

Characterization of Power Wheelchair Use in the Home and Community

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ABSTRACT.

Objective: To characterize the use of power wheelchairs and to determine if multiple measures of mobility and occupancy jointly provide a more comprehensive picture of wheelchair usage and daily activity in full-time power wheelchair users than daily distance alone.

Design: Prospective observational study.

Setting: Subjects' everyday mobility was measured in their homes and communities for two weeks and prompted recall interviews were conducted by phone.

Participants: A convenience sample of 25 non-ambulatory, full-time power wheelchair users.

Interventions: Not applicable.

Main Outcome Measures: Wheelchair usage was logged electronically and GPS / interview data were used to isolate chair use to home, indoors but not at home and outdoor environments. Distance wheeled, time spent wheeling, number of bouts, time spent in the wheelchair and the percent of time in the wheelchair spent wheeling were measured to describe wheelchair use.

Results: The median wheelchair user spent 10.6 hours (5.0-16.6) in his/her wheelchair daily and wheeled 1.085 km (0.238-10.585) over 58 minutes (16-173) and 110 bouts (36-282). Wheelchair use varied across subjects, within subjects from day-to-day, and between environments. Mobility bouts outdoors were longer and faster than those wheeled indoors. In a regression analysis, distance wheeled explained only 33% of the variation in the number of bouts and 75% in the time spent wheeling.

Conclusions: Power wheelchair use varies widely both within and between individuals. Measuring distance, time and number of bouts provides a clearer picture of mobility patterns than measuring distance alone, while occupancy helps to measure wheelchair function in daily activities.

Keywords: Community Participation, Wheelchair, Activities of Daily Living, Mobility Limitation, Rehabilitation

Mobility is an essential aspect of health status, quality of life, activity and participation. Health indicators such as increased obesity have been associated with decreased mobility¹. On the other hand, increased mobility function and independence have been tied to improved overall quality of life, particularly in spinal-cord injured populations^{2, 3}. Mobility is a key domain of the activity and participation component of the International Classification of Functioning, Disability and Health (ICF)⁴.

Most studies of mobility relate the amount of physical activity to the prevention and treatment of disease^{5, 6}. Typically, research into mobility reports global metrics such as the total distance and time spent moving per day, independent of environment. Indeed, the average daily distance walked or number of steps taken has been measured in many populations with and without functional limitations⁷⁻⁹. However, this approach provides limited insight into the relationships between mobility and daily activities.

The study of mobility is further complicated by the context in which the mobility takes place. A recent study identified personal, health and environmental factors that affected the physical activity of manual wheelchair users¹. Pearson et. al. also found that personal and environmental factors influence people's activity and community participation¹⁰.

A few studies of ambulation have used metrics in addition to total distance in order to highlight the complexity of mobility. One research group¹¹ distinguished between continuous walking periods that were meant to encompass all “substantial spatial translations” and shorter bouts of movement (“discontinuous walking periods”) believed to represent transitions between spaces. Busse et al. measured peak and sustained activity levels, as well as durations of inactivity⁷. In a study on mobility of older adults, Cavanaugh et. al. reported total distance and time of activity as well as total number of activity bouts, variability and randomness⁸.

The literature on wheelchair usage is more limited and typically reports mean distance as the primary descriptor of mobility^{12,13}. For example, one study monitored two groups of power wheelchair users for five days each and found that a group of veterans who participated in the National Veterans Wheelchair Games wheeled, on average, 3.433 ± 1.741 km / day compared to community dwellers who wheeled an average of 1.667 ± 1.414 km / day¹². Mean distance tells us little about why these two groups had such a difference in wheelchair use. A study by Fitzgerald et. al. compared seven persons using their own manual wheelchair versus a pushrim-activated power-assist wheelchairs¹³. They found that the subjects wheeled 1591.6 ± 687.3 m / day in their manual wheelchairs and 1522.5 ± 520.7 m / day in the power assist wheelchairs. Results based on distance alone imply that use of power assist wheelchairs had little impact on activity. However, a subsequent study comparing the same devices showed that the power assist wheelchairs improved the ability of the users to propel uphill and over uneven surfaces¹⁴.

It is helpful to think broadly about the functions wheelchairs serve in everyday activities and how they might be measured. Wheelchair usage may be important for the following activities: (1) As a stationary means of support while engaged in other activities (e.g. sitting at a desk or dining table). This could be reflected by the *occupancy time* (i.e. the amount of time a wheelchair is occupied). (2) Wheelchair mobility may be the activity itself (e.g., recreational wheeling in the park or playing basketball). *Distance wheeled* in conjunction with the *environment* in which the wheeling took place may provide a good representation of mobility as its own activity. (3) Wheelchairs may provide transition between stationary activities, as in going from meal preparation in the kitchen to the computer in the office. *Mobility bouts* form the basis for describing wheelchair use as a transition. The number of bouts provides important insight to the number of activities performed in different locations. These activity categories and modes of measurement may reflect the different purposes of wheelchair use. We know of no studies that have examined these three aspects of wheelchair usage.

This study aimed to characterize the use of power wheelchairs. A goal of the project was to measure mobility and occupancy descriptors to determine if jointly they might provide a more comprehensive picture of wheelchair usage and daily activity in full-time power wheelchair users. Three hypotheses were tested: 1) Wheelchair usage varies across environments, 2) Measures of wheelchair usage are not normally distributed, and 3) Distance wheeled alone does not sufficiently predict the number of bouts wheeled or time spent wheeling.

METHODS

Subjects

A convenience sample of 25 adults were recruited from a local rehabilitation hospital. All recruited subjects used an upright or tilt-in-space power wheelchairs as their primary mobility devices. IRB approval was received from the local university and the hospital and subjects signed informed consent forms prior to beginning their participation in the study. Twelve participants had cervical level spinal cord injuries (8 complete, 4 incomplete) while one participant had a thoracic complete spinal cord injury. Remaining diagnoses included multiple sclerosis, cerebral palsy, polio, stroke, muscular dystrophy and juvenile parkinsonism. Subjects' injuries or conditions had been diagnosed as recently as the year of the study and as long as 63 years prior (median = 10 years) Subjects' ages ranged from 22 to 69 (median 43) and included 16 men and 9 women.

Instrumentation

The instrumentation described below is part of a larger set of instrumentation known as the WhAMI (Wheelchair Activity Monitoring Instrument). The WhAMI was designed to fully measure activity and participation of wheelchair users^{15, 16}.

Wheel counts were recorded on a single wheel using a reed switch^a mounted radially to the wheelchair frame and 2-4 evenly spaced Neodymium magnets^b attached to the wheel. The number of times a magnet crossed the reed switch was recorded every 2 seconds on a custom data logger^c and converted to distance using the wheel diameter. Controlled testing of the wheel count setup demonstrated accuracy of greater than 95%. Wheelchair occupancy was monitored using Ribbon Switches^d placed beneath the cushion.

Information about subject location was collected with a Garmin^e receiver and recorded every 5 seconds on a custom logger. Raw latitude and longitude data were overlaid on maps and divided into "trips" based on travel velocity and stop durations using proprietary GeoStats^f software. In a prompted recall interview within two days following the data collection period, we presented subjects with geographical and temporal information about their travels and asked them to provide names, purposes and environments (predominantly indoors or outdoors) for each destination. All travel between destinations (as identified by GPS or wheel counts and recall) was tagged as outdoors.

Protocol

Subjects were asked to sign an informed consent form upon receiving verbal and written explanations of the study. Their wheelchairs were instrumented with the WhAMI for 13-15 days. During this time, the instrumentation worked without researcher intervention or interference to the subjects' wheelchairs. The prompted recall interview followed within 2 business days of the instrumentation removal.

Analysis

Steps were taken to validate data following collection. Occupancy data was compared with wheelchair use, vehicle trips and subject habits while wheel count data was compared with GPS data. If more than 10% of the data appeared questionable on any given day, that day was not included in the analysis.

The definition of a mobility bout was created empirically using data collected from 7 able-bodied adults navigating a work environment in a power wheelchair. Wheel counts were logged every second in order to minimize the effect of our sampling on the definition. Subjects were asked to perform several tasks at their preferred, comfortable speed. The tasks included: checking a mailbox, stopping to ask questions at the front desk, making a copy at the copy machine, washing hands in the bathroom, going to the refrigerator and removing an article of food, microwaving the food and carrying the food to a dining area to eat. The bout definition was optimized to include travel between intentional activities so the end of a bout marked the beginning of a stationary task. A mobility bout was initiated when a subject traveled a minimum 0.61 m within 5 seconds and continued until the subject traveled less than 0.76 m over 15 seconds.

Individual bouts were calculated for all days of data collection using custom Geostats^f software. Using GPS information and the prompted recall interview, each bout was tagged as 1) in the home, 2) not in the home indoors, or 3) not in the home outdoors. We calculated the following mobility and wheelchair occupancy variables (Matlab^g): Mobility - distance wheeled, number of bouts and time spent wheeling. Occupancy - amount of time spent in the wheelchair per day (occupancy time) and the percent of time in the wheelchair spent wheeling (% mobile).

We computed the daily averages of mobility and occupancy variables for each subject and report the mean, median and standard deviation of the subject daily averages. The normality between subjects is reported as the result of a Ryan-Joiner normality test (Minitab^h). Day-to-day variation is presented in terms of coefficients of variation (CoV). The CoV was computed for each subject as the standard deviation divided by the mean of each daily variable and then averaged over all subjects.

To characterize mobility in the context of its environment, wheelchair mobility is reported in three environments: in the home, not in the home indoors, and outdoors. As with the mobility variables, the percent of mobility occurring in each environment was averaged over days and then over subjects. Additionally, the median bout characteristics (distance, duration, speed) in each environment are reported. In order to test whether bout characteristics were different between environments, Kruskal-Wallis tests were run for each variable. $P < 0.01$ was considered to be significant. Mann-Whitney pairwise comparisons were run at a confidence level of 95% to identify specific differences in bout characteristics between indoors environments and outdoors when Kruskal-Wallis demonstrated a significant group difference.

Linear regressions between the natural logarithms of mobility parameters were computed. If distance explained 75% of the variation in time and number of bouts, then it would be concluded that there was not additional information to be learned by measuring time or number of bouts.

RESULTS

Data collected from 395 days over 25 subjects met our validation requirements, the results of which are presented here. Four of these subjects experienced data loss from the GPS, so only 21 subjects are included in environment-specific analyses. Similarly, only 20 of the subjects had successful occupancy data and are included in analysis of wheelchair occupancy variables.

Between Subjects: Normality of Mobility

The distance wheeled per day was heavily skewed towards zero, with nearly half of the subjects wheeling less than one kilometer per day (Tables 1 & 2 and Figure 1). Therefore, the mean distance (1.906 km) was representative of very few subjects. On the other hand, the time spent wheeling and number of bouts wheeled presented a more normal distribution. Occupancy time was the most normally distributed and least varied of the variables.

Within Subjects: Day-to-Day Variation

Subjects' day-to-day variation in mobility was high (Tables 1 & 2). The day-to-day CoV of distance wheeled was 57%. Although to a lesser extent, the number of bouts and time spent wheeling also varied significantly within subjects. Day-to-day variation was evident regardless of how much a subject wheeled. For example, Subject 21 had the smallest day-to-day range in distance wheeled (735 m) and the third smallest day-to-day range in time spent wheeling (31 min). Nonetheless, these ranges were greater than this subject's median daily distance (243 m) and time spent wheeling (18 min). Wheelchair occupancy exhibited the least day-to-day variation of all the measured variables.

Table 1: Daily mobility and occupancy measures

Mobility Variable (Daily)	Median	Mean	SD	Normality (p-val)	Day-to-Day CoV
Distance (km)	1.085	1.906	2.253	0.811 (<0.01)	57%
# of Bouts	110	118	65	0.963 (0.078)	33%
Time Wheeling (min)	58	61	36	0.948 (0.026)	42%
Occupancy Time (hours)	10.6	10.8	2.9	0.996 (>0.10)	20%
Percent Mobile	9.2	8.8	4.3	0.978 (>0.10)	39%

Mean and variance descriptions of daily mobility and occupancy variables over n=25 and n=20 subjects respectively. SD = Standard Deviation, CoV = coefficient of variation (within subject)

Table 2: Median and range of mobility measures

Subject	Distance (m)	Number Bouts	Time Moving (min)
14	158 (24-1127)	32 (9-88)	13 (3-48)
24	180 (101-3739)	48 (35-195)	11 (6-118)
2	236 (0-1801)	47 (0-88)	13 (0-39)
21	243 (161-896)	51 (25-88)	18 (11-42)
6	307 (120-960)	64 (30-108)	28 (12-51)
11	542 (295-1450)	126 (81-261)	60 (34-116)
15	545 (48-1475)	50 (7-114)	21 (2-56)
10	589 (379-1320)	91 (58-108)	39 (27-61)
17	616 (409-1303)	165 (96-206)	43 (28-66)
12	705 (389-1509)	97 (75-132)	45 (32-61)
20	811 (0-2146)	48 (0-84)	33 (0-53)
9	914 (702-1502)	70 (48-100)	40 (32-59)
13	922 (270-2941)	118 (67-210)	52 (25-103)
3	1119 (576-2530)	259 (166-441)	73 (38-134)
16	1157 (295-2126)	111 (66-150)	58 (19-89)
7	1328 (238-2001)	191 (53-405)	85 (16-135)
23	1703 (925-3062)	176 (93-243)	95 (49-145)
22	1961 (1035-2704)	187 (93-291)	112 (59-153)
1	2126 (765-4627)	108 (76-142)	66 (33-143)
18	2211 (609-5145)	152 (127-276)	79 (44-128)
25	2278 (1696-3769)	123 (70-178)	74 (54-108)
5	2545 (380-11952)	121 (56-206)	62 (17-160)
8	3724 (498-6920)	120 (79-160)	93 (19-130)
4	5490 (745-9668)	66 (19-111)	92 (18-138)
19	10636 (7297-13875)	236 (197-301)	170 (140-224)

Subjects are sorted by median distance. Number of bouts does not increase directly with distance. Notice the wide ranges for all parameters

Relationship Between Distance, Number of Bouts and Time Wheeling

In the regressions, distance explained 75% of the variance in time wheeling but only 33% of the variance in the number of bouts.

Mobility Based on Environment

Most wheelchair use occurred at home. The median values wheeled inside the home included 59% of distance, 75% of bouts and 64% of time (Table 3). Eleven of the 21 subjects used their wheelchairs outdoors 2% or less of the time. However, the differences between the median and mean wheelchair use values outdoors suggest the influence of outliers. In fact, the wheelchair use patterns of six subjects differed considerably from the median subjects. These six subjects wheeled outdoors 30-70% of the time and outdoor mobility accounted for over 50% of their daily wheeling distance. However, even among these subjects, the greatest number of bouts typically occurred at home.

To explain how subjects wheeling large distances and times outdoors could still wheel the greatest number of bouts in the home, we examined the differences between distance, duration and speed of bouts across environments (Table 4). Mann-Whitney post-hoc tests confirmed that outdoor bouts are longer in time and distance and faster than those wheeled indoors. However, no differences were found between bouts in the two indoor environments.

DISCUSSION

This study characterized wheelchair use by full-time power wheelchair users. The median wheelchair user spent 10.6 hours in his/her wheelchair daily and wheeled 1.085 km over 58 minutes and 110 bouts. For all but two of the subjects, the greatest number of bouts occurred in the home. Since a bout represents the transition between activities, this result suggests that the majority of transitions took place in the home.

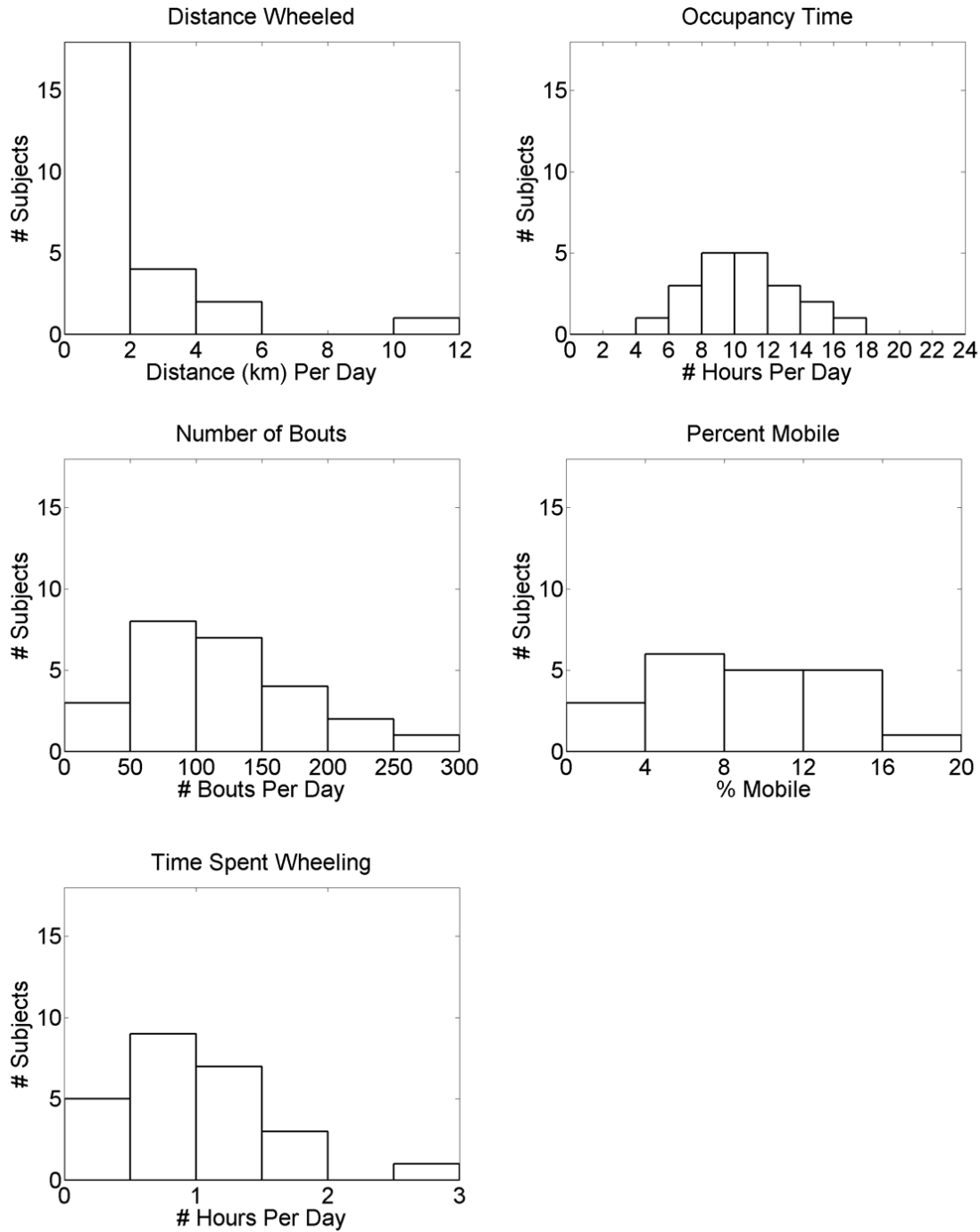
This study also set out to test three hypotheses: 1) Wheelchair usage varies across environments, 2) Measures of usage are not normally distributed, and 3) Distance wheeled alone does not sufficiently predict the number of mobility bouts or time spent wheeling. As might be expected, we found in response to our first hypothesis that wheelchair use varied by environment. Bouts of mobility indoors occurred more frequently, but with significantly smaller distances and speed than those occurring outdoors. Additionally, subjects who wheeled mostly outdoors tended to wheel greater distances and for longer periods of time. These results suggest an important influence of the environment. Research into environmental influence may better inform clinicians about the most appropriate wheeled mobility device for patients. Additional study may also help insurers and policy makers better understand the role of environment in the health of wheelchair users.

Secondly, we showed that wheelchair occupancy was normally distributed and had less day-to-day variation within a subject than mobility metrics. All the mobility metrics were skewed and non-normal. The mean distance traveled daily was nearly twice the median distance, indicating that the mean was biased towards people who travel longer distances. Therefore, median distance is a better descriptor for reporting wheelchair mobility of this subject cohort. Compared to distance, the number of bouts and time spent wheeling exhibited less variation within and across subjects. Although a larger dataset is needed to confirm the relative stability of the mobility metrics, it is possible that fewer subjects might be needed to observe significant changes in mobility when represented by number of bouts and time spent wheeling rather than distance wheeled.

Finally, distance alone explained only a small amount of the variation in number of mobility bouts. Subjects who traveled similar daily distances (Table 2), may have done so in few longer and higher speed bouts (e.g. Subject 15) or spread their travel over many short, low speed bouts (e.g. Subject 11). Conversely, subjects with a similar number of bouts may travel relatively little (e.g. Subject 6) or great (e.g. Subject 4) distances. Since different information is introduced by the mobility descriptors, jointly reporting the number of bouts and distance provides a more

comprehensive picture of wheelchair mobility. Distance explained 75% of the variance in time spent wheeling, indicating that distance and time appear to be closely related.

Figure 1: Histograms of mobility and wheelchair occupancy variables. Occupancy time was the only variable with a normal distribution. Reporting of the median is more appropriate in all cases.



The results of this study are generally consistent with published studies. The average daily distance (1.9km) measured in this study was comparable to that reported for community-dwelling power wheelchair users (1.7km)¹². At the same time, the large variation in distance traveled across subjects is consistent with previous studies of wheelchair use^{1, 12, 13, 17}. The presence and importance of short mobility bouts have been previously documented for wheelchair use and ambulation. Hoenig et. al. suggested that the short durations of scooter use reflected transitions between activities¹⁷. Schutz et. al. also found that most mobility in healthy adults (67%) occurred in “discontinuous walking activities” or short, transitive bursts of mobility¹¹. Cavanaugh et. al found that healthy older adults had the same number of steps and minutes of activity as younger adults, but fewer daily bouts of activity⁸. This finding reinforces our results that total distance alone might be an incomplete measure of overall mobility. Our findings were not consistent with those of Brant, et. al¹⁸. Whereas all our subjects used their wheelchairs inside the home and in the community, Brant reported that 80% of part-time wheelchair users used their wheelchairs only outdoors. More research into the differences between full-time and part-time wheelchair use will help to explain the differences in these results.

We presented five metrics of wheelchair usage: distance wheeled, number of bouts, time spent in the wheelchair (occupancy), time spent wheeling, and the percent of time spent wheeling while seated in the wheelchair. These were presented to reflect different dimensions of wheelchair use: 1) during stationary activities, 2) with mobility as the activity itself, and 3) as a transition between activities. Selection of mobility and occupancy metrics to be measured will depend on the research questions being asked. First, wheelchair occupancy can be used to reflect stationary activities. In our cohort of full time power wheelchair users, less than 10% of wheelchair usage was spent wheeling. Secondly, certain bouts of mobility were themselves activities, such as when users took trips around the neighborhood. Bouts of mobility can also be used to represent transitions between activities. Future studies should determine if bouts of mobility correlate to the performance of activities of daily living. Also, bouts of mobility may be important when studying manual wheelchair use. Each bout reflects the cost of initiating movement, which has a greater metabolic and kinetic cost than steady state motion¹⁹. Finally, taken together, distance, time and number of bouts inform the researcher about typical mobility characteristics.

Limitations

The design of this study included limitations in enrollment. The cohort of participants was a convenience sample who shared common functional mobility (full-time power wheelchair users). While the limited population may have affected average usage values, our values are consistent with existing literature and a significant amount of variability was still present.

The process of monitoring wheelchair usage also introduces limitations. First of all, instrumentation failure and data loss are always a concern. In the scope of this study, however, our conclusions regarding high variation are unlikely to be affected by lost data. Additionally, monitoring wheelchair usage may alter a subject’s mobility pattern. A two-week study duration and a passive monitoring system were devised, in part, to capture typical mobility over time without impacting subjects but the potential effect was not studied.

Finally, our definition of mobility bout requires additional study. Within the scope of this study we were unable to confirm if increased number of bouts correlated with increased activities. Although our prompted recall interviews support this assumption, further research is needed. Additionally, the definition of mobility bout was defined for power wheelchair use and may not be appropriate for other wheeled mobility devices. Ideally, a definition that is suitable for all mobility devices should be developed.

Table 3: Breakdown of mobility based on environment.

Environment	Variable	Median	Mean	SD
Home	% Distance	59	57	30
	% # Bouts	75	71	23
	% Time Wheeling	64	63	27
Not Home	% Distance	13	22	18
	% # Bouts	13	19	17
	% Time Wheeling	11	20	17
Not Home Outdoors	% Distance	2	19	29
	% # Bouts	2	8	12
	% Time Wheeling	2	15	22

SD = Standard Deviation. Daily wheelchair mobility was divided into three environments. Because the median values for each parameter (e.g. Home % Distance versus Outdoors % Distance) may not come from the same subject and therefore do not have to sum to 100%.

Table 4: Median bout characteristics differ based on environment.

	Distance (m)	Duration (sec)	Speed (km/hr)
Home	3.7	18	0.8
Not Home Indoors	4.2	18	1.0
Not Home Outdoors	11.3	34	1.6

Kruskal-Wallis testing showed all variables to be different between groups ($p < .001$, Distance $H = 1172.0$, Duration $H = 662.8$, Speed $H = 2269.4$). Post hoc analysis using Mann-Whitney confirmed differences between median variables in both indoor environments and outdoor environments.

CONCLUSION

There is no single typical behavior of full-time power wheelchair use, either across days within a person or across people. Mean distance alone provided an incomplete picture of mobility and wheelchair usage that was enhanced by measures of occupancy, bouts and time wheeling. A better understanding of the influence of the environment combined with a thorough description of the complexities of wheelchair use is needed to adequately study the health, activity and participation of wheelchair users.

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SUPPLIERS

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