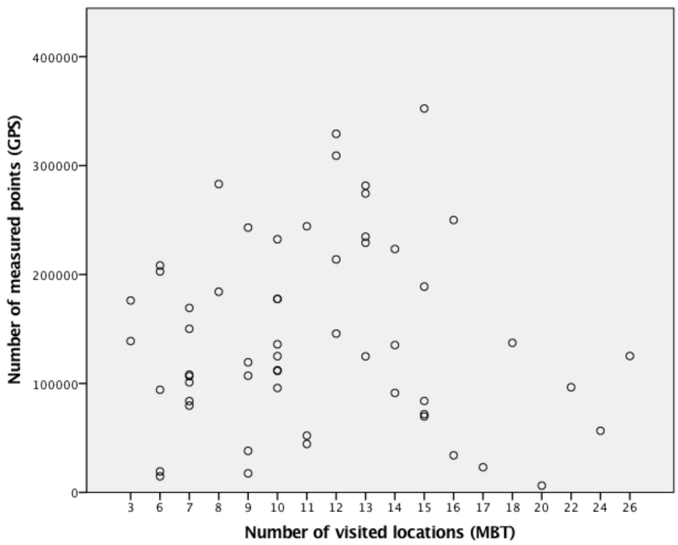

Figure 33: Scatterplot of the number of visited locations (MBT) and the number of measured GPS points.

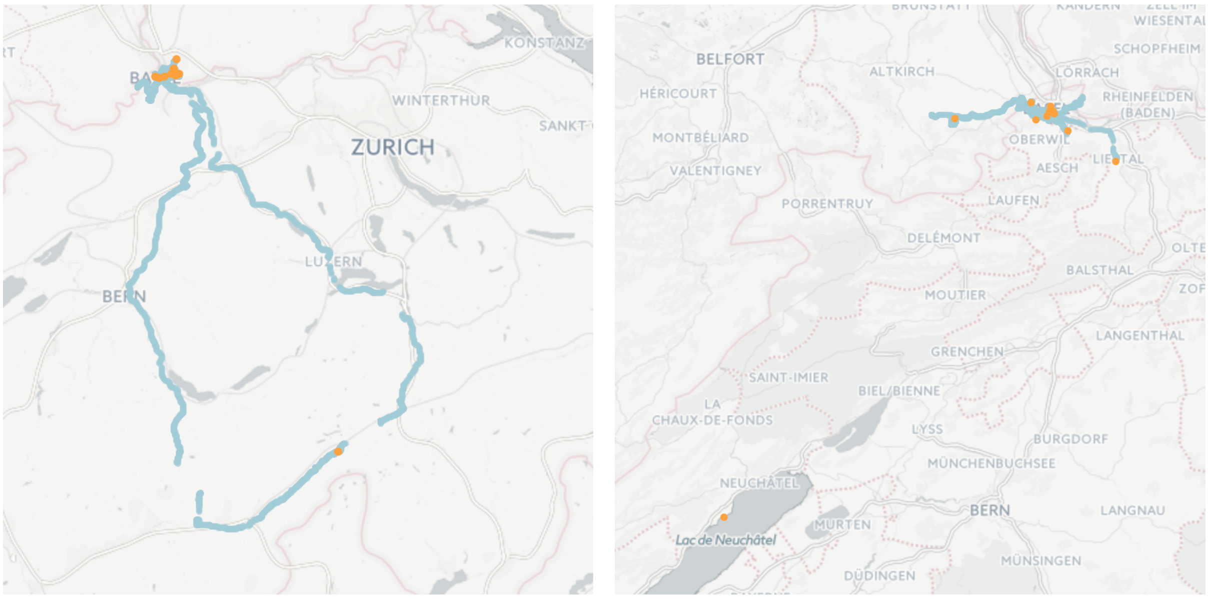

Figure 34: Left – Illustration of the routes between locations (GPS = light blue) compared to one visited location of the MBT (orange; ID = 28). Right – Illustration of a dataset in which the MBT (orange) shows a more distant location than GPS (light blue; ID = 19).

Moreover, the life-space indicators which should be derived from the GPS and MBT data as kernel density estimation (KDE) 50% and 95% contour areas could not be evaluated because the MBT mostly assessed too few locations. This is a limitation of the MBT compared to the GPS measurement approach.

Summary and outlook

In summary, it can be stated that the validity of the MBT in comparison to the LSA is only partially supported. On the other hand, a high similarity seems to exist between the MBT and GPS indicators. Although the validity results between the LSA and MBT were not satisfactory, it can be said that the MBT has other advantages over the LSA, such as explicitly showing a person's life-space mobility on a map by highlighting the semantic information in more detail. Thus, for instance, the frequencies of visiting a place could be shown with circles of varying size, with the life-space areas displayed in the background.

In general, it should be highlighted that the MBT allows to extract the same information about a person's life-space mobility as the LSA, and the MBT could assess a greater amount of semantic information. Additionally, it must be said that GPS and MBT data allow to derive even more indicators than those cited in this thesis. From GPS data, it is possible to extract the mode of transportation (MOT), allowing to distinguish between active and passive transportation, or a spatio-temporal stop detection could be applied in order to ascertain the number of outdoor activities an individual engaged in. Furthermore, GPS allows to create daily path areas as proposed by Hirsch et al. (2014). In contrast, the MBT would allow to identify locations which were visited voluntarily or involuntarily based on the stated purpose of visiting a particular place. Additionally, the general frequency of visiting a place (independently of the period of measurement) or the MOTs could be evaluated.

In conclusion, the MBT does not provide exactly the same results as the LSA, but it was shown that it has the potential to examine spatial and semantic information about a person's life-space mobility in more detail. Compared to the GPS, the data resolution of the MBT is markedly lower, but the derived indicators show similar results. Additionally, further semantic measures could be compared between the latter two measurement approaches.

9 Conclusion

9.1 Summary

Over the past decades, several measurement approaches have been developed to assess the life-space mobility of older adults, which can be classified into two types: sensor-based approaches, such as GPS, and questionnaires, such as the University of Alabama at Birmingham (UAB) Study of Aging life-space assessment (LSA). However, these assessment methods can collect either spatially-locatable data or semantic information about a person's mobility behavior, but not both types of data. Accordingly, this thesis aimed to develop and evaluate a map-based tool (MBT), with a focus on determining older adults' life-space mobility as an alternative to the commonly-used GPS and LSA measurement approaches. Hereby, the new MBT should reduce the burden of time imposed on participants compared to GPS, on the one hand, and provide a higher accuracy compared to questionnaires, on the other hand. These aims could be achieved by elaborating a list of tool and user-oriented requirements and implementing them in an MBT web application. After testing the newly-developed tool in a user study with older adults (the "MapSpace" experiment), the usability and the validity of the MBT could be examined by comparing it to the assessed LSA and GPS data. The results suggest that the MBT is usable, but adjustments need to be made. The focus of these adjustments should be on the tutorial, the concept of asking questions based on life-space levels, and the functionality of marking a point on the map. The evaluation of validity showed that the examined life-space indicators are comparable between GPS and the MBT. However, the validity of semantic indicators given by MBT and LSA is only partially supported.

9.2 Contributions

In the context of life-space mobility research, this thesis outlines one of the first approaches for developing a map-based tool and evaluating its usability for older adults. The newly-developed MBT can measure spatially-locatable data enriched with a range of semantic information. Accordingly, the MBT could improve the analysis of life-space mobility in future studies in which the correlation between life-space indicators and health-related measures is examined. As knowing people's movement patterns can help in understanding their health condition, the MBT could potentially be used by primary care physicians for analyzing the health situation of their patients. In conclusion, after some adjustments and further tests, the MBT could become an asset in future life-space mobility research and for primary care physicians in practice.

9.3 Outlook

In the future, a first step would be to adjust the usability aspects of the MBT which were rated poorly by older adults, e.g. the tutorial. Furthermore, the approach of questioning subject's life-space mobility based on life-space levels and how a point can be marked on the map should be revisited. Once adapted to these criteria, the tool should be re-tested in a user study which also collects overall written feedback on the MBT.

Once an adjusted and re-tested version of the MBT is available, it could be examined as to whether life-space indicators derived from the MBT can be related to other health-related factors, such as nursing home admissions or walking disabilities.

Another task for future work would be the further evaluation of the data assessed within the "MapSpace" experiment. For example, the life-space mobility of each participant could be examined in more detail by considering the semantic information captured by the MBT. This includes the purpose, the general frequency and the mode of transport (MOT) used for visiting a place. In addition, the latter could be also derived from the GPS data and a comparison of the results could be made. This analysis has not been addressed within this thesis. As the focus of this thesis was set on validity, the same measures would have had to be derived from the GPS data. But this would be beyond this thesis' scope (as mentioned in Section 7.1). Another example of further data analysis could be to examine the completeness and accuracy of data obtained by the MBT or GPS. For the MBT, the semantic information missing could be identified, e.g. when a participant did not answer all the questions per location, and at which map zoom level a location was marked. Additionally, for the GPS data, accuracy could be evaluated based on the number of visible satellites, and the frequency of data outages could be analyzed.

However, in conclusion, it can be stated that, after some adjustments, the MBT could be an effective tool to assess older adults' life-space mobility.

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Appendix A — List of tool and user-oriented requirements

The final list of identified tool and user-oriented requirements for an MBT aiming at measuring older adults' life-space mobility.

Tool requirements	
(T1)	The MBT should allow capturing spatially-referenced data of visited locations for measuring the spatial extent of movements.
(T2)[17]	The MBT should collect visited locations with the geographic primitive "point".
(T3)	The MBT should examine a person's home location.
(T4)	The MBT should gather the following semantic information: • (T4.1) the life-space level of each visited location • (T4.2) the frequency of visiting the location during a measurement period • (T4.3) the need of assistance to visit a location • (T4.4) the modes of transportation to reach a place • (T4.5) the purpose of visiting a place, respectively the activity at a location • (T4.6) the regular frequency of visiting a place (independently of the life-space measurement period) • (T4.7) the name or a description of the place
(T5)	The MBT should consider the following technical requirements: In general, the MBT should … • (T5.1) … be clearly structured. • (T5.2) … highlight important information. The most important elements should stand out. • (T5.3) … support simple navigation. • (T5.4) … provide a tutorial and/or a help button which describes the use of the map and other functionalities of the application. • (T5.5) … consider the trade-off between introducing a new tool and maintaining consistency with existing tools. Regarding the website design, the MBT should have … • (T5.6) … buttons should look clickable. • (T5.7) … a page design in bright colors. • (T5.8) … a harmonious color concept.

[17] Has been adjusted (Section 5.2 and Discussion section 8.1)

	Regarding the map interactivity, the MBT should …
	• (T5.9) … allow zooming in and out.
	• (T5.10) … allow panning with a continuous click-and-drag option.
	• (T5.11) … provide a search functionality, which …
	    ○ … is represented as a search box in which it is clarified what type of searching criteria can be entered.
	    ○ … centers the map according to the search results.

(T6)	At least, the map elements — city names, water bodies, streets and buildings — should be integrated in the map design of the MBT.
(T7)	Entering data through the MBT should be able to be done within a reasonable amount of time.
User-oriented requirements	
Language and functionalities	
(U1)	Use simple language, and a familiar and positive writing style.
(U2)	Provide clearly-defined and descriptive labels, annotate them with additional explanations and provide clear and unambiguous instructions.
(U3)	Avoid double mouse clicks.
(U4)	Avoid the drawing of lines.
(U5)	Avoid the use of mouse wheel functionalities or scroll-down tasks.
(U6)	Do not use drop-down menus or other features which hide information.
(U7)	Reduce the functionality of the MBT to a minimum.
Web design	
(U8)	Provide clear large headings.
(U9)	Reduce the number of buttons on the screen and provide large buttons.
(U10)	Text should be aligned to the left and text lines should not be too long.
(U11)	Use large font sizes and sans serif font styles, and enlarge line spacing reasonably.
(U12)	Choose highly contrasting foreground and background colors (no patterned background).
Map design	
(U13)	Remove redundant information and labels.
(U14)	Labels should be in black with a halo.
(U15)	Simplify symbols of map features.
(U16)	Combine road classes.
(U17)	Show fewer details on buildings.

Appendix B — Documents of the “MapSpace” study

CRF 1 – Basisdaten zur Person (1. Termin)

Probanden-ID: ☐☐

Prüfer-ID: ☐

Datum Ersttermin: ☐☐ . ☐☐ . ☐☐☐☐

Teil I: Auszufüllen durch Prüfer

0. Auf welchem Weg wurde der Proband/die Probandin auf die Studie aufmerksam?

Als Patient/In in einer Hausarztpraxis über die Studie informiert ○
Andere Wege ○

1. Geschlecht: Männlich ○
Weiblich ○

2. Alter: __________ Jahre

3. uTrail Nr. _________

4. uTrail mit: Schlaufe ○
Clip ○

Probanden-ID: ☐☐

Teil II: Auszufüllen durch Proband/Probandin

In diesem Fragebogen finden Sie unterschiedliche Fragetypen:
a) Fragen, bei denen Sie mehrere Kreuze machen dürfen. In diesem Fall steht dies immer ausdrücklich in der Frage („Mehrfachantwort möglich").
b) Bei allen anderen Fragen bitte nur ein Kreuz machen (dies trifft auf die meisten Fragen zu).

Für die Auswertung des Fragebogens ist es sehr wichtig, dass alle Fragen beantwortet werden. Wenn Sie bei einer Frage finden, es stimme keine Antwort ganz genau, so kreuzen Sie einfach diejenige an, die für Sie am ehesten zutrifft. Dieser Fragebogen ist kein Test, es gibt also keine richtigen oder falschen Antworten. Wir möchten gerne wissen, was Sie denken. Ihre Angaben werden anonym und streng vertraulich behandelt.

A. GESUNDHEIT

Zuerst möchten wir Ihnen Fragen zu Ihrer Gesundheit stellen.

5. Hat ein Arzt jemals eine der folgenden Krankheiten bei Ihnen festgestellt?

	Ja	Nein
a) Diabetes, Zuckerkrankheit	○	○
b) Erhöhter Blutdruck (Hypertonie)	○	○
c) Herzinfarkt (Herzschlag), Erkrankung der Herzkranzgefässe (Koronare Herzkrankheit)	○	○
d) Herzschwäche, eingeschränkte Herzfunktion (Herzinsuffizienz)	○	○
e) Schlaganfall (Schlägli)	○	○
f) Durchblutungsstörung der Beine („Schaufensterkrankheit")	○	○
g) Chronische Bronchitis, Emphysem	○	○
h) Arthrose (Gelenkverschleiss) oder (rheumatische) Arthritis	○	○
i) Osteoporose	○	○
j) Krebs	○	○
k) Probleme mit dem Hören, z.B. Schwerhörigkeit/Ohrgeräusche	○	○
l) Probleme mit dem Sehen, z.B. grauer Star (Linsentrübung) / grüner Star (Glaukom)	○	○

6. Welches Hilfsmittel verwendeten Sie in der letzten Woche, um ausserhalb des Hauses zu gehen?

- O kein Hilfsmittel notwendig
- O Gehhilfe im Sinne eines Gehstocks bzw. zwei Gehstöcken notwendig
- O Gehhilfe im Sinne eines Rollators bzw. Gehwagens notwendig

B. ALLTAGSAKTIVITÄTEN

7. Im Folgenden sind verschiedene Alltagsaktivitäten aufgelistet. Bitte geben Sie jeweils an, ob Sie das ohne Schwierigkeiten, mit leichten Schwierigkeiten, mit starken Schwierigkeiten oder überhaupt nicht machen können.

	Ja, ohne Schwierig-keiten	Ja, mit leichten Schwierig-keiten	Ja, aber mit starken Schwierig-keiten	Nein, überhaupt nicht
a) Selbständig Essen zubereiten	O	O	O	O
b) Selbständig telefonieren	O	O	O	O
c) Selbständig einkaufen	O	O	O	O
d) Selbständig Wäsche waschen	O	O	O	O
e) Selbständig leichte Hausarbeit erledigen	O	O	O	O
f) Selbständig gelegentlich schwere Hausarbeit erledigen (z. B. schwere Möbel verschieben, Frühjahrputz, Boden nass aufnehmen, Fenster putzen)	O	O	O	O
g) Sich selbständig um Finanzen kümmern	O	O	O	O
h) Selbständig die öffentlichen Verkehrsmittel benützen	O	O	O	O

8. Haben Sie einen Hund/Hunde mit dem/denen Sie „Gassi“ gehen?

- O Ja
- O Nein

C. MOBILITÄT

9. Wie häufig benutzen Sie die öffentlichen Verkehrsmittel?

- O nie
- O seltener als 1 Mal pro Woche
- O mindestens einmal pro Woche

10. Haben Sie die Möglichkeit, in Ihrem Haushalt ein Privatauto (mit) zu benutzen?

- O Ja (<u>weiter zu Frage 11</u>)
- O Nein (<u>weiter zu Frage 13</u>)

  11. <u>Wenn ja</u>, wer fährt das Auto in der Regel?

  - O Ich selbst
  - O Eine andere Person

  12. Wie häufig nutzen Sie das Auto?

  - O seltener als 1 Mal pro Woche
  - O mindestens einmal pro Woche

13. Wo kaufen Sie Ihre Lebensmittel und Waren des täglichen Bedarfs <u>überwiegend</u> ein?
(nur EINE Antwort auswählen)

- O In der Nachbarschaft
- O Ausserhalb der Nachbarschaft, aber innerhalb der Gemeinde
- O Ausserhalb der Gemeinde

14. Wenn Sie an eine <u>typische Woche</u> denken, in welchem Umkreis um Ihr zu Hause bewegen Sie sich <u>üblicherweise</u>? (nur EINE Antwort auswählen)

- O Zuhause / auf dem eigenen Grundstück
- O Innerhalb der Nachbarschaft
- O Innerhalb der Gemeinde
- O Inner- und ausserhalb der Gemeinde, bis zu einem Umkreis von 20 km
- O Inner- und ausserhalb der Gemeinde, auch an Orten die weiter als 20 km entfernt sind

15. Gibt es in Ihrer Umgebung Hindernisse, die Sie daran hindern sich öfter draussen aufzuhalten?

- O Nein
- O Ja (Bitte <u>alle zutreffenden</u> Hindernisse ankreuzen):

  - O Schlechter Zustand der Strassen
  - O Hohe Bordsteine
  - O Hügel in der näheren Umgebung
  - O Lange Distanzen zu ÖV-Haltestellen
  - O Mangel an Sitzgelegenheiten
  - O Reger Strassenverkehr
  - O Gefährliche Kreuzungen
  - O Fahrräder auf dem Trottoir

D. WOHNSITUATION

16. Das Wohngebiet, in dem Sie wohnen, ist vom Typ her eher:

- O Urban (sehr städtisch, zentrumsnah)
- O Sub-urban (Agglomeration)
- O Ländlich

17. Leben Sie in...

- O Ihrem eigenen Haushalt.
- O einer betreuten Wohneinrichtung.

18. Wie viele Personen leben ständig in Ihrem Haushalt, Sie selbst eingeschlossen? Denken Sie dabei bitte auch an alle im Haushalt lebenden Kinder.

- O eine Person, d.h. nur Sie selbst
- O zwei Personen
- O ____ Personen

19. Bei dem Gebäude, in dem Sie wohnen, handelt es sich um ein:

- O Einfamilienhaus, Doppelhaushälfte oder Reihenhaus (weiter zu Frage 21)
- O Mehrfamilienhaus (weiter zu Frage 20)
- O Andere Gebäudeart (weiter zu Frage 20)

20. Ihre Wohnung ist im folgenden Stock (Mehrfachantwort möglich):

- O Untergeschoss/Souterrain
- O Erdgeschoss
- O Hochparterre
- O Erster Stock
- O Zweiter Stock
- O Dritter Stock
- O Anderer Stock: ____________

21. Gibt es einen Fahrstuhl?

- O Ja
- O Nein

E. TECHNIK UND RÄUMLICHE FÄHIGKEITEN

In den folgenden Fragen möchten wir etwas über Ihre Sicherheit bzw. Vertrautheit im Umgang mit Technik erfahren.

22. Benutzen Sie ein(e/en) ...			**23. Wie sicher bzw. vertraut fühlen Sie sich im Umgang damit?**				
	Ja	Nein	Sehr unsicher	Eher unsicher	Eher sicher	Sehr sicher	Keine Angabe
a) Telefon	○	○	○	○	○	○	○
b) Mobiltelefon	○	○	○	○	○	○	○
c) Smartphone	○	○	○	○	○	○	○
d) Computer / Laptop	○	○	○	○	○	○	○
e) iPad / Tablet	○	○	○	○	○	○	○
f) Navigationsgerät	○	○	○	○	○	○	○
g) Aktivitäten- / Bewegungs-Messgerät („Tracker“)	○	○	○	○	○	○	○
h) Internet	○	○	○	○	○	○	○
i) Kartenanwendungen im Internet	○	○	○	○	○	○	○
j) Geographische Informationssysteme	○	○	○	○	○	○	○

24. Der folgende Fragebogen besteht aus mehreren Aussagen, die sich auf Ihre räumlichen und navigatorischen Fähigkeiten, Präferenzen und Erfahrungen beziehen. Machen Sie bei jedem Statement ein Kreuz bei der Zahl, die ihre Zustimmung zur Aussage widerspiegelt.

	Trifft zu 1	2	3	Weder /noch 4	5	6	Trifft nicht zu 7
a) Ich kann sehr gut Wegbeschreibung geben.	○	○	○	○	○	○	○
b) Ich kann mich schlecht daran erinnern, wo ich Dinge gelassen habe.	○	○	○	○	○	○	○
c) Ich kann sehr gut Distanzen schätzen.	○	○	○	○	○	○	○
d) Mein Orientierungssinn ist sehr gut.	○	○	○	○	○	○	○
e) Ich tendiere dazu, mir meine Umgebung in Himmelsrichtungen (N, O, S, W) vorzustellen.	○	○	○	○	○	○	○
f) Ich verlaufe mich in einer Stadt sehr schnell.	○	○	○	○	○	○	○
g) Ich lese gerne Karten.	○	○	○	○	○	○	○
h) Ich habe Mühe, Richtungsangaben zu verstehen.	○	○	○	○	○	○	○
i) Ich bin sehr gut im Kartenlesen.	○	○	○	○	○	○	○
j) Ich kann mir Routen sehr schlecht merken, wenn ich als Beifahrer in einem Auto sitze.	○	○	○	○	○	○	○
k) Ich gebe nicht gerne Wegbeschreibungen.	○	○	○	○	○	○	○
l) Es ist mir nicht wichtig, zu wissen, wo ich bin.	○	○	○	○	○	○	○
m) Normalerweise überlasse ich die navigatorische Planung von langen Reisen jemand anderem.	○	○	○	○	○	○	○
n) Ich kann mir normalerweise eine neue Route sehr gut merken, nachdem ich sie einmal bereist habe.	○	○	○	○	○	○	○
o) Ich habe keine sehr gute „mentale Karte“ von meiner Umgebung.	○	○	○	○	○	○	○

Vielen Dank!!!

Written instruction sheet regarding the handling of the *uTrails*

Willkommen zur Studie "Evaluation einer kartenbasierten Methode zur Erfassung des Lebensraums älterer Menschen"

Hier erkläre ich Ihnen in 10 einfachen Schritten, wie Sie den uTrail verwenden und was Sie über das Gerät wissen sollten.

1. Was ist der uTrail?
uTrail ist ein Gerät, das
- Ihren Aufenthaltsort und
- Ihre Aktivität

über den Tag hindurch aufzeichnet.

2. Wie kann ich den uTrail tragen?
Sie können den uTrail mithilfe des Clips
- um Ihren Hals oder
- in Ihrer Hosen- / Rocktasche

tragen.

3. Wie bediene ich den uTrail?
Es gibt zwei Knöpfe:
- Ein / Aus
- Audio (wird nicht verwendet)

4. Was bedeuten die LED-Lämpchen?
Grün: Messung läuft
Blau: GPS wird aufgenommen
Rot: Keine Messung

5. Zeichnet der uTrail die ganze Zeit meine Daten auf?
Jedes der zwei zu erfassenden Merkmale hat einen eigenen Zeitplan: Aktivität wird kontinuierlich erfasst und das GPS einmal pro Sekunde.

6. Wie wird meine Privatsphäre geschützt?
Während das Gerät aufgeladen wird, finden keine Messungen statt. Wir empfehlen Ihnen, das Gerät immer über Nacht aufzuladen.

7. Wie oft sollte ich das Gerät aufladen?
Bitte immer einmal pro Tag, und zwar über Nacht, damit tagsüber Messungen stattfinden können.

8. Wie sind meine Daten gesichert?
Ihre Daten sind auf dem uTrail passwortgeschützt und werden anschliessend anonymisiert gespeichert und für Forschungszwecke verwendet.

9. Wie kann ich das Gerät aufladen?
Mithilfe des USB-Kabels entweder direkt an der Steckdose oder über ein USB-Zugang an Ihrem Computer einstecken.

10. Ist der uTrail wasserfest?
Einfacher Regen ist kein Problem, aber das Gerät ist an sich **nicht wasserfest**. Bitte nehmen Sie es vor dem Duschen oder Baden unbedingt ab!

Dies ist der uTrail in Originalgrösse:

Wenn Sie weitere Fragen haben, rufen Sie **Mo-Fr** zwischen **9:00 -12:00 Uhr und 14:00 -17:00 Uhr** an unter:

+41 79 665 14 35 (Adriana Zanda)

oder schreiben Sie eine E-Mail an: **mapspace@unibas.ch**

DSBG
UNIVERSITÄT BASEL
Departement für Sport, Bewegung und Gesundheit

Universität Basel, Departement für Sport, Bewegung und Gesundheit
Universität Zürich, Geographisches Insitut, Geoinformationssysteme

CRF 2 – Tagebuch uTrail

Tag (durch Prüfperson auszufüllen)	**Datum** (durch Prüfperson auszufüllen)	**Haben Sie das uTrail-Gerät den ganzen Tag getragen?**	**Waren Sie an diesem Tag ausser Haus?**	**Bemerkungen** (durch Prüfperson auszufüllen)
1 ☐☐	☐☐.☐☐. 2016	Nein ☐ Ja ☐	Nein ☐ Ja ☐	
2 ☐☐	☐☐.☐☐. 2016	Nein ☐ Ja ☐	Nein ☐ Ja ☐	
3 ☐☐	☐☐.☐☐. 2016	Nein ☐ Ja ☐	Nein ☐ Ja ☐	
4 ☐☐	☐☐.☐☐. 2016	Nein ☐ Ja ☐	Nein ☐ Ja ☐	
5 ☐☐	☐☐.☐☐. 2016	Nein ☐ Ja ☐	Nein ☐ Ja ☐	
6 ☐☐	☐☐.☐☐. 2016	Nein ☐ Ja ☐	Nein ☐ Ja ☐	
7 ☐☐	☐☐.☐☐. 2016	Nein ☐ Ja ☐	Nein ☐ Ja ☐	

Bitte denken Sie daran, Ihr uTrail-Gerät täglich aufzuladen und den gesamten Tag über zu tragen.

Bitte bringen Sie dieses Tagebuch und das uTrail-Gerät zum zweiten Termin unbedingt mit.

Vielen Dank!

CRF 3 – GPS/MapTool (2. Termin)

Prüfer-ID: ☐

Datum Zweittermin: ☐☐ . ☐☐ . ☐☐☐☐

Teil I: Auszufüllen durch Prüfer

uTrail zurückgegeben: *   Ja ○
Nein ○   Bemerkung:
____

Ladegerät zurückgegeben: *   Ja ○
Nein ○   Bemerkung:
____

uTrail Tagebuch zurückgegeben: *   Ja ○
Nein ○   Bemerkung:
____

** Kein Eintrag in die Datenbank*

Weiter zu Teil II dieses CRFs!

Teil II: Auszufüllen durch Proband/Probandin

A. TRAGEN UND BENUTZUNG DES GPS-GERÄTES

1. Während der letzten 7 Tage: In welchem Ausmass ...

	Trifft sehr gut zu 1	2	3	4	Trifft gar nicht zu 5
a) ...waren Sie sich des Geräts in ihrem Alltag bewusst?	○	○	○	○	○
b) ...haben Sie das Tragen des Geräts aufgrund seiner Grösse oder seines Gewichts als unangenehm empfunden?	○	○	○	○	○
d) ...war die Benutzung des Geräts intuitiv verständlich?	○	○	○	○	○
e) ...hat der Ein- & Ausschalt-Knopf beim Ausüben von Druck reagiert?	○	○	○	○	○
f) ...haben Sie die LED Lichter als störend empfunden?	○	○	○	○	○
g) ...fühlte sich das Material / die Konstruktion des Geräts robust an?	○	○	○	○	○
h) ...gefiel Ihnen insgesamt das Design des Geräts?	○	○	○	○	○
i) ...hat das Gerät Ihre alltäglichen Aktivitäten eingeschränkt?	○	○	○	○	○
j) ...hat das Gerät Ihr gewöhnliches Verhalten verändert?	○	○	○	○	○
k) ...haben Sie mit Menschen in Ihrer Umgebung über das Gerät gesprochen?	○	○	○	○	○

Weiter zur Durchführung des MapTools (siehe SOP 1: Map-Tool) und zeitgleich zum Ausfüllen von Teil III dieses CRFs durch den Prüfer!

Teil III: Auszufüllen durch Prüfer

A. DURCHFÜHRUNG DES MAPTOOLS (BEWERTUNG PRÜFER)

2. Benötigte Zeit (Proband klickt „Zur Anleitung“ → START der Stoppuhr; Proband oder Tester klickt auf „Zeichnung speichern“ → STOP der Stoppuhr; auf ganze Sekunden auf- bzw. abrunden; spätestens nach 50 Minuten abbrechen)

☐☐ min ☐☐ sec

3. Bitte geben Sie an, ob Fragen zu den folgenden Themen gestellt wurden. Bei Bemerkungen angeben welche Frage, welches Fenster, welche Funktion, etc. nicht verständlich waren.

	Ja	Nein
a) Bedienung Maus und Tastatur **Bemerkungen:**	○	○
b) Navigation zwischen den Einstiegsfenstern **Bemerkungen:**	○	○
c) Verständnisfragen zum Inhalt der Einstiegsfenster **Bemerkungen:**	○	○
d) Navigation in der linken Spalte des Tools (Buttons Vor, Zurück, Hilfe) **Bemerkungen:**	○	○
e) Definition der Lebensraum-Stufen (Inhalt linke Spalte) **Bemerkungen:**	○	○
f) Bedienung der Suchfunktion **Bemerkungen:**	○	○
g) Navigation in der Karte (Zoom, Hin- und Herziehen) **Bemerkungen:**	○	○
h) Verständnisfragen zu Fragen im Info Fenster über dem Marker **Bemerkungen:**	○	○
i) Handhabung des Info-Fensters zum Marker (Antworten, Speichern) **Bemerkungen:**	○	○
j) Marker auf die Karte setzen **Bemerkungen:**	○	○
k) Marker anwählen und verschieben **Bemerkungen:**	○	○
l) Marker löschen **Bemerkungen:**	○	○
m) Kartenlesen, Orte identifizieren **Bemerkungen:**	○	○

4. Hat der/die Proband/In das Map-Tool mehrmals ausfüllen müssen? (Neustart der Webseite)

- O Ja (Weiter zu Frage 5)
- O Nein (Weiter zu Frage 8)

5. Wenn ja, wieso musste das Tool nochmals ausgefüllt werden? (Mehrfachantwort möglich)

- O Das Tool wurde beendet (Zeichnung gespeichert) und der/die Proband/In wollte noch weitere Punkte ergänzen.
- O Die Zeichnung wurde gespeichert und der/die Proband/In wollte/musste neu anfangen.
- O Der/Die Proband/In hat aus Versehen den Browser geschlossen **oder** die Seite neu geladen **oder** zur vorherigen Webseite gewechselt.
- O Die Webseite ist abgestürzt.

6. Wie oft wurde das Map-Tool für den/die Proband/In gespeichert? (Zahl angeben)

__________ Mal

7. Welche Speicherungen sind geltend und müssen für die Analyse berücksichtigt werden?

- O Die Speicherungen **ergänzen** sich alle gegenseitig.
- O Die allerletzte Speicherung **löst** alle zuvor gespeicherten **ab**.
- O Nur einzelne Speicherungen sind gültig (Zahlen der geltenden Speicherungen in der Speicherreihenfolge angeben):

Speicherung _______ & _______ & _______ sind geltend

8. Hat der/die Proband/In das Map-Tool bis zum Schluss selbst ausgefüllt?

- O Ja
- O Nein

Sobald das MapTool erfolgreich abgeschlossen und gesichert ist, weiter zu Teil IV dieses CRFs!

Teil IV: Auszufüllen durch Proband/Probandin

A. DURCHFÜHRUNG DES MAPTOOLS (BEWERTUNG PROBAND/PROBANDIN)

9. Der folgende Fragebogen besteht aus mehreren Aussagen, die sich darauf beziehen, wie benutzerfreundlich Sie die Online-Kartenanwendung empfunden haben. Machen Sie bei jedem Statement ein Kreuz bei der Zahl, die ihre Zustimmung zur Aussage widerspiegelt.

	Trifft zu 1	2	Weder /noch 3	4	Trifft nicht zu 5
a) Ich denke, dass ich diese Anwendung gerne regelmässig verwenden würde.	○	○	○	○	○
b) Ich fand, dass die Anwendung unnötigerweise kompliziert war.	○	○	○	○	○
c) Ich denke, die Anwendung ist einfach zu bedienen.	○	○	○	○	○
d) Ich denke, dass ich technische Unterstützung durch eine Person benötige, um die Anwendung zu bedienen.	○	○	○	○	○
e) Ich finde, dass die verschiedenen Funktionalitäten dieser Anwendung gut integriert sind.	○	○	○	○	○
f) Ich denke, dass zu viel Inkonsistenz in dieser Anwendung vorhanden ist.	○	○	○	○	○
g) Ich kann mir vorstellen, dass viele Leute sehr schnell lernen würden, mit dieser Anwendung umzugehen.	○	○	○	○	○
h) Ich fand es sehr umständlich, die Anwendung zu nutzen.	○	○	○	○	○
i) Ich fühlte mich sehr sicher bei der Bedienung der Anwendung.	○	○	○	○	○
j) Ich musste viele Sachen lernen, bevor ich mit der Anwendung zurechtkam.	○	○	○	○	○

10. Hatten Sie Schwierigkeiten mit der Online-Kartenanwendung umzugehen?

- O Ja (Weiter zu Frage 11)
- O Ein wenig (Weiter zu Frage 11)
- O Nein

11. Welche Gründe dafür treffen auf Sie zu? (Mehrfachantwort möglich)

- O Ich habe noch nie einen **Computer** bedient.
- O Ich habe im Allgemeinen Schwierigkeiten einen **Computer** zu bedienen.
- O Ich habe noch nie das **Internet** genutzt.
- O Ich habe im Allgemeinen Schwierigkeiten das **Internet** zu nutzen.

Nach Beantwortung dieser Fragen geht es weiter mit der Durchführung der Funktionstests (CRF 4)!

CRF 4 – Funktionstests (2. Termin)

Probanden-ID: ☐☐

1. Größe: ☐☐☐,☐cm 2. Gewicht: ☐☐☐,☐kg 3. Taillenumfang: ☐☐☐,☐cm

Handkraft der dominanten Hand *(bester aus drei Versuchen)*

4. Dominante Hand: rechts ☐1 links ☐2 *„Welche Hand benutzen Sie, um Brot mit einem Messer zu schneiden?"*

5. Test durchführbar: nein ☐0 ja ☐1 → 6. Versuch 1: ☐☐,☐ kg

* Bemerkungen: ____________________ Versuch 2: ☐☐,☐ kg

____________________ Versuch 3: ☐☐,☐ kg

Side-by-side Stand *(maximaler Wert: 10,00 Sekunden)*

7. Test durchführbar: nein ☐0 ja ☐1 → 8. Ergebnis: ☐☐,☐☐ Sekunden

* Bemerkungen: ____________________

Semi-Tandemstand *(maximaler Wert: 10,00 Sekunden)*

9. Test durchführbar: nein ☐0 ja ☐1 → 10. Ergebnis: ☐☐,☐☐ Sekunden

* Bemerkungen: ____________________

Tandemstand *(maximaler Wert: 10,00 Sekunden)*

11. Test durchführbar: nein ☐0 ja ☐1 → 12. Ergebnis: ☐☐,☐☐ Sekunden

* Bemerkungen: ____________________

Tandemgang *(bester aus zwei Versuchen), maximaler Wert: 8 Schritte*

13. Test durchführbar: nein ☐0 ja ☐1 → 14. Besserer von 2 Versuchen: ☐ Schritte

0 Schritte eintragen, wenn der Test prinzipiell durchführbar aber nicht ein korrekter Schritt möglich ist!

* Bemerkungen: ____________________

4m-Gait Speed *(zwei Versuche)*

15. Gehhilfe notwendig: nein ☐0 ja ☐1 → 16. Art: Gehstütze/-stock einseitig ☐1

Gehstütze/-stock beidseitig ☐2 Rollator ☐3

17. Test durchführbar: nein ☐0 ja ☐1 → 18. Versuch 1: ☐☐,☐☐ Sekunden

→ 19. Versuch 2: ☐☐,☐☐ Sekunden

* Bemerkungen: ____________________

Chair-Rise *(ein Versuch; Abbruch nach 60 Sek.)*

20. Einmal aufstehen ohne Arme möglich: nein ☐0 ja ☐1

21. Test durchführbar: nein ☐0 *→ <u>andere</u> Gründe als „einmal aufstehen unmöglich" unter Bemerkungen aufführen* ja ☐1

22. Innerhalb von 60 Sek. geschafft: nein ☐0 ja ☐1 → 12. ☐☐,☐☐ Sekunden

* Bemerkungen: ____________________

** Kein Eintrag in die Datenbank*

Nach Beenden der Tests weiter zu CRF 5 „Diverse Fragebögen".

CRF 5 – Diverse Fragebögen (2. Termin)

Auszufüllen durch Proband/Probandin

Für die Auswertung des Fragebogens ist es sehr wichtig, dass alle Fragen beantwortet werden. Wenn Sie bei einer Frage finden, es stimme keine Antwort ganz genau, so kreuzen Sie einfach diejenige an, die für Sie am ehesten zutrifft. Dieser Fragebogen ist kein Test, es gibt also keine richtigen oder falschen Antworten. Wir möchten gerne wissen, was Sie denken. **Ihre Angaben werden anonym und streng vertraulich behandelt**.

A. KÖRPERLICHE AKTIVITÄT

Wir sind daran interessiert herauszufinden welche Arten von körperlichen Aktivitäten Menschen in ihrem alltäglichen Leben vollziehen. Die Befragung bezieht sich auf die Zeit die Sie während der **letzten 7 Tage (bis und mit gestern)** in körperlicher Aktivität verbracht haben. Bitte beantworten Sie alle Fragen (auch wenn Sie sich selbst nicht als aktive Person ansehen). Bitte berücksichtigen Sie die Aktivitäten im Rahmen Ihrer Arbeit, in Haus und Garten, um von einem Ort zum anderen zu kommen und in Ihrer Freizeit für Erholung, Leibesübungen und Sport.

Denken Sie an all Ihre **anstrengenden** und **moderaten** Aktivitäten in den **vergangenen 7 Tagen**. **Anstrengende** Aktivitäten bezeichnen Aktivitäten die starke körperliche Anstrengungen erfordern und bei denen Sie deutlich stärker atmen als normal. **Moderate** Aktivitäten bezeichnen Aktivitäten mit moderater körperlicher Anstrengung bei denen Sie ein wenig stärker atmen als normal.

1. Denken sie nur an die körperlichen Aktivitäten die Sie **für mindestens 10 Minuten** ohne Unterbrechung verrichtet haben. An wie vielen der **vergangenen 7 Tage** haben Sie **anstrengende** körperliche Aktivitäten wie Aerobic, Laufen (Jogging), schnelles Fahrradfahren oder schnelles Schwimmen in ihrer **Freizeit** verrichtet?

   _____Tage pro Woche ○ Keine anstrengende Aktivität (→ weiter zu Frage 3)

2. Wie viel Zeit haben Sie für gewöhnlich an **einem** dieser Tage mit **anstrengender** körperlicher Aktivität in ihrer Freizeit verbracht?

   _____Stunden pro Tag _____Minuten pro Tag

3. Denken Sie erneut nur an die körperlichen Aktivitäten die Sie **für mindestens 10 Minuten** ohne Unterbrechung verrichtet haben. An wie vielen der **vergangenen 7 Tage** haben sie **moderate** körperliche Aktivitäten wie das Tragen leichter Lasten, Fahrradfahren bei gewöhnlicher Geschwindigkeit oder Schwimmen bei gewöhnlicher Geschwindigkeit verrichtet? Hierzu zählt **nicht** zu Fuß gehen.

   _____Tage pro Woche   O Keine moderate Aktivität (→ weiter zu Frage 5)

4. Wie viel Zeit haben Sie für gewöhnlich an **einem** dieser Tage mit **moderater** körperlicher Aktivität in ihrer Freizeit verbracht?

   _____Stunden pro Tag   _____Minuten pro Tag

5. An wie vielen der **vergangenen 7 Tage** sind Sie **mindestens 10 Minuten** ohne Unterbrechung **zu Fuß** gegangen? Dieses beinhaltet Gehstrecken daheim oder in der Arbeit, gehen um von einem Ort zu einem anderen zu gelangen, sowie alles andere Gehen zur Erholung, Bewegung oder Freizeit.

   _____Tage pro Woche   O Keine entsprechenden Wege zu Fuss (→ weiter zu Frage 7)

6. Wie viel Zeit haben Sie für gewöhnlich an **einem** dieser Tage mit **Gehen** verbracht?

   _____Stunden pro Tag   _____Minuten pro Tag

7. Wie viel Zeit haben Sie in den **vergangenen 7 Tagen** an **einem Wochentag** mit **Sitzen** verbracht? Dies kann Zeit beinhalten wie Sitzen am Schreibtisch, Besuchen von Freunden, vor dem Fernseher sitzen oder liegen und auch sitzen in einem öffentlichen Verkehrsmittel.

   _____Stunden pro Tag   _____Minuten pro Tag

B. STÜRZE

8. Sind Sie in den letzten **12 Monaten** ausgerutscht, gestolpert oder gestürzt in der Weise, dass Sie das Gleichgewicht verloren haben und auf dem Boden gelandet sind?
   - O Ja (→ weiter zur nächsten Frage)
   - O Nein (→ weiter zu Frage 10)

9. Wie häufig sind Sie in den letzten **12 Monaten** gestürzt?

   ______mal

10. Wir würden Ihnen nun gerne einige Fragen darüber stellen, **welche Bedenken Sie haben hinzufallen**, wenn Sie bestimmte Aktivitäten ausführen.
Bitte denken Sie noch mal darüber nach, wie sie diese Aktivität normalerweise ausführen. Wenn Sie die Aktivität zurzeit nicht ausführen (z.B. wenn jemand ihren Einkauf erledigt), geben Sie bitte (trotzdem) eine Antwort um anzuzeigen, ob Sie Bedenken **hätten** zu stürzen, wenn Sie die Aktivität ausführen **würden**.
Ihnen stehen bei jeder der nachfolgenden Fragen vier Antwortmöglichkeiten zur Verfügung, nämlich „keinerlei Bedenken“, „einige Bedenken“, „ziemliche Bedenken“ und „sehr große Bedenken“. Markieren Sie bitte diejenige Angabe, die **am ehesten** ihrem eigenen Empfinden entspricht, um anzuzeigen welche Bedenken Sie haben zu stürzen, wenn Sie diese Aktivität ausüben. Bitte kreuzen Sie jeweils **nur eine Antwort** an.

	Keinerlei Bedenken	Einige Bedenken	Ziemliche Bedenken	Sehr grosse Bedenken
a) Den Hausputz machen (z.B. Kehren, Staubsaugen oder Staub wischen)	○	○	○	○
b) Sich an- oder ausziehen	○	○	○	○
c) Einfache Mahlzeiten zubereiten	○	○	○	○
d) Ein Bad nehmen oder duschen	○	○	○	○
e) In einem Laden einkaufen	○	○	○	○
f) Von einem Stuhl aufstehen oder sich hinsetzen	○	○	○	○
g) Eine Treppe hinauf- oder hinuntergehen	○	○	○	○
h) In der Nähe der Wohnung draußen umhergehen	○	○	○	○
i) Etwas erreichen, was sich oberhalb des Kopfes oder auf dem Boden befindet	○	○	○	○
j) Das Telefon erreichen, bevor es aufhört zu klingeln	○	○	○	○
k) Auf einer rutschigen Oberfläche gehen (z.B. wenn es nass oder vereist ist)	○	○	○	○
l) Einen Freund oder Verwandten besuchen	○	○	○	○
m) In einer Menschenmenge umhergehen	○	○	○	○
n) Auf unebenem Boden gehen (z.B. Kopfsteinpflaster, ungepflegter Gehweg)	○	○	○	○
o) Eine Steigung hinauf- oder hinunter gehen	○	○	○	○
p) Eine Veranstaltung besuchen (z.B. ein Familientreffen, eine Vereinsversammlung oder Gottesdienst)	○	○	○	○

C. GESUNDHEITSBEZOGENE LEBENSQUALITÄT

In den folgenden Fragen geht es um Ihre Beurteilung Ihres Gesundheitszustandes. Die Fragen ermöglichen es im Zeitverlauf nachzuvollziehen, wie Sie sich fühlen und wie Sie im Alltag zurechtkommen.

Bitte beantworten Sie jede Frage, indem Sie bei den Antwortmöglichkeiten den Kreis ankreuzen, der am besten auf Sie zutrifft. Bitte kreuzen Sie jeweils nur einen Kreis an.

	Ausge-zeichnet	Sehr gut	Gut	Weniger gut	Schlecht
11. Wie würden Sie Ihren Gesundheitszustand im Allgemeinen beschreiben?	○	○	○	○	○

	Derzeit viel besser	Derzeit etwas besser	Etwa wie vor einem Jahr	Derzeit etwas schlechter	Derzeit viel schlechter
12. Im Vergleich zum vergangenen Jahr, wie würden Sie Ihren derzeitigen Gesundheitszustand beschreiben?	○	○	○	○	○

13. Im Folgenden sind einige Tätigkeiten beschrieben, die Sie vielleicht an einem normalen Tag ausüben. Sind Sie durch Ihren derzeitigen Gesundheitszustand bei diesen Tätigkeiten eingeschränkt? Wenn ja, wie stark ?

	Ja, stark einge-schränkt	Ja, etwas einge-schränkt	Nein, überhaupt nicht eingeschränkt
a) anstrengende Tätigkeiten, z.B. schnell laufen, schwere Gegenstände heben, anstrengenden Sport treiben	○	○	○
b) mittelschwere Tätigkeiten, z.B. einen Tisch verschieben, staubsaugen, kegeln, Golf spielen	○	○	○
c) Einkaufstaschen heben oder tragen	○	○	○
d) mehrere Treppenabsätze steigen	○	○	○
e) einen Treppenabsatz steigen	○	○	○
f) sich beugen, knien, bücken	○	○	○
g) mehr als 1 Kilometer zu Fuß gehen	○	○	○
h) mehrere Straßenkreuzungen weit zu Fuß gehen	○	○	○
i) eine Straßenkreuzung weit zu Fuß gehen	○	○	○
j) sich baden oder anziehen	○	○	○

14. Hatten Sie in den vergangenen 4 Wochen aufgrund Ihrer körperlichen Gesundheit irgendwelche Schwierigkeiten bei der Arbeit oder anderen alltäglichen Tätigkeiten im Beruf bzw. zu Hause?

	Ja	Nein
a) Ich konnte nicht so lange wie üblich tätig sein.	○	○
b) Ich habe weniger geschafft als ich wollte.	○	○
c) Ich konnte nur bestimmte Dinge tun.	○	○
d) Ich hatte Schwierigkeiten bei der Ausführung (z.B. ich musste mich besonders anstrengen).	○	○

15. Hatten Sie in den vergangenen 4 Wochen aufgrund seelischer Probleme irgendwelche Schwierigkeiten bei der Arbeit oder anderen alltäglichen Tätigkeiten im Beruf bzw. zu Hause (z.B. weil Sie sich niedergeschlagen oder ängstlich fühlten)?

	Ja	Nein
a) Ich konnte nicht so lange wie üblich tätig sein.	○	○
b) Ich habe weniger geschafft als ich wollte.	○	○
c) Ich konnte nicht so sorgfältig wie üblich arbeiten.	○	○

	Überhaupt nicht	Etwas	Mässig	Ziemlich	Sehr
16. Wie sehr haben Ihre körperliche Gesundheit oder seelischen Probleme in den vergangenen 4 Wochen Ihre normalen Kontakte zu Familienangehörigen, Freunden, Nachbarn oder zum Bekanntenkreis beeinträchtigt?	○	○	○	○	○

	Keine Schmerzen	Sehr leicht	Leicht	Mässig	Stark	Sehr stark
17. Wie stark waren Ihre Schmerzen in den vergangenen 4 Wochen?	○	○	○	○	○	○

	Überhaupt nicht	Ein bisschen	Mässig	Ziemlich	Sehr
18. Inwieweit haben die Schmerzen Sie in den vergangenen 4 Wochen bei der Ausübung Ihrer Alltagstätigkeiten zu Hause und im Beruf behindert?	○	○	○	○	○

19. In diesen Fragen geht es darum, wie Sie sich fühlen und wie es Ihnen in den vergangenen 4 Wochen gegangen ist. (Bitte kreuzen Sie in jeder Zeile die Zahl an, die Ihrem Befinden am ehesten entspricht). Wie oft waren Sie in den vergangenen 4 Wochen...

	Immer	Meistens	Ziemlich oft	Manch-mal	Selten	Nie
a) ...voller Schwung?	○	○	○	○	○	○
b) ...sehr nervös?	○	○	○	○	○	○
c) ...so niedergeschlagen, dass Sie nichts aufheitern konnte?	○	○	○	○	○	○
d) ...ruhig und gelassen?	○	○	○	○	○	○
e) ...voller Energie?	○	○	○	○	○	○
f) ...entmutigt und traurig?	○	○	○	○	○	○
g) ...erschöpft?	○	○	○	○	○	○
h) ...glücklich?	○	○	○	○	○	○
i) ...müde?	○	○	○	○	○	○

	Immer	Meistens	Manch-mal	Selten	Nie
20. Wie häufig haben Ihre körperliche Gesundheit oder seelischen Probleme in den vergangenen 4 Wochen Ihre Kontakte zu anderen Menschen (Besuche bei Freunden, Verwandten usw.) beeinträchtigt?	○	○	○	○	○

21. Inwieweit trifft jede der folgenden Aussagen auf Sie zu?

	Trifft ganz zu	Trifft weit-gehend zu	Weiss nicht	Trifft weit-gehend nicht zu	Trifft über-haupt nicht zu
a) Ich scheine etwas leichter als andere krank zu werden.	○	○	○	○	○
b) Ich bin genauso gesund wie alle anderen, die ich kenne.	○	○	○	○	○
c) Ich erwarte, dass meine Gesundheit nachlässt.	○	○	○	○	○
i) Ich erfreue mich ausgezeichneter Gesundheit.	○	○	○	○	○

D. PERSÖNLICHE ANGABEN

Im nun folgenden Abschnitt möchten wir einige Daten zu Ihrer Person erfragen. Wir erinnern Sie an dieser Stelle, dass alle Daten komplett anonym ausgewertet werden.

22. Welchen Familienstand haben Sie?
- ○ ledig (nie verheiratet)
- ○ verheiratet oder eingetragene Partnerschaft
- ○ geschieden
- ○ verwitwet

23. Bitte geben Sie an, **wie viele Jahre Schul- und Berufsausbildung** Sie **insgesamt** absolviert haben.

Hierzu zunächst 2 Beispiele:
Beispiel 1: 6 (Primarschule) + 3 (Sekundarschule) + 4 (Berufslehre) = 13 Jahre.
Beispiel 2: 6 (Primarschule) + 7 (Gymnasium) + 4 (Studium) = 17 Jahre.

Jahre in der Schul- und Berufsausbildung insgesamt: ______Jahre

24. Wurde Ihre Teilhabe am gesellschaftlichen Leben **in den letzten vier Wochen durch eine problematische finanzielle Situation** (z.B. Geldmangel, fehlende staatliche Unterstützung) gar nicht, etwas oder massiv erschwert? Bitte beziehen Sie sich dabei darauf, wie Sie sich Ihr gesellschaftliches Leben wünschen würden.
- ○ Hatte **keinen Einfluss**.
- ○ Hat mein Leben **etwas** erschwert.
- ○ Hat mein Leben **massiv** erschwert.

E. LEBENSRAUM

25. Handelte es sich **bei der letzten Woche (bis und mit gestern)** um eine **übliche Woche** hinsichtlich des Aufsuchens von Orten ausserhalb Ihres zu Hauses?
- ○ Ja
- ○ Nein

26. Waren Sie **in der letzten Woche (bis und mit gestern)** durch ein aktuelles Ereignis (z.B. Sturz, Unfall, schwere Grippe) in Ihren **ausserhäuslichen** Aktivitäten merklich eingeschränkt?
- ○ Ja
- ○ Nein

Vielen Dank! Die Prüfperson wird Ihnen jetzt noch einen weiteren kurzen Fragebogen zum Lebensraum vorlegen (CRF 6).

CRF 6 – LSA (2. Termin)

Aufgeschlagene Seite 2 erst vor Proband/in hinlegen, wenn diese/r bereit ist zum Ausfüllen eines weiteren Fragebogens.
Sobald Seite 2 vor dem/der Probanden/Probandin liegt → Stoppuhr starten.

Beim Ausfüllen beobachten, sobald 3. d) beantwortet ist ggf. auf noch nicht beantwortete Fragen hinweisen. Ansonsten fragen „Sind Sie mit dem Ausfüllen fertig?“, bei Antwort „nein“ noch etwas Zeit lassen und dann erneut fragen. Bei Antwort „ja“ → Zeit anhalten.

Benötigte Zeit (auf ganze Sekunden auf- bzw. abrunden; durch Prüfperson auszufüllen)

☐☐ min ☐☐ sec

Im Anschluss ans Ausfüllen der Seite 2 durch Probanden und Notieren der Zeit weiter zu CRF 7 (MMSE)!

Lebensraum

Die folgenden Fragen beziehen sich nur auf Ihre Aktivitäten der letzten **7 Tage (bis und mit gestern)**.
Bitte wenden Sie sich an die Untersuchungsperson, falls Sie Hilfe beim Ausfüllen benötigen.

	a. Waren Sie während der letzten 7 Tage an…		**b. Wie oft waren Sie in den letzten 7 Tagen insgesamt an diesen Orten?**				**c. Haben Sie eine Gehhilfe benötigt?**		**d. Haben Sie Hilfe von einer anderen Person benötigt?**	
LEBENSRAUM STUFEN	Ja	Nein	1 mal	2-3 mal	4-6 mal	täg-lich	Ja	Nein	Ja	Nein
Stufe 1 **… Orten innerhalb Ihrer Nachbarschaft?**	○	○	○	○	○	○	○	○	○	○
Stufe 2 **… Orten ausserhalb Ihrer Nachbarschaft, aber innerhalb Ihrer Gemeinde?**	○	○	○	○	○	○	○	○	○	○
Stufe 3 **… Orten ausserhalb Ihrer Gemeinde?**	○	○	○	○	○	○	○	○	○	○

CRF 7 – MMSE (2. Termin)

Auszufüllen durch Prüfer

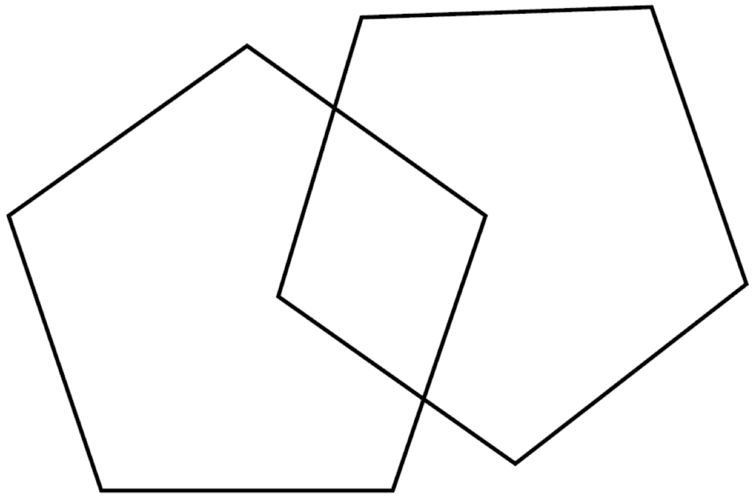
Vorbemerkungen

- Benötigtes Material: Armbanduhr, leere Blätter (nicht liniert oder kariert), laminierten „Schliessen Sie...“-Zettel
- Die Items sind in der vorgeschriebenen Reihenfolge durchzugehen
- Falls ein Patient Probleme mit der Schriftsprache hat, dürfen die Fragen in Mundart vorgegeben werden.
- Bei Hörschwierigkeiten dürfen die Fragen wiederholt werden, doch darf keine Hilfe bei der Beantwortung geleistet werden.
- Eine positive Verstärkung ist erlaubt („das machen Sie gut“), Hinweise auf die Richtigkeit der Antwort sind jedoch zu unterlassen („ja, das ist richtig“)
- Da die Fragen zum Teil sehr einfach sind, sollte eine Vorbemerkung erfolgen, wie z.B.: “Einiges von dem, was ich Sie jetzt frage, ist für Sie wahrscheinlich zu einfach, aber es gehört zur standardmässigen Untersuchung“
- Wenn der Proband unsicher ist, bitten Sie ihn nochmals, sich festzulegen (raten ist erlaubt, keine halben Punkte vergeben!). Falls er keine Antwort gibt, geben Sie 0 Punkte.
- Bei Unsicherheit hinsichtlich der Bewertung einer Antwort als 0 oder 1, Antwort notieren und Bewertung später klären.

			0	1
Zeitliche Orientierung	1. Welches Jahr haben wir?	Keine Toleranz	○	○
	2. Welche Jahreszeit ist jetzt?	Toleranz von ±2 Wochen Sommer: bis 20. September Herbst: 21. September bis 20. Dezember	○	○
	3. Der wievielte des Monats ist heute?	Toleranz von ± 1 Tag	○	○
	4. Welcher Wochentag ist heute?	Keine Toleranz	○	○
	5. Welcher Monat ist jetzt?	Keine Toleranz	○	○
Örtliche Orientierung	6. In welchem Land sind wir?	Keine Toleranz	○	○
	7. In welchem Kanton befinden wir uns?	Keine Toleranz Basel-Stadt/Basel-Land wird beides akzeptiert	○	○
	8. In welcher Ortschaft sind wir jetzt?	Keine Toleranz akzeptiert wird Basel, Muttenz, Münchenstein	○	○
	9. Auf welchem Stockwerk befinden wir uns?	Keine Toleranz akzeptiert wird EG, UG, Sous-terrain	○	○
	10. Wo sind wir hier?	Keine Toleranz akzeptiert wird St. Jakob-Arena, Eishalle, Sportmedizin, DSBG, Brüglingen 33 und ähnliches	○	○
3 Wörter wiederholen	Darf ich nun Ihr Gedächtnis testen? Gut! Ich werde Ihnen jetzt drei Wörter nennen. Hören Sie bitte zuerst zu und wiederholen Sie die drei Wörter, sobald ich fertig bin.	3 Wörter nacheinander langsam und deutlich vorsprechen (ca. eines pro Sekunde). Probanden die Wörter erst wiederholen lassen, nachdem alle 3 Wörter gesagt wurden.		
	11. Zitrone	Die erste Wiederholung gibt die Punktzahl! Werden nicht alle Wörter im ersten Versuch nachgesprochen, alle drei Begriffe wiederholen, bis alle Wörter gelernt sind (bis zu 6mal).	○	○
	12. Schlüssel		○	○
	13. Ball		○	○

			0	1
Rechnen	Können Sie von der Zahl 100 jeweils 7 abziehen, also 100 minus 7, minus 7 usw.? *(langsam und deutlich sprechen)*	Jeden einzelnen Rechenschritt unabhängig vom vorangehenden beurteilen, damit ein Fehler nicht mehrfach gewertet wird.		
	14. (93)		○	○
	15. (86)		○	○
	16. (79)		○	○
	17. (72)		○	○
	18. (65)		○	○
Gedächtnis	Welche 3 Wörter haben Sie mir vorhin nachgesprochen?	Reihenfolge der Wörter spielt keine Rolle.		
	19. Zitrone		○	○
	20. Schlüssel		○	○
	21. Ball		○	○
Benennen	22. Was ist das? *(Bleistift oder Kugelschreiber vorzeigen)*	Bei Kugelschreiber darf nicht „Bleistift“ gesagt werden und umgekehrt. Bei Antwort „Stift“ nachfragen.	○	○
	23. Was ist das? *(auf Armbanduhr zeigen)*	korrekt ist „Uhr“ oder „Armbanduhr“	○	○
Nachsprechen	24. Hören Sie bitte gut zu und sprechen Sie mir nach *(deutlich sprechen)*: „<u>Kein wenn **und** oder aber.</u>“	Der Satz muss unmittelbar nachgesprochen werden, nur 1 Versuch ist erlaubt. Es ist <u>nicht</u> zulässig, die Redewendung "Kein wenn und aber." zu benutzen.	○	○
Drei-Punkte-Befehl	*(Ein leeres Blatt Papier zunächst mittig mit <u>beiden</u> Händen vor dem eigenen Körper halten und dem Probanden noch nicht hinstrecken, erst nach dem Lesen von allen Befehlen dem Probanden das Blatt mit beiden Händen hinstrecken.)* Ich gebe Ihnen nun ein Blatt Papier:	Anweisung nicht wiederholen!		
	25. Nehmen Sie das Blatt Papier mit Ihrer <u>rechten</u> Hand,	Jede korrekt ausgeführte Handlung ergibt einen Punkt.	○	○
	26. falten Sie es mit beiden Händen und		○	○
	27. legen Sie es dann auf Ihren Schoss!		○	○
Schriftliche Aufforderung	28. (*Dem Probanden das Blatt mit "Schliessen Sie Ihre Augen!" vorlegen und sagen:)* Lesen Sie dies laut vor und führen Sie es aus!	Erst die Ausführung (Augen schliessen) ergibt einen Punkt.	○	○
Satz schreiben	29. *(Dem Probanden ein leeres Blatt A4 Hochformat geben und sagen:)* Schreiben Sie hier bitte einen vollständigen Satz	Der Satz muss mindestens aus einem Subjekt und Verb bestehen und einen Sinn ergeben. Schreibfehler werden nicht berücksichtigt.	○	○
Figur abzeichnen	30. *(Dem Probanden die Vorlage mit den zwei Fünfecken vorlegen (nächste Seite) und die folgende Instruktion geben:)* Zeichnen Sie bitte diese Figur auf dem gleichen Blatt Papier ab!	Nur <u>ein</u> Versuch! Es müssen alle Ecken/Winkel vorhanden sein und 2 Ecken müssen sich wie in der Originalzeichnung überschneiden. Zittrige Linien oder eine Rotation der Figuren werden nicht berücksichtigt.	○	○
Total MMS	*(Maximum = 30 Punkte, Minimum = 0 Punkte)*	Erst später zusammenzählen.	________P.	

Weiter zur Terminüberprüfung Dritttermin.



CRF 8 – Diverse Fragebögen (3. Termin)

Prüfer-ID: ☐

Datum Dritttermin: ☐☐ . ☐☐ . ☐☐☐☐

Teil I: Auszufüllen durch Prüfer

A. DURCHFÜHRUNG DES MAPTOOLS (BEWERTUNG PRÜFER)

1. Benötigte Zeit (Proband klickt „Zur Anleitung“ → START der Stoppuhr; Proband oder Tester klickt auf „Zeichnung speichern“ → STOP der Stoppuhr; auf ganze Sekunden auf- bzw. abrunden; spätestens nach 50 Minuten abbrechen)

☐☐ min ☐☐ sec

2. Bitte geben Sie an, ob Fragen zu den folgenden Themen gestellt wurden. Bei Bemerkungen angeben welche Frage, welches Fenster, welche Funktion, etc. nicht verständlich waren.

	Ja	Nein
a) Bedienung Maus und Tastatur **Bemerkungen:**	○	○
b) Navigation zwischen den Einstiegsfenstern **Bemerkungen:**	○	○
c) Verständnisfragen zum Inhalt der Einstiegsfenster **Bemerkungen:**	○	○
d) Navigation in der linken Spalte des Tools (Buttons Vor, Zurück, Hilfe) **Bemerkungen:**	○	○
e) Definition der Lebensraum-Stufen (Inhalt linke Spalte) **Bemerkungen:**	○	○
f) Bedienung der Suchfunktion **Bemerkungen:**	○	○
g) Navigation in der Karte (Zoom, Hin- und Herziehen) **Bemerkungen:**	○	○
h) Verständnisfragen zu Fragen im Info Fenster über dem Marker **Bemerkungen:**	○	○
i) Handhabung des Info-Fensters zum Marker (Antworten, Speichern) **Bemerkungen:**	○	○

j) Marker auf die Karte setzen **Bemerkungen:**	O	O
k) Marker anwählen und verschieben **Bemerkungen:**	O	O
l) Marker löschen **Bemerkungen:**	O	O
m) Kartenlesen, Orte identifizieren **Bemerkungen:**	O	O

3. Hat der/die Proband/In das Map-Tool mehrmals ausfüllen müssen? (Neustart der Webseite)

- O Ja (Weiter zu Frage 4)
- O Nein (Weiter zu Frage 7)

4. Wenn ja, wieso musste das Tool nochmals ausgefüllt werden? (Mehrfachantwort möglich)

- O Das Tool wurde beendet (Zeichnung gespeichert) und der/die Proband/In wollte noch weitere Punkte ergänzen.
- O Die Zeichnung wurde gespeichert und der/die Proband/In wollte/musste neu anfangen.
- O Der/Die Proband/In hat aus Versehen den Browser geschlossen **oder** die Seite neu geladen **oder** zur vorherigen Webseite gewechselt.
- O Die Webseite ist abgestürzt.

5. Wie oft wurde das Map-Tool für den/die Proband/In gespeichert? (Zahl angeben)

__________ Mal

6. Welche Speicherungen sind geltend und müssen für die Analyse berücksichtigt werden?

- O Die Speicherungen **ergänzen** sich alle gegenseitig.
- O Die allerletzte Speicherung **löst** alle zuvor gespeicherten **ab**.
- O Nur einzelne Speicherungen sind gültig (Zahlen der geltenden Speicherungen in der Speicherreihenfolge angeben):

Speicherung _______ & _______ & _______ sind geltend

7. Hat der/die Proband/In das Map-Tool bis zum Schluss selbst ausgefüllt?

- O Ja
- O Nein

Teil II: Auszufüllen durch Proband/Probandin

B. DURCHFÜHRUNG DES MAPTOOLS (BEWERTUNG PROBAND/PROBANDIN)

8. Der folgende Fragebogen besteht aus mehreren Aussagen, die sich darauf beziehen, wie benutzerfreundlich Sie die Online-Kartenanwendung empfunden haben. Machen Sie bei jedem Statement ein Kreuz bei der Zahl, die ihre Zustimmung zur Aussage widerspiegelt.

	Trifft zu 1	2	Weder /noch 3	4	Trifft nicht zu 5
a) Ich denke, dass ich diese Anwendung gerne regelmässig verwenden würde.	○	○	○	○	○
b) Ich fand, dass die Anwendung unnötigerweise kompliziert war.	○	○	○	○	○
c) Ich denke, die Anwendung ist einfach zu bedienen.	○	○	○	○	○
d) Ich denke, dass ich technische Unterstützung durch eine Person benötige, um die Anwendung zu bedienen.	○	○	○	○	○
e) Ich finde, dass die verschiedenen Funktionalitäten dieser Anwendung gut integriert sind.	○	○	○	○	○
f) Ich denke, dass zu viel Inkonsistenz in dieser Anwendung vorhanden ist.	○	○	○	○	○
g) Ich kann mir vorstellen, dass viele Leute sehr schnell lernen würden, mit dieser Anwendung umzugehen.	○	○	○	○	○
h) Ich fand es sehr umständlich, die Anwendung zu nutzen.	○	○	○	○	○
i) Ich fühlte mich sehr sicher bei der Bedienung der Anwendung.	○	○	○	○	○
j) Ich musste viele Sachen lernen, bevor ich mit der Anwendung zurechtkam.	○	○	○	○	○

9. Im Vergleich zum letzten Mal, welche Schwierigkeiten hatten Sie bei diesem Mal, mit der Online-Kartenanwendung umzugehen?

- O Ich hatte dieses Mal deutlich mehr Schwierigkeiten als beim letzten Mal.
- O Ich hatte dieses Mal ein bisschen mehr Schwierigkeiten als beim letzten Mal.
- O Ich hatte dieses Mal gleich viele Schwierigkeiten wie beim letzten Mal.
- O Ich hatte dieses Mal ein bisschen weniger Schwierigkeiten als beim letzten Mal.
- O Ich hatte dieses Mal deutlich weniger Schwierigkeiten als beim letzten Mal.

C. KÖRPERLICHE AKTIVITÄT

Wir sind daran interessiert herauszufinden welche Arten von körperlichen Aktivitäten Menschen in ihrem alltäglichen Leben vollziehen. Die Befragung bezieht sich auf die Zeit die Sie während der **letzten 7 Tage (bis und mit gestern)** in körperlicher Aktivität verbracht haben. Bitte beantworten Sie alle Fragen (auch wenn Sie sich selbst nicht als aktive Person ansehen). Bitte berücksichtigen Sie die Aktivitäten im Rahmen Ihrer Arbeit, in Haus und Garten, um von einem Ort zum anderen zu kommen und in Ihrer Freizeit für Erholung, Leibesübungen und Sport.

Denken Sie an all Ihre **anstrengenden** und **moderaten** Aktivitäten in den **vergangenen 7 Tagen**. **Anstrengende** Aktivitäten bezeichnen Aktivitäten die starke körperliche Anstrengungen erfordern und bei denen Sie deutlich stärker atmen als normal. **Moderate** Aktivitäten bezeichnen Aktivitäten mit moderater körperlicher Anstrengung bei denen Sie ein wenig stärker atmen als normal.

10. Denken sie nur an die körperlichen Aktivitäten die Sie **für mindestens 10 Minuten** ohne Unterbrechung verrichtet haben. An wie vielen der **vergangenen 7 Tage** haben Sie **anstrengende** körperliche Aktivitäten wie Aerobic, Laufen (Jogging), schnelles Fahrradfahren oder schnelles Schwimmen in ihrer **Freizeit** verrichtet?

    _____Tage pro Woche   O Keine anstrengende Aktivität (→ weiter zu Frage 12)

    11. Wie viel Zeit haben Sie für gewöhnlich an **einem** dieser Tage mit **anstrengender** körperlicher Aktivität in ihrer Freizeit verbracht?

        _____Stunden pro Tag   _____Minuten pro Tag

12. Denken Sie erneut nur an die körperlichen Aktivitäten die Sie **für mindestens 10 Minuten** ohne Unterbrechung verrichtet haben. An wie vielen der **vergangenen 7 Tage** haben sie **moderate** körperliche Aktivitäten wie das Tragen leichter Lasten, Fahrradfahren bei gewöhnlicher Geschwindigkeit oder Schwimmen bei gewöhnlicher Geschwindigkeit verrichtet? Hierzu zählt **nicht** zu Fuß gehen.

    _____Tage pro Woche   O Keine moderate Aktivität (→ weiter zu Frage 14)

    13. Wie viel Zeit haben Sie für gewöhnlich an **einem** dieser Tage mit **moderater** körperlicher Aktivität in ihrer Freizeit verbracht?

        _____Stunden pro Tag   _____Minuten pro Tag

14. An wie vielen der **vergangenen 7 Tage** sind Sie **mindestens 10 Minuten** ohne Unterbrechung **zu Fuß** gegangen? Dieses beinhaltet Gehstrecken daheim oder in der Arbeit, gehen um von einem Ort zu einem anderen zu gelangen, sowie alles andere Gehen zur Erholung, Bewegung oder Freizeit.

    _____Tage pro Woche   O Keine entsprechenden Wege zu Fuss (→ weiter zu Frage 16)

    15. Wie viel Zeit haben Sie für gewöhnlich an **einem** dieser Tage mit **Gehen** verbracht?

        _____Stunden pro Tag   _____Minuten pro Tag

16. Wie viel Zeit haben Sie in den **vergangenen 7 Tagen** an **einem Wochentag** mit **Sitzen** verbracht? Dies kann Zeit beinhalten wie Sitzen am Schreibtisch, Besuchen von Freunden, vor dem Fernseher sitzen oder liegen und auch sitzen in einem öffentlichen Verkehrsmittel.

    _____Stunden pro Tag   _____Minuten pro Tag

D. LEBENSRAUM

Die folgenden Fragen beziehen sich nur auf Ihre Aktivitäten der letzten **7 Tage (bis und mit gestern)**.
Bitte wenden Sie sich an die Untersuchungsperson, falls Sie Hilfe beim Ausfüllen benötigen.

	a. Waren Sie während der letzten 7 Tage an…		**b. Wie oft waren Sie in den letzten 7 Tagen insgesamt an diesen Orten?**				**c. Haben Sie eine Gehhilfe benötigt?**		**d. Haben Sie Hilfe von einer anderen Person benötigt?**	
LEBENSRAUM STUFEN	Ja	Nein	1 mal	2-3 mal	4-6 mal	täg-lich	Ja	Nein	Ja	Nein
Stufe 1 **… Orten innerhalb Ihrer Nachbarschaft?**	O	O	O	O	O	O	O	O	O	O
Stufe 2 **… Orten ausserhalb Ihrer Nachbarschaft, aber innerhalb Ihrer Gemeinde?**	O	O	O	O	O	O	O	O	O	O
Stufe 3 **… Orten ausserhalb Ihrer Gemeinde?**	O	O	O	O	O	O	O	O	O	O

20. Handelte es sich bei der letzten Woche (bis und mit gestern) um eine übliche Woche hinsichtlich des Aufsuchens von Orten ausserhalb Ihres zu Hauses?

- O Ja
- O Nein

21. Waren Sie in der letzten Woche (bis und mit gestern) durch ein aktuelles Ereignis (z.B. Sturz, Unfall, schwere Grippe) in Ihren ausserhäuslichen Aktivitäten merklich eingeschränkt?

- O Ja
- O Nein

Vielen Dank!

Personal Declaration

I hereby declare that the submitted thesis is the result of my own, independent work. All external sources are explicitly acknowledged in the thesis.

Olten, 21 April 2017

Adriana Zanda