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Psychometric properties of the MOBITEC-GP mobile application for real-life mobility assessment in older adults

Eleftheria Giannouli, PhD[a,b,*], Eun-Kyeong Kim, PhD[c,d,e], Cheng Fu, PhD[c], Robert Weibel, PhD[c,d], Alexandros Sofios[c], Denis Infanger, PhD[a], Erja Portegijs, PhD[f], Taina Rantanen, PhD[g], Haosheng Huang, PhD[h], Arno Schmidt-Trucksäss, MD[a], Andreas Zeller, MD[i], Roland Rössler, PhD[a,j], Timo Hinrichs, MD[a]

[a] Division of Sport and Exercise Medicine, Department of Sport, Exercise and Health, University of Basel, Basel, Switzerland
[b] Department of Health Sciences & Technology, Institute of Human Movement Sciences and Sport, ETH Zurich, Zurich, Switzerland
[c] Department of Geography, University of Zurich, Zurich, Switzerland
[d] University Research Priority Program (URPP) Dynamics of Healthy Aging, University of Zurich, Zurich, Switzerland
[e] Department of Urban Development and Mobility, Luxembourg Institute of Socio-Economic Research (LISER), Esch-sur-Alzette, Luxembourg
[f] University of Groningen, University Medical Center Groningen, Center for Human Movement Sciences, Groningen, the Netherlands
[g] Gerontology Research Center and Faculty of Health Sciences, University of Jyväskylä, Jyväskylä, Finland
[h] Department of Geography, Ghent University, Ghent, Belgium
[i] Centre for Primary Health Care, University of Basel, Basel, Switzerland
[j] Basel Mobility Center, Department of Geriatric Medicine Felix Platter, Basel, Switzerland

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A B S T R A C T

Aim of this study was to test the reliability and validity of the life-space measures and walking speed delivered by the MOBITEC-GP app. Participants underwent several supervised walking speed assessments as well as a 1-week life-space assessment during two assessment sessions 9 days apart. Fifty-seven older adults (47.4% male, mean age= 75.3 (±5.9) years) were included in the study. The MOBITEC-GP app showed moderate to excellent test-retest reliability (ICCs between 0.584 and 0.920) and validity (ICCs between 0.468 and 0.950) of walking speed measurements of 50 meters and above and of most 1-week life-space parameters, including life-space area, time spent out-of-home, and action range. The MOBITEC-GP app for Android is a reliable and valid tool for the assessment of real-life walking speed (at distances of 50 metres and above) and life-space parameters of older adults. Future studies should look into technical issues more systematically in order to avoid invalid measurements.

Introduction

Mobility can be defined as "the ability to move oneself (either independently or by using assistive devices or transportation) within environments that expand from one's home to the neighbourhood and to regions beyond".[1] Thus, measures that describe a person's mobility should include tests of physical function and assessments of "life-space".[2–4]

Mobility is a key component of active and healthy aging. Age-related mobility limitations are associated with various adverse consequences such as cognitive decline,[5] physical disability,[6] falls,[7] loss of independence[8] and even mortality.[9] Thus, maintaining physical functioning throughout the lifespan plays an important role in preventing chronic diseases or preventing their progression.

A decline in mobility is detectable and should be discovered as early as possible in order to identify people at risk of negative health-related outcomes as it can still be stabilized or even reversed in early stages by targeted interventions.[10] To date, mobility assessments are largely dependent on self-reported or laboratory-based assessment tools and/or standardised field tests.[11] However, such assessments are either time or resource intensive and they do not cover all aspects of a person`s mobility, which besides physical function also includes the ability to move around in environments beyond the own four walls.[1]

Modern technologies such as the Global Navigation Satellite System (GNSS, including GPS and others) and inertial measurement units (IMUs) (including accelerometry) provide the ability to track

*Correspondence: Dr. Eleftheria Giannouli, Division of Sport and Exercise Medicine, Department of Sport, Exercise and Health, University of Basel, Grosse Allee 6, 4052, Basel, Switzerland
E-mail address: eleftheria.giannouli@unibas.ch (E. Giannouli).

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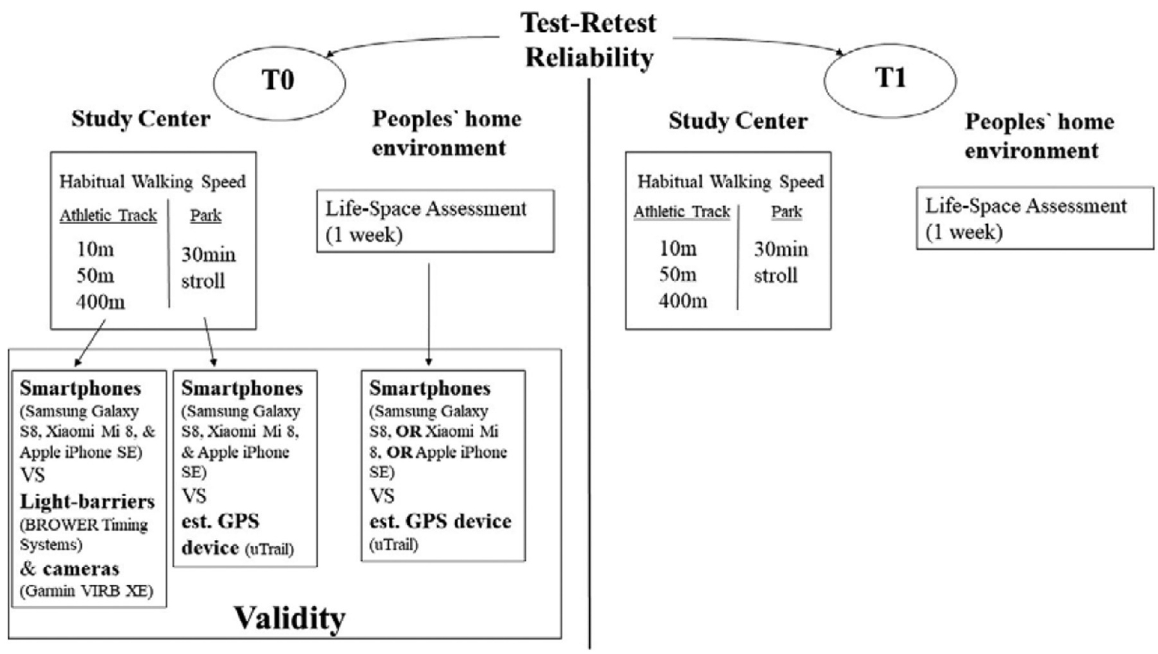

Fig. 1. Study Procedures.

the mobility of older individuals over time. Advantages of these measurement techniques are that the mobility of older people can be recorded in a real-life setting and in interaction with their environment, and that these technologies are nowadays embedded in every smartphone.

In order to allow older people and health care professional to make use of the possibilities offered by modern smartphones easy-to-use, valid and reliable applications for the conduction of mobility assessments in older adults' real life are urgently needed. We have recently developed a mobile application ("MOBITEC-GP app") that allows older adults as well as their General Practitioners (GPs) to quantify specific parameters of their patients` real-life mobility in everyday conditions and monitor mobility over time.[12] The MOBITEC-GP app allows collection of different mobility parameters related to physical function and life space. The aim of this study is to test the reliability and validity of the walking speed and life-space parameters assessed by the MOBITEC-GP app. It was hypothesized that – based on intraclass correlations coefficients (ICCs) and their 95% confidence intervals (CIs) – there would be evidence of: 1) reliability (test vs. retest); and 2) validity (app vs. light barrier or separate GNSS/IMU-device respectively) of MOBITEC-GP app-based measurements of walking speed and one-week life-space. It was also hypothesized that app-based walking speed measurements would be less valid and reliable for shorter compared to longer walks due to the expected GNSS error.

If found to be reliable and valid, the MOBITEC-GP app could be a useful tool for mobility assessment. Since older adults are increasingly using smartphones and mobile apps,[13,14] the app's mobility performance metrics could potentially be used for early risk detection not only by the older adults themselves but also their GPs and other healthcare providers.

Methods

Study design and procedures

This study is part of the iterative design followed within the Research & Development project MOBITEC-GP (MOBIlity assessment with modern TEChnology in older patients' real-life by the General Practitioner) (https://mobility.dsbg.unibas.ch/en/projects/mobitec-gp/). It was an observational study and included two assessment sessions (T0 and T1) (8 days apart) that took place in and around the premises of the study center as well as two one-week monitoring periods (T0 and T1) that started right after the assessment sessions (Fig. 1).

The Ethics Committee of Northwestern and Central Switzerland approved the project (Reg.-No. 2018–02257). Methods have been described in detail elsewhere.[12]

Participants

Recruitment

We targeted community-dwelling older adults (≥65 years of age) with two or more chronic health conditions as these are at higher risk for developing mobility limitations than their healthy counterparts.[15] In order to maximize our reach, we used a broad-based recruitment strategy. Potential participants were approached by study personnel in GP practices (affiliated with the Center of Primary Health Care, University of Basel) as well as through adult education centers clubs, service organizations for older adults, pharmacies, and churches. Furthermore, people who previously expressed interest in participating in studies of the corresponding author's institution were also approached.

Inclusion criteria

To be included in the study, participants had to live in their own homes, be aged 65 years or older and be diagnosed (self-report) with at least two of the following chronic diseases (according to the "Self-Administered Comorbidity Questionnaire" (SCQ)[16,17]): heart disease, high blood pressure, lung disease, diabetes, ulcer or stomach disease, kidney disease, anemia or other blood disease, cancer, depression, osteoarthritis, degenerative arthritis, back pain and/or rheumatoid arthritis. In addition, participants had to be able to perform a 30-min outdoor walk at their own pace, with or without breaks, with or without walking aid, but without the help of another person (self-report). All participants had to give informed consent.

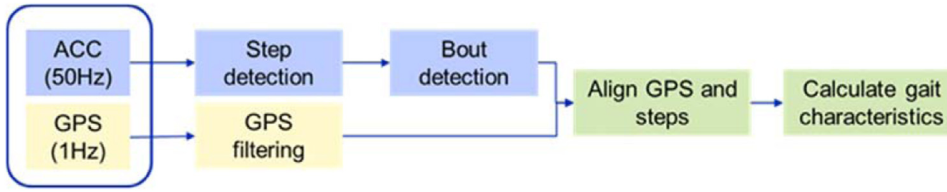

Fig. 2. Workflow for walking speed calculation.

Exclusion criteria

Persons who were incapable of judgment and persons who are unable to follow procedures or have insufficient knowledge of the German language were excluded.

Assessments

Walking speed assessment

At the study centre, participants performed three supervised walking tasks (10m, 50m, and 400m) at self-selected, habitual pace on an outdoors athletics track. During those walks, they were equipped with three different smartphone models (Samsung Galaxy S8, Xiaomi Mi 8, and Apple iPhone SE) on which the MOBITEC-GP app was installed and an additional GNSS/IMU device (uTrail, CDD Ltd., Athens, Greece). The walks were also videotaped (Garmin VIRB XE, Garmin Ltd., Olathe, KS, USA) and timed (light barrier system; BROWER Timing Systems, Draper, UT, USA). Afterwards, participants were asked to perform a stroll in a nearby park. No predefined track/trajectory was given. Participants were instructed to walk at a comfortable speed for 30 minutes and only take a break if they really needed to (e.g. due to fatigue and pain). While the light barrier measurements served as gold standard for the assessment of walking speed on the athletic track, the additional GNSS/IMU device (uTrail) served as gold standard for the assessment of the 30-minute stroll. The custom-built uTrail device has been used in previous studies of our group[18] and has shown good accuracy.[19]

Data processing and calculation of walking speed. For walking speed calculation (Fig. 2), the tri-axis acceleration from the accelerometer in the smartphone's IMU (sampling rate: 50 Hz) for move-stop detection by modeling steps and bouts was used. In the next step, the detected moves and stops from the accelerometer were assigned locations from GNSS by aligning timestamps.

For step detection, the algorithm by Pham et al., (2018)[20] was adapted. The algorithm relies on a set of hyperparameters for signal processing to identify the peaks of acceleration that occur when the foot treads on the ground. We used the manually counted steps in the supervised walks (10m, 50m, and 400m) as the validation set for model selection to find the best hyperparameter set that minimizes the difference of step counts for all walks. We then detected the bouts using the definition by Shah et al., (2021)[21] that each bout should have at least three steps with less than 1.25s between each step. Afterwards we modeled the location of each step by aligning their time with the GNSS records. The location of a step is the linearly interpolated location of its proceeding and succeeding GNSS points in time. After the alignment, we calculated the walking speed of each step in the modeled bouts and used their arithmetic average as the average walking speed for each walk. Stayings and trivial steps between two bouts were modeled as stops and were excluded from the calculating walking speed. This procedure was applied to data records of all walks in both supervised (10m, 50m, 400m) and semi-supervised (30-minute stroll) experiments.

Life-space assessments

For the one-week real-life mobility assessments each participant was given one of the three smartphone models mentioned above (chosen randomly) and a uTrail device. They were asked to carry the devices with them for 9 consecutive days whenever they went out of their home and charge them overnight. The devices logged GNSS data in the background with a sampling rate of 1 GNSS fix per second. The raw data consist of timestamp (in Coordinated Universal Time, UTC), longitude, latitude, and altitude. The data also contained measurement conditions such as the number of detected satellites for each GNSS fix. To avoid bias from including visits to areas that do not belong to participants` habitual mobility, the first and last recording days which included the lab visits were excluded from the analyses (resulting in an analyzed period of 7 full days). For the calculation of weekly life space measures, the median of the valid days was used for every participant.

Data Processing and calculation of life space metrics. To calculate life space metrics with GNSS data, there are several procedures including: (1) GNSS data preprocessing, (2) GNSS data quality and study day selection, (3) home validation, and (4) life space metric computation. In more detail:

(1) **Data preprocessing.** Raw GNSS data from four devices were preprocessed to transform the 'timestamp' attribute from the UTC time to local time zone and project geographic coordinates on a plenary coordinate system. Missing or erratic data points (e.g., GNSS points with erratic timestamp) were removed. As a result, the preprocessed GNSS data had a consistent format across GNSS data collected from different devices.
(2) **GNSS data quality and study day selection.** The number of GNSS recordings can fluctuate by day, device, and participant. This is potentially because of variable daily behaviors (e.g., sleeping hours; time spent indoors), the compliance rate of carrying GNSS devices, GNSS signal loss, or device failure.[22] To minimize biases induced by such different GNSS recording hours across study days, GNSS data quality was evaluated based on the minimum daily GNSS recording duration that is the time difference between the first and last GNSS fixes of a study day. For our analysis, we set the minimum GNSS recording duration of 9 hours per day to ensure that enough hours of day are recorded.[23] Only study days with more than 9-hour GNSS recordings were defined as a valid study day. To be a valid weekly session, a session had to contain at least three valid days.
(3) **Home validation.** To validate a home location of a participant, participant's home address location (self-reported) was compared to a home location detected from GNSS data. The self-reported home address was converted to geographic coordinates (i.e., longitude, latitude). In the GNSS data, the home location was detected by the density-based clustering algorithm, *DBSCAN*,[24] over the first and last GNSS fixes of each day. For further analysis, the home location with more GNSS points was selected.

(4) **Life space metric computation**. Five life space metrics listed below were calculated for each valid one-week session with at least three valid study days. First of all, the metrics were computed at a day level for each valid study day, and then, those daily metrics were aggregated for each one-week session by computing summary statistics of median, mean, and standard deviation. For validity and reliability analyses in this study, the median was used.

Among various aspects of life space mobility (e.g.[25]), we focused mainly on the spatial extent and time duration of daily activities and chose five life-space metrics for evaluation:

Time out of home. Time spent out of home (hours) is defined as the sum of time durations between all consecutively recorded out-of-home GNSS fixes. Home range is defined as a surrounding area by the radius of 150 meters from a verified home location.[26] The out-of-home GNSS fixes are all GNSS fixes not belonging to the home range. In our computation, we interpolated time gaps up to one hour between those subsequent out-of-home GNSS fixes.[25]

Total distance travelled. Total distance travelled (km) is the sum of Euclidean distances between all the subsequent GNSS fixes projected in a planer coordinate system. The 'total distance travelled' derived from GNSS traces could be higher than one's actual travel distance due to GNSS signal noise,[27] so GNSS outliers were filtered out by the maximum speed threshold (i.e., 250 km/h) in data preprocessing.

Maximum distance to home. Maximum distance to home from GNSS fixes (km) is the maximum Euclidean distance between all GNSS fixes and home location in a planer coordinate system. The 'maximum distance to home' is a measure of spatial extent that quantifies how far from home one reaches within a given time frame (e.g., day, week), similar to traditional life space questionnaire.[28] With GNSS tracking, such metric can be measured more precisely and accurately.

Area of convex hull. Area (km^2) of convex hull enclosing all GNSS fixes (Fig. 2). The convex hull is defined as the smallest convex set enclosing a set of the points and represented as a polygon linking the outermost points with inner angles less than 180 degrees.[29] The further one travels from home with more diverse direction from home, the larger the area of convex hull.

Area of standard deviational ellipse. Area (km^2) of two-dimensional ellipse defined by one standard deviation (SD) of GNSS point coordinates (Fig. 3). The ellipse contains approximately 63% of GNSS points within its boundary.[30] Similar to the 'area of convex hull', if one travels to places further away from home and in more varying directions from home, the 'area of standard deviational ellipse' may get larger. However, the 'area of standard deviational ellipse' is affected also by the distribution and density of GNSS fixes over geographic space. If the GPS fixes are concentrated in some area (e.g., residential neighborhood area), only a few GNSS fixes very far away from home can be treated as outliers and make little impacts on the shape of standard deviational ellipse.

Assessment of participant characteristics

Basic socio-demographic data (age, sex, years of education, type of residential area, living situation, use of walking aids, fall incidence, comorbidities, and engagement in sporting activities) were assessed by self-report. Subjective limitations and restrictions on individuals' activities and participation in society was assessed using the World Health Organization disability assessment schedule 2.0 (WHODAS 2.0).[31] Gait Efficacy was assessed using the German Version of the Modified Gait Efficacy Scale (mGES).[32] Weight and height were measured by an assessor, body mass index (BMI) was calculated.

Data analyses

Analyses

Participant characteristics were analyzed descriptively.

Test-retest reliability was assessed by calculating Intraclass Correlation Coefficients (ICCs)[33] and 95% confidence intervals (CIs) between the smartphone-derived metrics of T0 and T1.

Validity of the GNSS/IMU-based measurements was assessed by calculating Intraclass Correlation Coefficients (ICCs) (McGraw & Wong, 1996) and 95% Cis between the smartphone-derived metrics and the gold standard metrics collected at T0.

All statistical analyses were performed using SPSS version 28.

Results

Descriptive statistics

Fifty-seven participants were included in the study. No participants reported having major troubles handling the mobile devices during the 2 weeks of ambulatory mobility assessments and there were no adverse events during the laboratory-based and the outdoor assessments. Regarding home validation, in 60% of the cases the difference between address-based and GNSS-based home location was less than 20 meters.

The vast majority of the participants (47.4% male) lived in urban (67%) or suburban (25%) residential areas and 70% of them lived with

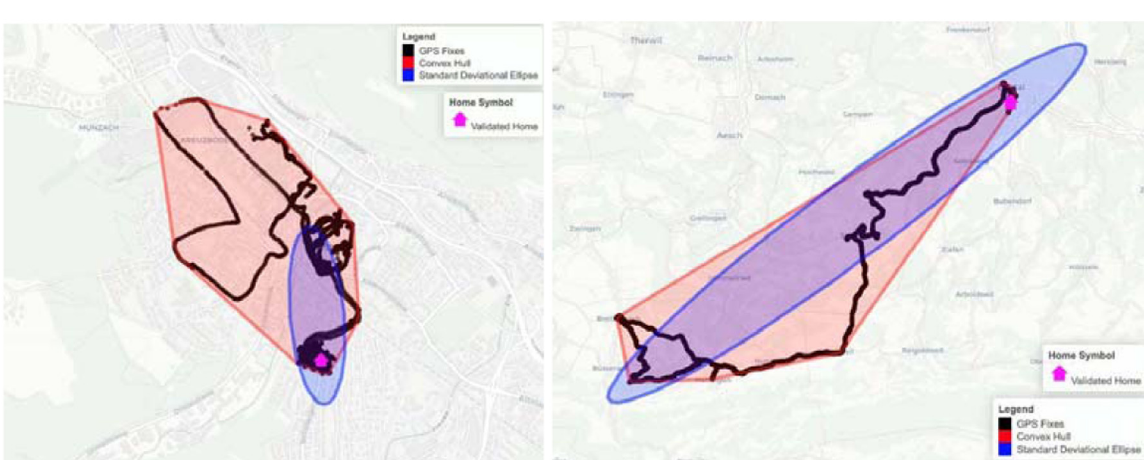

Fig. 3. Illustration of the GNSS traces, the area of convex hull and the area of standard deviational ellipse of a sample participant on two separate days (left: smaller life space; right: larger life space).

Table 1
Participant characteristics (n=57)

	Mean	SD	Min.	Max.
Age	75.3	5.9	66	90
Education (years)	14	3.8	7	26
BMI	27.2	4.0	20.5	40.1
Modified Gait Efficacy Scale Score [32]	90.1	11.9	48.0	100.0
WHODAS Questionnaire (Simple Score) [31]	15.8	3.8	12.0	28.0

Table 2
Descriptive data from the supervised walking speed and one-week life-space assessments

	Mean	SD	Min.	Max.
Walking speed [a]				
10m straight distance (m/s)	1.37	0.24	0.26	1.72
50m straight distance (m/s)	1.41	0.26	0.02	1.75
400m oval distance (m/s)	1.43	0.21	0.86	1.74
1-week life space [b]				
Time out-of-home (h)	2.84	1.14	0.44	4.75
Total distance (km)	52.78	26.33	16.31	102.12
Action range (km)	9.45	9.35	0.53	31.21
Convex hull perimeter (km)	22.93	20.90	1.78	71.51
Convex hull area (km^2)	51.66	89.23	0.22	382.77
Standard deviation ellipse area (km^2)	23.65	41.80	0.04	191.21

[a] measured at T0 by gold standard (light barrier system)
[b] measured at T0 by gold standard (established GNSS/IMU device (uTrail))

at least another one person in the same household. Only three participants used walking aids and only thirteen of them experienced a fall in the last 12 months. Though all of them had at (mean age 75.3, SD 5.9; range 66-90) least two chronic diseases (self-report) (arthritis and back-pain being the most prevalent), the majority of them (83%) engaged in regular sporting activities (self-report) and had no major functional mobility limitations as measured by standard questionnaire-based geriatric tests (Table 1). Further descriptive data from the supervised walking speed assessments as well as the one-week life-space assessments are presented on Table 2.

The location data provided by the iPhone did not include a timestamp from the satellites, making it impossible to reliably synchronize location data with IMU data and thus gait-analysis cannot be performed correctly. For this reason, the iPhone data were not analyzed further and the MOBITEC-GP app at the current stage only runs on Android.

Reliability analysis

Based on the ICCs (Tables 3 and 4), the test-retest reliability was moderate to excellent for the walking speed measurements during walks of 50m and above and moderate to good for the life-space parameters.[34]

Validity analysis

Results of the validity analysis for the assessment of walking speed (average walking speed as assessed using the smartphones versus ground truth as assessed by light barriers) are shown in Table 5. Similar to the results of the reliability analyses, walking speed assessments using the mobile application on short distance (10m) had an insufficient validity while validity for the longer distances (≥ 50m) was good to excellent, with the Xiaomi showing somewhat better validity than the Samsung device.

With the validation criteria for the calculation of life space parameters mentioned in the methods section, the total number of “valid” days were 585 (372 for the first week and 213 for the second week) and the number of “valid” one-week sessions for each device was 24 (85.7%) for Samsung, 29 (72.5%) for Xiaomi, and 26 (49.1%) for the uTrail.

Validity of spatial mobility measures was assessed using ICCs and 95% CIs between measures from the smartphones and from the uTrail devices, which served as the gold standard for these measures (Table 6). Except total distance, all other life-space measures showed good to excellent validity.

Table 3
Test-retest reliability (ICCs and 95% Cis) for average walking speed measures assessed by the mobile application

Walking distance/duration	n	ICC	95% CI
10m, Samsung	32	0.240	0 – 0.522
10m, Xiaomi	39	-0.183	0 – 0.121
50m, Samsung	32	0.691	0.454 - 0.836
50m, Xiaomi	35	0.595	0.336 – 0.771
400m, Samsung	19 [§]	0.848	0.636 - 0.939
400m, Xiaomi	16 [§]	0.713	0.345 – 0.890
30-minute stroll, Samsung	42	0.735	0.559 - 0.848
30-minute stroll, Xiaomi	40	0.920	0.854 - 0.957

[§] Smaller n caused by technical problems with the camera system

Table 4
Test-retest reliability (ICCs and 95% Cis) for life-space measures assessed by the mobile application (n=27)

Life-Space Parameter	ICC	95% CI
Time Out-of-home	0.636	0.339 – 0.816
Total Distance	0.584	0.276 – 0.787
Action Range	0.745	0.512 – 0.847
Convex Hull perimeter	0.725	0.480 – 0.864
Convex Hull Area	0.652	0.367- 0.825
Standard Deviation Elipse Area	0.825	0.653 – 0.916

Table 5
Validity (ICCs and 95% Cis) of walking speed measurement by the mobile application (app vs. light beams)

Walking distance, smartphone model	n	ICC	95% CI
10m, Samsung	39	0.359	0 – 0.626
10m, Xiaomi	49	0.082	0 – 0.274
50m, Samsung	40	0.809	0.667 – 0.894
50m, Xiaomi	47	0.720	0.396 – 0.861
400m, Samsung	29	0.468	0.136 – 0.708
400m, Xiaomi	28	0.928	0.735 – 0.973

Table 6
Validity (ICCs and 95% Cis) of life-space measures (app vs. uTrail devices) (n=19)

Life-Space Parameter	ICC	95% CI
Time Out-of-home	0.535	0.110 – 0.792
Total Distance	0.346	0 – 0.685
Action Range (average)	0.875	0.703 – 0.950
Action Range (maximum)	0.793	0.541 – 0.915
Convex Hull perimeter	0.845	0.641 – 0.937
Convex Hull Area	0.950	0.846 – 0.980
Standard Deviation Elipse Area	0.639	0.353 – 0.870

Discussion

The aim of this study was to examine the test-retest reliability and validity of the newly developed MOBITEC-GP app. The results establish the app`s reliability and validity for walking speed assessments in trajectories over 50m and life-space measures over one week with moderate to good correlations between repeated measures as well as between the app and gold standard measures.

Due to the expected GNSS error[27] and the modeling results on the walking distance and the walking speed of the empirical experiments (Table 2 and Table 4), neither reliability nor validity were sufficient for shorter (10m) trajectories.

Similar to other studies looking into walking speed as measured by smartphone GNSS,[35] we found good test-retest reliability for walking speed in 50m and 400m trajectories as well as in unsupervised strolls over 30 min. The intraclass correlations coefficients for gait speed reported by Obuchi et al., (2018) (ICC=0.902, CI: 0.872−0.926) are almost identical to the results of our study (ICC=0.920, CI=0.854 - 0.957) using the Xiaomi Mi8 and somewhat lower to values using the Samsung Galaxy S8 (ICC=0.73, CI=0.559-0.848) during the 30-minute stroll. Interestingly, reliability of walking speed increased with increased trajectory length (ICC of 0.595 for the 50m length trajectory to 0.920 for the 30min stroll), which is in line with previous findings suggesting increasing reliability of gait speed assessments with increasing number of gait cycles.[36] Moderate to good reliability values were also found for the life-space mobility metrics, which is in line with a recent systematic review reporting on questionnaire-based life-space mobility tools.[37]

Validity results were similar to the reliability ones. Shorter trajectories (10m) do not allow valid assessments of walking speed as measured by GNSS, which again is caused due to the high GPS error but results for the 50m and the 400m long trajectories showed in average good validity results. Total distance and time out-of-home seem to be the least valid life-space metrics compared to area-based measures; e.g. convex-hull area which showed excellent validity (ICC=0.95, CI=0.846 − 0.980). These associations are partly higher than validity values reported on previous research.[38] This may have to do with the comparison tool used. In the study by Ho et al., (2020), the GPS-based metrics were correlated with questionnaire-based assessments of life-space mobility (which are known to produce e.g. recall bias or social desirability bias) whereas in our study an objective tool (uTrail) was used.

The MOBITEC-GP app is, to our knowledge, the first app especially designed for older adults to enable tracking of life-space mobility and walking speed. Though most of the app`s metrics were found to be reliable and valid, there are some limitations to be considered. First, the strict criteria applied for the selection of valid days (at least 9 hours of GNSS recordings) per participant as well as some technical issues with some of the devices (camera system broke down during the supervised assessments and having to drop all iphone data) resulted in conducting the validity analysis which smaller sample size, which might have caused bias. Invalid life space measurements may limit the feasibility of using the app in real-life settings. Despite using a broad-based recruitment strategy; the selected sample may not be representative of the general population of this age group. Future studies should look into technical issues more systematically in order to avoid invalid measurements.

Before the measured real-life parameters can be used and interpreted in a clinically meaningful way, their predictive value for health-related outcomes (e.g. falls, hospitalization, mobility disability and nursing home admission) has still to be shown. In addition, clinical cut-off values as well as minimal clinically significant and smallest detectable change have to be determined in order to timely identify those in need for an intervention and to personalize interventions. Studies have shown that reliable and valid tools do not always show good acceptability.[39] especially by populations such as older adults. Therefore, future studies should also assess the usability and acceptability of the MOBITEC-GP app by both target groups the app addresses; older adults as well as GPs.

Ethics approval and consent to participate

The study was conducted according to the principles of the Declaration of Helsinki. The Ethics Committee of Northwestern and Central Switzerland (EKNZ) approved the project (Reg.-No. 2018-02257). All participants had to provide written informed consent.

Consent for publication

Not applicable.

Availability of data and material

Data are available from the corresponding author on reasonable request. The MOBITEC-GP app can be requested here: https://mobility.dsbg.unibas.ch/en/resources/mobitec-gp-app/

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Authors' contributions

TH (Principal Investigator), RW, AZ, HH, DI, AST, EP and TR conceptualized the study. EKK processed the GNSS data and calculated and visualized life-space metrics. CF processed the IMU data and conducted the walking-speed calculations. AS programmed the app. EG oversaw data collection, and conducted the statistical analysis. EG, EKK, and CF drafted the first version of the manuscript. All authors critically revised and approved the final version of the manuscript.

Declaration of interest

None.

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