Data quality of travel behaviour studies: factors influencing the reporting rate of self-reported and GPS-recorded trips in persons with disabilities

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DATA QUALITY OF TRAVEL BEHAVIOUR STUDIES:
FACTORS INFLUENCING THE REPORTING RATE OF SELF-REPORTED AND GPS-RECORDED TRIPS IN PERSONS WITH DISABILITIES

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ABSTRACT
In persons with disabilities, the accuracy of self-report data collection methods in travel behaviour studies may be influenced by disease-related dysfunctions. The present study determines in detail whether disease-related physical, cognitive or psychosocial impairments contribute to the reporting rate of subjective self-report travel diaries and objective GPS tracking devices, besides socio-demographic and trip-related characteristics. The reporting rate of both data collection methods was analysed in 108 persons with Multiple Sclerosis with various disability severities during a seven days data collection period. The results demonstrated that there was only limited influence of disease-related dysfunctions on the reporting rate of both data collection methods, as well as only limited significant differences between subgroups with various disability severity. Overall, the data quality of the diary was higher than the quality of the GPS data: 66% of the trips were reported in both data collection methods, while overall more than one fifth of all trips were forgotten to be registered by GPS, and 11% were forgotten to be reported in the diary. Self-report travel diaries seemed to be more suitable for persons with a higher disability severity, as these persons more often forgot to take their GPS device with them when making a trip due to a number of organizational issues because of their mobility limitations.

1 INTRODUCTION

Physical activity (PA) levels are often measured in order to identify current levels and changes in PA of specific population groups, and to evaluate the effectiveness of interventions designed to increase activity levels *(1)*; which is an important part of health promotion research *(2)*. The measurement method may have a significant impact on the observed PA levels, as self-report PA measures generally differ with direct, objective measures of PA *(1)*. While self-report methods like questionnaires, interviews or diaries are often preferred as they are cheap to administer and offer additional information on the context of activities, objective measurement devices like pedometers or accelerometers provide more accurate measurement of PA and are not prone to certain biases in self-report methods such as recall bias *(3)*. Especially in research studies of persons with disabilities (PWD), the accuracy of self-report surveys for measuring PA can be influenced by cognitive dysfunctions like memory or emotional problems *(4)*. Commonly used activity questionnaires and diaries rely on recall and honest reporting, and require individuals to have no or limited cognitive deficits to reduce potential bias in reporting results *(5)*. According to research conducted by *(6)*, *(7)* and *(8)*, self-report subjective PA questionnaires show only limited reliability and validity regarding the frequency of different activity types (e.g. respondents tend to indicate their highest recent frequency of participation) and the duration and amount of PA. On the other hand, data of objective monitors as well may sometimes yield incomplete data, e.g. because participants may forget to wear their monitors, or because external device limitations such as low battery life, signal interference or malfunction *(9)*.

Recently, travel behaviour studies have been increasingly used in public health studies to assess PA levels, as interventions to encourage car use and substitute active travel alternatives are motivated by concerns to improve health through increased PA *(10)*. In this respect, traditional travel behaviour studies make use of self-report activity-related travel diaries, typically requiring participants to provide information about activity purpose, travel mode, start and end time, location of trip origin and destination, and company of the trip. Over the past decade, recent advances in GPS technology and mobile positioning data have resulted in supplementing (and sometimes replacing) of conventional paper self-report activity-related travel diaries as a collection method with GPS tracking devices to record travel behaviour *(11-14)*. In the context of health promotion, accurate measurement of travel behaviour by means of this combination of self-report and objective estimates allows e.g. a detailed assessment of the time spent using active modes of transport *(15)*, or the classification of accelerometer-derived PA bouts into walking behaviour *(16)*.

Similar to problems with self-report PA questionnaires, it has been documented previously that traditional travel behaviour survey data suffer from incompleteness and inaccuracies of reported trips *(17)*, because of the detailed required trip-level information. Under-reporting of trips in travel studies has being documented by comparing self-reported trips with travel data collected by GPS tracking devices, to identify those trips recorded in the GPS data that were not reported by respondents in the travel diaries. A number of key *demographic factors* were found *(18-21)* to significantly contribute to the misreporting of trips: younger respondents, men, individuals with a lower educational degree, unemployed individuals, low-income households, households with ≥ 3 vehicles, or households with ≥ 3 workers, were more likely to under-report their trips. As well, *trip-related characteristics* were found to significantly influence trip under-reporting *(22)*. Short duration activities or trips, discretionary trips, trips made at the end of the travel day, among others, were more often forgotten or omitted in paper travel diaries *(17, 20, 23)*. Individuals who made many trips in one day, were also more likely to underreport their travel *(24)*.

On the other hand, there are also some (but fewer) studies that focused on situations, and/or associated factors, where fewer trips were recorded by GPS tracking devices than as reported in the travel diary. Missing data with GPS devices may encounter device limitations such as signal drop insides buildings or low battery life; as well as user errors like forgetting carrying the device *(9)*. Previous studies showed that trips occurring before respondents went to work, or after they left work; as well as trips on Saturday or Thursday, were more often forgotten to be recorded by GPS *(25)*.

While there are studies available comparing diaries and GPS tracking for the estimation of travel behaviour of healthy persons, there is relatively little research available about the *reliability of travel behaviour studies in PWD (26-28)*. It may be expected that the accuracy of self-report data collection methods in travel behaviour studies of PWD may be influenced by disease-related cognitive dysfunctions as well, e.g. because of problems remembering (details of) all performed trips.

Therefore, the present study contributes to the field by determining in detail whether *disease-related physical, cognitive or psychosocial impairments* also contributed significantly to changes in reporting in activity-related travel diaries and recording by GPS tracking devices by PWD.

Participants of this study were diagnosed with Multiple Sclerosis (MS), a progressive inflammatory and neurodegenerative chronic disease of the central nervous system, and had a various degree of disability. As MS is characterized by a combination of physical, cognitive and psychosocial symptoms, the cognitive status of persons with MS (PwMS) may interfere with its ability to accurately recall and report the locations, distances, and frequencies of her/his community mobility *(4)*. In MS, cognitive impairment occurs in 40-65% of its patients *(29)*. In this study, the differences between both travel behaviour data collection methods (travel diaries and GPS tracking devices) were analysed during a seven days data collection period. A large number of both physical, cognitive and psychosocial function tests were included, to investigate their specific and relative impact to the misreporting. The study is part of a large-scale research about influencing factors in travel behaviour in MS.

2 METHODOLOGY

2.1 Participants

There were 108 persons with clinical definite MS who gave written informed consent and participated. The study was approved by ethical committees of Hasselt University, Antwerp University Hospital and National MS Centre Melsbroek. PwMS were recruited based on databases of the REVAL Rehabilitation Research Center, by neurologists of the rehabilitation centers, and after information sessions in an MS-specialized fitness center and support groups of MS Society Flanders. PwMS were included if they made minimal one trip weekly, and were excluded if they were bedridden, or had a relapse or related corticosteroid treatment within one month before the study.

Participating PwMS were further divided in three subgroups, according to their Disease Steps (DS) *(30)* describing ambulatory dysfunction. The DS is a simple brief clinical rating scale, based on a general physical examination and the assistive devices needed to walk 25 feet (7.62 meters). Persons in the ‘mild’ subgroup (DS $\leq$ 2, n=51) experienced no to mild limitations or might have a visible abnormal gait, but did not require ambulation aids. Persons in the ‘moderate’ subgroup (DS 3-4, n=27) required intermittent or continuous unilateral support to walk more than 25 feet; while persons in the ‘severe’ subgroup (DS 5-6, n=30) required bilateral support or were confined to a wheelchair.

The division in subgroups was based on ambulatory (physical) dysfunction, because it was shown previously that changes in activity and travel behaviour in MS were (mainly) related to increasing ambulatory dysfunction *(26)*. Hereby, it was possible to examine the influence of trip-related factors (e.g. number of trips) on the reporting rate; as well as to determine to what extent the agreement between objective GPS devices and self-reported diaries would differ between disability status. Socio-demographic characteristics of PwMS by subgroup are summarized in table 1 (missing socio-demographic data of 1 PwMS in mild subgroup).

INSERT TABLE 1

2.2 Experimental Design and Outcome Measures

A detailed overview of the experimental design can be found in Neven et al. *(26)*. During the first individual contact moment with the PwMS, measures of physical, cognitive and psychosocial functioning were taken. Socio-demographic data was collected by means of a questionnaire, and activity-related travel behaviour measures were thoroughly explained. Then, during 7 consecutive days, activity-related travel behaviour was measured by completing a travel diary and wearing a GPS logger. These devices were additionally explained in a self-written manual and a permanent helpline was available. In the second meeting, the self-report indices and the GPS logger were returned.

2.2.1 Travel Behaviour Outcome Measures

Both subjective self-reported activity-related travel diaries and objective GPS tracking devices were used to obtain a comprehensive understanding of the activity-related travel behaviour of PwMS. In the diaries, persons had to indicate all information about their outdoor activities (e.g. activity type, start time and location) and resulting trips (e.g. travel mode and company). Participants were asked to carry out the GPS logger for each outdoor trip in a handbag or trouser pocket, by which the current location could be determined and saved in memory. The GPS logger, 747Pro 66-Channel GPS Trip Recorder with motion sensor (TranSystem Inc.) allowed obtaining more accurate information about travelled routes, as well as detecting trips that were not filled out in the travel diaries (see further for the description of detecting trips by GPS). A trip means an outdoor displacement which is identified by a clear activity motive (e.g. working), and can consist of one or several travel modes.

Activities were divided in one of the following categories: working/education, shopping/ services, social (e.g. visiting friends), leisure (e.g. hobbies), bring or get activities (bringing or getting relatives or things to somewhere), personal care (e.g. rehabilitation and doctor), other (not belonging to one of the previous) and home activities. Walking (either independently or using any assistive device), driving or cycling around without destination was also seen as a trip, and was classified as 'travelling'. The outcome measures that were analyzed in this study were: research day, week day, departure time, trip duration, activity type, transport mode, planning of trips, chain of trips.

2.2.2 Clinical Outcome Measures
Clinical characteristics of PwMS by subgroup are shown in table 2. Physical, cognitive and psychosocial functions were assessed in order to investigate their specific and relative impact on the reporting rate of the data collection methods in patient profiles with various disability severity. The multidimensional *Multiple Sclerosis Functional Composite* (MSFC) measured the ambulation/leg function by the Timed 25-Foot Walk test (T25FW), the arm/hand function by the 9-Hole Peg test (9HPT) and cognition by the Paced Visual Serial Addition Test (PVSAT) *(31)*.

Physical functioning:
- *Timed 25-Foot Walk test* (T25FW): measured the time PwMS needed to walk 25 feet as quickly as possible, using their usual assistive devices *(31)*.
- *Multiple Sclerosis Walking Scale* (MSWS-12): measured the impact of MS on walking ability by means of a questionnaire consisting of 12 items *(32)*.
- *9 Hole Peg test* (9HPT): measured the time PwMS needed to put nine pegs in holes in a plastic board, and remove them again *(31)*.
- *36-item Short-Form Health Survey* (SF-36): measured the self-reported health related quality of life (QoL), resulting in a physical health summary score *(33)*.

Cognitive functioning:
- *Paced Visual Serial Addition Test* (PVSAT): measured working memory, arithmetic capabilities and attention, by which PwMS were shown a number every three seconds and asked to say aloud the sum of the second last *(31, 34)*.
- *Trail Making Test* (TMT): measured visual attention and task switching by recording the time PwMS needed to connect 25 consecutive dots on a sheet of paper (numbers in part A, numbers and letters in part B) *(35)*.

Psychosocial functioning:
- *Modified Fatigue Impact Scale* (MFIS): measured the impact of fatigue on daily functioning *(36)*.
- *Hospital Anxiety and Depression Scale* (HADS): measured the level of depression and anxiety *(37)*.
- *Frenchay Activities Index* (FAI): measured instrumental activities of daily living which required some initiative from the patient in the last three and six months *(38)*.
- *36-item Short-Form Health Survey* (SF-36): measured the self-reported health related QoL, resulting in a mental health summary score *(33)*.

In table 2, values are presented as mean ± SD (range). Ns means not significant. Upward arrows indicate better performance with higher scores (e.g. a higher score on T25FW (m/s) means that the participant has a better ambulation/leg function); while downward arrows indicate worse performance with higher scores (e.g. a higher score on MSWS-12 means that the participant experiences more (negative) impact of MS on his walking ability).

INSERT TABLE 2

2.3 Data Processing and Statistical Analysis

As a first step, the data of the travel diaries were implemented in a database in Access. Next, all individual trips were manually compared by the researcher, by viewing the GPS traces of participants in the geographic information system software package ArcGIS and visually comparing them with the information from the travel diary (i.e., the data which was inserted in the database). If the trip was forgotten in the diary (and thus not in the database), the database was complemented with the trips detected by the GPS data. As such, the final database consisted of all trips made during the data collection period. Every trip was labelled if it was either (i) registered in the diary alone, (ii) by means of the GPS tracking device alone, of (iii) by both data collection instruments. If a trip was forgotten by both instruments (e.g. a homewards trip) but could be logically deduced (e.g. if the next trip again started from the home location), it was complemented in the database as ‘forgotten by GPS and diary’. Other examples of these discovered trips are a trip starting at location C, while the previous trip was from location A to location B (in this example the trip B-C was forgotten); or if the first trip of the day started from the work location while the person arrived home the day before (in this example the trip home-work was forgotten).

Numerical data were analyzed using SPSS Statistics ($p < 0.05$). Descriptive analyses were used for the questionnaires and travel diaries. The Shapiro-Wilk test indicated non-normal distributions of most variables and therefore, non-parametric Kruskal-Wallis analysis of variance (anova), and post-hoc Mann-Whitney tests for independent samples were used to examine differences between MS subgroups (e.g. ‘Is the reporting rate by GPS better in the mild subgroup compared to the moderate subgroup?’). The Wilcoxon test was applied to determine differences in outcome measures for each data collection method (e.g. ‘Was research day 1 better filled in in the diary than research day 2?’). Bivariate Spearman correlation coefficients were calculated to assess the level of association between variables, by which a correlation was considered as poor (<0.30), low (0.30-0.50), moderate (0.50-0.70), high (0.70-0.89), and very high (>0.90). Multiple regression analyses with a stepwise selection procedure were performed to determine the most predictive outcome measures for the reporting rate of the travel diary and the GPS. Multicollinearity was checked for all models.

3 RESULTS

3.1 Differences Between MS Subgroups: Clinical Characteristics

Table 2 shows that the overall significant disparity among MS subgroups justified the selected DS cut-off scores 2 and 5 for differentiating between patients with various ambulatory dysfunction. Significant differences were found in disease duration, MSFC, all physical and cognitive functioning measures outcomes and almost all outcomes on psychosocial functioning measures; meaning that the moderate, and especially the severe MS subgroup, suffered more from physical, cognitive and psychosocial symptoms than the mild MS subgroup.

3.2 Baseline Results: Reporting Rate of Data Collection Methods

The 108 individuals reported a total of 2562 trips in their diaries, while the GPS tracking devices carried by these individuals recorded a total of 2311 trips. In general, 71 individuals (66%) reported more trips in the diary than were detected by GPS; 8 individuals (8%) reported the same number of trips in both data collection methods; and 28 individuals (26%) reported fewer trips in the diary. More information about the travel behaviour (in terms of number of trips, modal split, activities, etc.) can be found in *(26)*.

Table 3 shows that the majority of trips (66%) were reported in both data collection methods. In general, more than one fifth of all trips (21%) were only reported by diary and thus forgotten to be registered by GPS (e.g. forgotten to carry or to switch on the GPS); compared to 11% of trips that were only registered by GPS and thus forgotten to be reported in the diary. Overall, as well as across MS subgroups, the data quality of the diary was higher than the quality of the GPS data. In the severe MS subgroup, more trips were forgotten to be registered by GPS, while no significant difference was found between subgroups. Values are presented as mean % ± SD (range), and ns means not significant.

INSERT TABLE 3

3.3 Reporting Rate of Data Collection Methods Across Research Days and Travel Outcome Measures

Wilcoxon signed-rank tests were applied to determine if the travel outcome measures influenced the reporting rate of the different data collection methods. Figure 1 shows that trips were less registered by GPS on the first research day compared to the next days, which appeared to be significant (Wilcoxon signed-rank test, $p < 0.05$). There were no significant differences between reporting on weekdays or weekend days, neither in the diary nor by GPS. Registration by GPS was more often forgotten in trips in the afternoon (16h-20h) compared to other time periods, in trips of short trip duration (< 10min) compared to longer trip durations, and in trips that did not occur as part of a trip chain. Reporting in the diary was less complete in home-wards trips compared to other activity types, and in trips by bicycle or public transport compared to trips by car. It is possible that home-wards trips were more often forgotten because participants forgot that return home trips were also part of their outdoor activities. Trips by bicycle or public transport may be forgotten because they were more often part of a travel chain (by which participants may have forgotten to indicate all travel modes used). The planning of the trips did not influence the reporting rate of the data collection methods.

INSERT FIGURE 1

3.4 Reporting Rate of Data Collection Methods by Travel Outcome Measure and MS Subgroup

Table 4 shows the reporting rate per outcome measure, indicating only limited significant differences between MS subgroups. Persons with mild MS more often forgot to carry their GPS device for short trips or for single trips, compared to other subgroups. As well, they more often forgot to report trips in the morning (6h-12h), trips as car passenger and spontaneous trips, in their diary. On the other hand, persons with mild MS better reported their leisure trips in both data collection methods compared to other subgroups. Persons with severe MS better reported trips in the morning and afternoon in their diary, and reported their trips as car passenger better compared to the other subgroups. There was no difference between the reporting rate of MS subgroups regarding the research day or the type of day (weekday versus weekend day). It was notable that none of the work or educational trips was forgotten to be filled in the travel diary in none of the subgroups. In the table, values are presented as mean ± SD (range), and ns means not significant.

INSERT TABLE 4

3.5 Influencing (Disease-related) Clinical, Socio-demographic and Trip-related Factors

Table 5 shows the correlation coefficients between the reporting rate of both data collection methods, and clinical, socio-demographic and trip-related outcome measures by MS subgroup. Within the total sample, associations with clinical measures were absent for both data collection methods. In the mild MS subgroup, persons with a higher MSFC (lower overall disability severity) score better filled out their travel diary. In the moderate MS subgroup, there was a lowly positive correlation between the DS and the reporting rate of the GPS, while the T25FW correlated negatively moderate. Persons in the moderate MS subgroup who had more ambulatory (walking) problems, seemed thus to register their trips better by GPS. There was a low correlation between the physical component of the SF36 in the severe MS subgroup and the reporting rate of the diary, indicating that persons with severe MS who experienced a higher (physical) QoL, worse reported their trips in the diary.

Regarding the socio-demographic factors, the educational level correlated poorly with the reporting rate of the diary within the total sample, and moderately in the moderate and severe MS subgroup. Persons with a higher educational level seem to better report their trips in the diary. The work situation was positively associated with the reporting rate of the diary (PwMS who worked better filled out their diary), while the household size seemed to correlate negatively (PwMS with a larger household size filled out their diary worse). In the moderate MS subgroup, the registration of trips by GPS was positively influenced by a higher age. Overall, PwMS who performed more trips reported their trips worse in their travel diary. In the mild MS subgroup, planned trips were reported better in the diary but however, worse registered by GPS. The correlation coefficients between trips by public transport and the reporting rate of the GPS were dissimilar between the subgroups. However, it should be noted that a bad registration by GPS when travelling by public transport, can also be due to external factors like signal interference (e.g. in trains). In the table, significant correlations coefficients are indicated with * if $p < 0.05$ and with † if $p < 0.01$. Ns means not significant.

INSERT TABLE 5

Results of the multiple regression analyses, performed with the total sample and the subgroups separately, are presented in table 6. Overall, the models better explained variability in the mild subgroup regarding the reporting rate of the diary, and in the moderate subgroup regarding the reporting rate by GPS (respectively 57.7% and 38.6%), which were the models with as well clinical variables as significant predictors. In the mild MS subgroup, the overall disability severity (MSFC) and trip-related factors like the share of planned trips and trips performed as car passenger, determined the reporting rate of the diary. In the moderate MS subgroup, the reporting rate by GPS was influenced by the perceived QoL (SF-36) and the age of the participants. Within the total sample, only trip-related factors were of importance; while clinical or socio-demographic factors did not contribute in explaining the variability regarding the reporting rate of the diary. In the table, R^2 is predictive value, β is estimate, SE is standard error and t is t-value. Significant regression coefficients are indicated with * if $p < 0.05$ and † if $p < 0.01$.

INSERT TABLE 6

4 DISCUSSION

The present study investigated the influence of disease-related physical, cognitive and psychosocial characteristics, besides socio-demographic and trip-related variables, on the data quality of different data collection methods in a travel survey in PWD (more specific PwMS). This study demonstrated that there was only limited influence of clinical variables on the reporting rate (and associating data quality) of subjective travel diaries and objective GPS tracking devices, as well as only limited significant differences between subgroups with various disability severity. 66% of the trips were reported in both data collection methods, while overall more than one fifth of all trips were forgotten to be registered by GPS, and 11% were forgotten to be reported in the diary.

Within the total sample, it was interesting (but unexpected) that no clinical variable correlated with the reporting rate of neither the travel diary nor the GPS device. Since there was overall significant disparity among subgroups regarding the cognitive tests (table 2), we expected more potential bias in reporting results by PwMS with severe dysfunction. Persons in this subgroup more often forgot to carry their GPS, but however, better reported their trips in their travel diary (although not significant different between subgroups). This could be explained by family members assisting in complementing the diaries. However, it seemed that the household size negatively influenced the reporting rate of the diary, possibly because of other household activities with higher priority. In the moderate MS subgroup, persons with a higher perceived health-related QoL (mental component of SF-36) better registered trips by GPS. Persons with a lower perceived QoL might have more difficulties with making an (independent) trip, and therefore likely might less think of carrying the GPS device with them.

Confirming previous literature *(22)*, the educational level and work situation positively correlated, however dissimilar among subgroups, with the reporting rate of the travel diary. Education seemed to correlate moderately in the more advanced disease stages, while the work situation was only of importance in the mild MS subgroup and the total sample. It was somewhat surprising that, in the moderate subgroup, older persons better registered their trips by GPS, in contrast with literature *(22)* stating that GPS should be used for younger generations. The number of trips negatively influenced the reporting rate of the travel diary in the total sample and mild subgroup, likely because it is too difficult to remember a high number of trips, or perhaps because of the amount of time involved to report each trip. As well in the mild subgroup and within the total sample, persons who planned more trips in advance better reported their trips – probably because it is easier to recall trips that were planned before.

Overall, using GPS tracking devices (the current standard method) only for collecting data in PwMS and more generally PWD, should be undertaken with caution, as more than one fifth of all trips was not registered in this study, and even 29% in the severe subgroup. Persons were allowed to keep the device switched on (only at night they were asked to switch it off), as the logger automatically switched to the stand-by function when no movement was detected for more than 5 minutes (by a motion sensor) and similarly, started recording when the person moved again. However, persons had to remember to take the device with them at the moment they started travelling, which often appeared to be problematic. Besides possible cognitive problems, PWD likely have to think about a number of organizational issues when making a trip (e.g. carrying assistive mobility devices) because of their mobility limitations, which may explain why they forgot to take their GPS with them more often than persons without limitations. A (straightforward) solution may be to attach the GPS device to another attribute they usually carry while moving outdoors. Current innovations in GPS technology and mobile positioning data, by which trips and stops can be automatically extracted from GPS traces and presented on a map to the traveler (prompted recall) *(12)*, may lower the respondent burden. If the GPS acquisition would become (almost) completely automated, it is expected that the majority of trips would be registered by GPS, leading to a higher data quality. Although we assumed in our study that we captured the complete travel behaviour of participants by combining the travel diary and the GPS data, it is possible that some trips were not logged due to GPS device problems (and thus not due to user errors), as we did not control the GPS data quality at the individual point level or for each trip.

The results suggest that traditional (subjective) paper and pencil diaries may be better suitable for PWD with more advanced stages of the disease. The difference hereby is that persons do not have to think about filling in the diary immediately, but are able to do this at a later time when they have less organizational things on their mind. On the other hand, this longer time period may cause delayed memory problems with more potential bias in reporting results. Informing family members or caregivers about the research could be helpful to achieve more complete results.

In summary, we recommend the complemented use of both subjective self-report and objective GPS tracking devices to obtain detailed information about the actual activity-related travel behaviour in PWD. Despite recent advances in GPS technology, self-report diaries remain an important source of information for understanding why and how people make their trips (e.g. for which purpose, with whom), at least for persons for whom it is possible to use this method. While in this study the missing diary data were complemented by visually checking the logged GPS data, this is not feasible in a larger population; leading that an automatic checking approach is necessary. Persons suffering from problems with physical problems like fine hand motor skills, as well as persons with intellectual impairments, may not be able to fill in diaries or questionnaires. For these persons, GPS devices may provide a convenient solution to capture their travel behaviour, but it must be ensured that this device will not be forgotten during the trips, e.g. by sending a daily message to participants to remember them to carry their GPS. As well, new technologies that enable researchers to collect objective data about underlying activity types and accompanying persons, like visual life-logging technologies capturing every day activities, may potentially make self-report diaries redundant *(39)*. In order to make a substantiated choice of data collection instrument in travel behaviour studies in PWD, the (disease-related) capabilities of the participants should be taken into account and the selected method should be targeted towards the (disability level) of the target group. The present study may give initial indications about how this can be done.

Author Contribution statement: The authors confirm contribution to the paper as follows: study conception and design: Neven, Wets, Feys, Janssens; data collection: Neven, De Schutter; analysis and interpretation of results: Neven, De Schutter, Wets, Feys, Janssens; draft manuscript preparation: Neven. All authors reviewed the results and approved the final version of the manuscript.

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LIST OF TABLES AND FIGURES

TABLE 1 Socio-demographic Characteristics of PwMS by Subgroup

Variable	**Mild MS (n = 51)**	**Moderate MS (n = 27)**	**Severe MS (n = 30)**	**Total MS (n=108)**
Age (22-34/35-44/45-54/55-64/>64)	7/15/20/8/0	1/4/8/12/2	0/5/6/7/12	8/24/34/27/14
Gender (M/F)	16/34	13/14	12/18	41/66
Education (primary/secondary/higher)	3/25/22	1/17/9	4/19/7	8/61/38
Work (not working/half-time/full-time)	31/10/9	22/5/0	28/1/1	81/16/10
Driving ability (no/uncertain/yes)	7/4/39	5/4/18	18/2/10	30/10/67
Household size (1 pers/2 pers/more than 2)	5/17/28	3/13/11	10/13/7	18/43/46
Household income (< €1000/€1000-€2500/€2500-€5000/> €5000/ unknown)	0/20/21/1/8	0/10/10/0/7	1/12/5/0/12	1/42/36/1/27
Cars in household (0/1/2 or more)	4/24/22	2/22/3	7/16/7	13/62/32

TABLE 2 Clinical Characteristics of PwMS by Subgroup

Disability variable	**Mild MS (n = 51) Subgroup 1**	**Moderate MS (n = 27) Subgroup 2**	**Severe MS (n = 30) Subgroup 3**	**Kruskal-Wallis anova**	**Mann-Whitney post-hoc comparison between MS subgroups**		
					1-2	**1-3**	**2-3**
Disease Steps	1.4 ± 0.6 (0 - 2)	3.4 ± 0.5 (3 - 4)	5.4 ± 0.5 (5 - 6)	< 0.01	< 0.01	< 0.01	< 0.01
Disease duration	10.6 ± 7.6 (1 - 30)	15.3 ± 7.7 (5 - 32)	21.4 ± 11.1 (2 - 48)	< 0.01	< 0.01	< 0.01	< 0.05
MSFC ↑	0.5 ± 0.4 (-0.4 - 1.3)	-0.1 ± 0.6 (-2.3 - 0.9)	-2.9 ± 2.5 (-6.6 - 0.3)	< 0.01	< 0.01	< 0.01	< 0.01
Physical functioning							
T25FW (m/s) ↑	1.4 ± 0.3 (0.9 - 2.0)	0.8 ± 0.3 (0.3 - 1.3)	0.2 ± 0.3 (0.0 - 0.9)	< 0.01	< 0.01	< 0.01	< 0.01
MSWS-12 ↓	27.4 ± 11.2 (12 - 58)	47.1 ± 9.7 (21 - 60)	46.6 ± 21.1 (0 - 60)	< 0.01	< 0.01	< 0.01	ns
9HPT (s) ↓	23.4 ± 5.2 (15.0 - 39.9)	29.5 ± 10.4 (17.5 - 60.2)	41.1 ± 15.8 (17.2 - 76.0)	< 0.01	< 0.01	< 0.01	< 0.01
SF36 physical ↑	39.6 ± 10.2 (15.9 - 59.1)	28.7 ± 8.1 (12.40 - 43)	22.3 ± 9.0 (9.1 - 51.5)	< 0.01	< 0.01	< 0.01	< 0.01
Cognitive functioning							
PVSAT ↑	51.8 ± 9.7 (22 - 60)	47.8 ± 13.2 (0 - 60)	38.5 ± 16.0 (0 - 60)	< 0.01	ns	< 0.01	< 0.05
TMT (s) ↓	47.5 ± 20.3 (18.9 - 106.6)	58.2 ± 21.2 (32.8 - 137.0)	106.6 ± 66.0 (32.6 - 257)	< 0.01	< 0.05	< 0.01	< 0.01
Psychosocial functioning							
MFIS ↓	31.7 ± 17.9 (2 - 74)	46.7 ± 15.0 (13 - 72)	36.3 ± 19.9 (0 - 70)	< 0.01	< 0.01	ns	< 0.05
HADS ↓	10.2 ± 7.9 (1 - 33)	14.0 ± 6.9 (1 - 27)	11.7 ± 7.6 (0 - 25)	0.04	< 0.05	ns	ns
FAI ↑	29.0 ± 7.2 (12 - 42)	24.2 ± 7.2 (7 - 35)	17.9 ± 7.8 (5 - 31)	< 0.01	< 0.01	< 0.01	< 0.01
SF36 mental ↑	50.4 ± 10.6 (20.8 - 66.1)	47.1 ± 12.9 (20.2 - 63.7)	53.5 ± 10.2 (25 - 73.1)	ns	/	/	/

TABLE 3 Reporting Rate by Data Collection Method of PwMS by Subgroup

Reporting method (%)	**Total MS (n=108)**	**Mild MS (n = 51) Subgroup 1**	**Moderate MS (n = 27) Subgroup 2**	**Severe MS (n = 30) Subgroup 3**	**Kruskal -Wallis anova**	**Mann-Whitney post-hoc comparison between MS subgroups**		
						1-2	**1-3**	**2-3**
Diary	87.65 ± 18.09 (0 - 100)	84.94 ± 21.39 (0 - 100)	87.78 ± 15.93 (50 - 100)	92.29 ± 12.28 (50 - 100)	ns	/	/	/
GPS	76.95 ± 23.00 (0 - 100)	78.59 ± 20.58 (0 - 100)	80.56 ± 16.35 (41 - 100)	70.70 ± 30.66 (0 - 100)	ns	/	/	/
Diary & GPS	66.31 ± 25.46 (0 - 100)	65.35 ± 26.24 (0 - 97)	69.50 ± 20.36 (25 - 100)	65.04 ± 28.76 (0 - 100)	ns	/	/	/
Only diary	21.34 ± 21.77 (0 - 100)	19.59 ± 20.12 (0 - 97)	18.28 ± 15.79 (0 - 59)	27.26 ± 28.07 (0 - 100)	ns	/	/	/
Only GPS	10.64 ± 16.60 (0 - 100)	13.24 ± 20.36 (0 - 100)	11.06 ± 14.19 (0 - 47)	5.66 ± 8.84 (0 - 35)	ns	/	/	/
Forgotten by GPS & diary	1.71 ± 5.49 (0 - 50)	1.82 ± 3.16 (0 - 14)	1.16 ± 3.14 (0 - 15)	2.05 ± 9.32 (0 - 50)	< 0.05	ns	< 0.05	ns

TABLE 4 Reporting Rate of Data Collection Instrument by Travel Outcome Measure and MS Subgroup

REPORTING RATE (%)	Only diary (GPS forgotten)				Only GPS (diary forgotten)				Diary & GPS				Mann-Whitney comparison between subgroups								
													Only diary			Only GPS			Diary & GPS		
MS SUBGROUP	**Tot**	**Mild**	**Mod**	**Sev**	**Tot**	**Mild**	**Mod**	**Sev**	**Tot**	**Mild**	**Mod**	**Sev**	**1-2**	**1-3**	**2-3**	**1-2**	**1-3**	**2-3**	**1-2**	**1-3**	**2-3**
Research day																					
Day 1	31.7	24.2	35.3	42.7	6.6	7.0	5.1	7.3	61.6	68.7	59.6	50.0	ns	ns	ns	ns	ns	ns	ns	ns	ns
Day 2	18.2	16.5	15.6	25.0	9.2	11.2	9.9	3.7	72.7	72.3	74.5	71.2	ns	ns	ns	ns	ns	ns	ns	ns	ns
Day 3	21.5	16.0	22.6	33.3	13.3	17.1	12.4	5.3	65.2	67.0	65.0	61.3	ns	ns	ns	ns	ns	ns	ns	ns	ns
Day 4	20.7	22.0	11.8	27.5	11.3	11.2	14.4	8.2	68.0	66.8	73.8	64.3	ns	ns	ns	ns	ns	ns	ns	ns	ns
Day 5	19.7	22.5	7.4	23.1	11.9	13.3	15.1	6.6	68.4	64.2	77.5	70.3	ns	ns	ns	ns	ns	ns	ns	ns	ns
Day 6	23.1	25.6	21.6	17.7	11.1	10.9	14.4	7.0	65.8	63.5	64.0	75.3	ns	ns	ns	ns	ns	ns	ns	ns	ns
Day 7	21.6	23.3	22.1	17.6	11.1	14.0	12.9	3.8	67.3	62.7	65.0	78.6	ns	ns	ns	ns	ns	ns	ns	ns	ns
Week day																					
Weekday	22.3	21.7	19.8	25.5	10.2	12.9	9.6	5.9	67.7	65.4	70.6	69.3	ns	ns	ns	ns	ns	ns	ns	ns	ns
Weekend day	22.0	20.0	18.7	28.6	12.6	12.4	19.8	6.6	65.4	67.6	61.5	64.8	ns	ns	ns	ns	ns	ns	ns	ns	ns
Departure time																					
6h-12h	24.2	22.4	21.1	30.5	7.0	10.0	4.6	3.7	68.8	67.6	74.4	65.8	ns	ns	ns	ns	< 0.05	ns	ns	ns	ns
12h-16h	20.6	17.0	15.4	31.9	9.9	13.1	11.3	3.2	69.5	70.0	73.3	65.0	ns	ns	ns	ns	ns	< 0.05	ns	ns	ns
16h-20h	26.3	22.4	24.8	35.1	12.8	15.8	13.6	6.3	61.0	61.9	61.6	58.6	ns	ns	ns	ns	< 0.05	ns	ns	ns	ns
20h-6h	19.7	14.9	17.5	33.1	18.2	23.1	18.9	6.4	62.1	62.0	63.6	60.5	ns	ns	ns	ns	ns	ns	ns	ns	ns
Trip duration																					
< 10 min	21.0	23.0	15.7	22.6	13.2	14.9	14.5	8.2	65.9	62.2	69.8	69.3	< 0.05	ns	ns	ns	ns	ns	ns	ns	ns
11-20 min	18.4	14.7	19.9	25.0	12.8	13.1	16.6	7.7	68.8	72.2	63.6	67.3	ns	ns	ns	ns	ns	< 0.05	ns	ns	ns
> 20 min	15.2	14.0	11.7	21.0	7.7	10.4	6.8	3.3	77.1	75.6	81.6	75.7	ns	ns	ns	ns	ns	ns	ns	ns	ns
Activity type																					
Work/ Education	26.3	31.7	0.0	33.3	0.0	0.0	0.0	0.0	73.7	68.3	100.0	66.7	< 0.05	ns	< 0.01	ns	ns	ns	< 0.05	ns	< 0.01
Shops/services	19.6	16.5	12.5	34.2	1.5	2.6	0.0	1.1	78.9	80.9	87.5	64.7	ns	ns	ns	ns	ns	ns	ns	ns	< 0.05

Leisure	21.6	16.2	25.9	28.8	2.8	1.4	6.1	2.1	75.7	82.4	68.0	69.2	ns	ns	ns	ns	ns	ns	< 0.05	ns	ns
Social	27.2	30.0	22.0	26.7	2.9	1.8	4.6	3.5	69.9	68.2	73.4	69.8	ns	ns	ns	ns	ns	ns	ns	ns	ns
Personal care	29.5	24.0	31.2	37.4	0.9	0.9	1.7	0.0	69.6	75.0	67.2	62.6	ns	ns	ns	ns	ns	ns	ns	ns	ns
Walking	23.0	31.2	12.5	17.2	4.0	3.0	10.0	0.0	73.0	65.8	77.5	82.8	ns	ns	ns	ns	ns	ns	ns	ns	ns
Bring/get	27.3	27.1	24.6	37.5	3.1	4.6	0.0	0.0	69.6	68.3	75.4	62.5	ns	ns	ns	ns	ns	ns	ns	ns	ns
Other	35.6	50.0	0.0	60.0	0.0	0.0	0.0	0.0	64.6	50.0	100.0	40.0	ns	ns	ns	ns	ns	ns	ns	ns	ns
Home	22.8	19.3	20.5	31.1	10.6	13.1	11.4	5.2	66.7	67.6	68.1	63.7	ns	ns	ns	ns	ns	ns	ns	ns	ns
Transport mode																					
Car driver	19.4	22.1	16.9	14.2	2.5	1.6	54.	1.1	77.9	76.0	77.3	84.7	ns	ns	ns	ns	ns	ns	ns	ns	ns
Car passenger	24.3	21.7	20.8	32.5	2.4	0.0	9.2	0.8	72.7	78.3	70.0	64.2	ns	ns	ns	< 0.01	ns	< 0.05	ns	ns	ns
Cyclist	26.3	26.5	31.7	0.0	16.4	13.6	8.3	100.0	53.2	54.6	60.0	0.0	ns	ns	ns	ns	ns	ns	ns	ns	ns
Pedestrian	28.3	31.2	25.3	21.4	5.4	4.3	2.2	20.0	65.9	64.2	71.5	58.6	ns	ns	ns	ns	ns	ns	ns	ns	ns
Public transport	35.9	41.7	4.8	66.7	13.6	18.2	11.7	0.0	49.6	40.2	80.2	33.3	ns	ns	ns	ns	ns	ns	ns	ns	ns
Wheelchair	22.9	0.0	0.0	33.5	7.5	0.0	16.7	3.3	69.5	0.0	83.3	63.2	ns	ns	< 0.01	ns	ns	ns	ns	ns	< 0.05
Adapted	43.0	0.0	50.0	47.5	0.0	0.0	0.0	0.0	57.0	100	50.0	52.5	ns	ns	ns	ns	ns	ns	ns	ns	ns
Unknown	18.1	7.7	22.2	40.6	31.0	28.4	48.1	18.8	11.5	14.9	0.0	15.6	ns	ns	ns	ns	ns	ns	ns	ns	ns
Planning trips																					
Planned	24.6	20.6	29.9	26.2	4.9	7.1	2.6	3.3	70.5	72.2	67.5	70.5	ns	ns	ns	ns	ns	ns	ns	ns	ns
Spontaneous	21.2	17.2	26.8	22.5	4.3	7.6	0.4	2.5	74.6	75.2	72.9	75.0	ns	ns	ns	< 0.05	ns	ns	ns	ns	ns
Unknown	8.9	7.6	9.8	10.3	62.6	62.7	50.7	73.6	28.5	29.7	39.4	16.1	ns	ns	ns	ns	ns	ns	ns	ns	ns
Trip chaining																					
Single	26.0	24.7	33.9	23.9	8.7	12.6	5.3	5.1	64.5	62.7	60.8	71.0	< 0.05	ns	ns	ns	ns	ns	ns	ns	ns
Chain	14.8	13.3	13.7	18.5	16.9	21.7	9.7	15.2	68.3	65.1	76.6	66.3	ns	ns	ns	ns	ns	ns	ns	ns	ns

TABLE 5 Bivariate Spearman Correlation Analysis between Reporting Rate and Clinical, Socio-demographic and Trip-related Variables by MS Subgroup

REPORTING RATE (%)	DIARY				GPS			
MS SUBGROUP	**Total**	**Mild**	**Mod**	**Sev**	**Total**	**Mild**	**Mod**	**Sev**
CLINICAL								
Disease Steps	ns	ns	ns	ns	ns	ns	**0.44 ***	ns
Disease duration (yrs)	ns	ns	ns	ns	ns	ns	ns	ns
MSFC ↑	ns	**0.33 ***	ns	ns	ns	ns	ns	ns
Physical functioning								
T25FW (m/s) ↑	ns	ns	ns	ns	ns	ns	**- 0.51 †**	ns
MSWS-12 ↓	ns	ns	ns	ns	ns	ns	ns	ns
9HPT (s) ↓	ns	ns	ns	ns	ns	ns	ns	ns
SF36 physical ↑	ns	ns	ns	**- 0.39 ***	ns	ns	ns	ns
Cognitive functioning								
TMT (s) ↓	ns	ns	ns	ns	ns	ns	ns	ns
PVSAT ↑	ns	ns	ns	ns	ns	ns	ns	ns
Psychosocial functioning								
MFIS ↓	ns	ns	ns	ns	ns	ns	ns	ns
HADS ↓	ns	ns	ns	ns	ns	ns	ns	ns
FAI ↑	ns	ns	ns	ns	ns	ns	ns	ns
SF36 mental ↑	ns	ns	ns	ns	ns	ns	**0.47 ***	ns
SOCIODEMOGRAPHIC								
Age	ns	ns	ns	ns	ns	ns	**0.56 †**	ns
Gender	ns	ns	ns	ns	ns	ns	ns	ns
Education	**0.28 †**	ns	**0.50 †**	**0.61 †**	ns	ns	ns	ns
Work situation	**0.23 ***	**0.36 ***	ns	ns	ns	ns	ns	ns
Driving ability	ns	ns	ns	ns	ns	ns	ns	ns
Household size	**- 0.22 †**	ns	ns	ns	ns	ns	**- 0.41 ***	ns
Household income	ns	ns	ns	ns	ns	ns	ns	ns
Cars in household	ns	ns	ns	ns	ns	ns	ns	ns
TRIP-RELATED								
Number of trips	**- 0.25 †**	**-0.31 ***	ns	ns	ns	ns	ns	ns
Car passenger	ns	**0.29 ***	ns	ns	ns	ns	ns	ns
Public transport	ns	ns	ns	ns	**- 0.25 †**	**- 0.28 ***	**0.44 ***	ns
Planned trips	**0.25 ***	**0.37 †**	ns	ns	ns	**- 0.30 ***	ns	ns
Trips to work	ns	**0.37 †**	ns	ns	ns	ns	ns	ns
Trips to shops/services	**0.29 †**	ns	**0.54 †**	ns	ns	ns	ns	ns
Trips for personal care	**0.20 ***	ns	ns	ns	ns	ns	ns	ns
Trips 12h-16h	ns	ns	ns	ns	**0.26 †**	ns	ns	ns

TABLE 6 Multiple Linear Regression: Clinical, Socio-demographic and Trip-related Factors Related to Reporting Rate

REPORTING RATE (%)	**DIARY**									**GPS**		
MS SUBGROUP	**Total**			**Mild**			**Severe**			**Moderate**		
	β	**SE**	**t**	**β**	**SE**	**t**	**β**	**SE**	**t**	**β**	**SE**	**t**
Clinical factors												
MSFC				0.16	0.05	3.37 †						
SF-36 mental										0.01	0.00	2.25 *
Socio-demographic factors												
Age										0.01	0.00	2.71 *
Education							0.04	0.02	2.40 *			
Trip-related factors												
Number of trips	- 0.02	0.01	- 2.35 *									
Car passenger				0.29	0.10	2.94 †						
Planned trips	0.22	0.06	4.01 †	0.51	0.08	6.13 †						
Trips to shops/services	0.20	0.08	2.61 *									
OVERALL MODEL												
R^2	0.224			0.577			0.176			0.386		
Adjusted R^2	0.201			0.550			0.146			0.335		
β constant	0.757			0.381			0.775			0.154		
Standard error	0.056			0.065			0.065			0.173		
p	< 0.001			< 0.001			< 0.05			< 0.01		

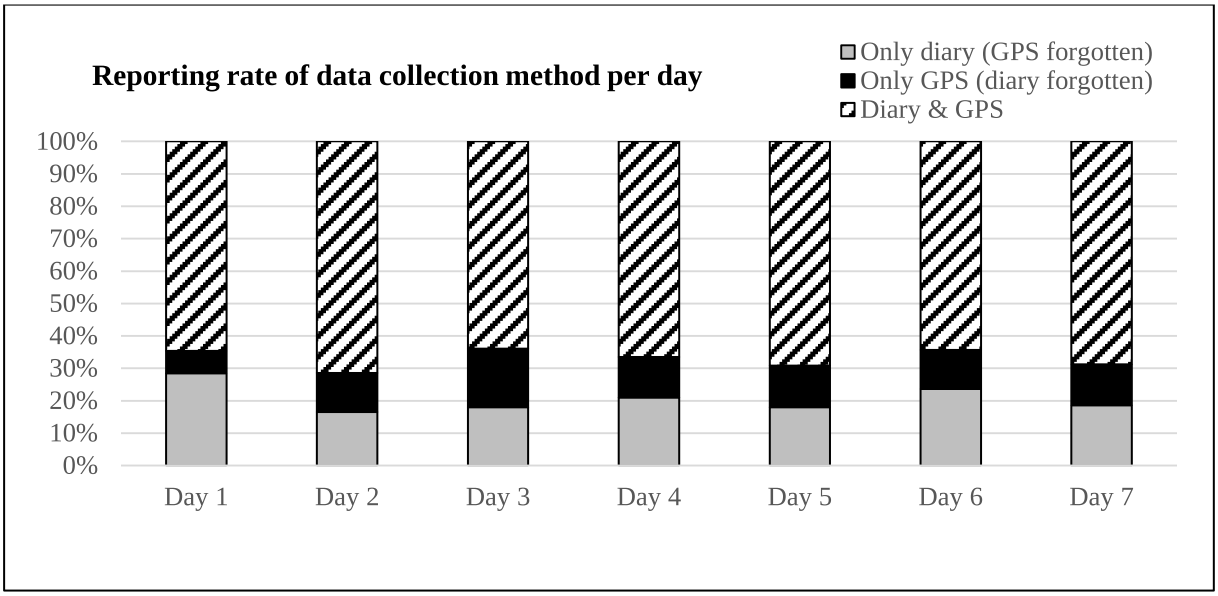

FIGURE 1 Reporting rate of data collection method per day