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Analyzing wheelchair mobility patterns of community-dwelling older adults

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Abstract—This study determined and compared wheelchair mobility patterns for older adults during an organized sporting event and within their community. In July 2008, 39 veterans participating in the 28th National Veterans Wheelchair Games (Omaha, Nebraska) completed the study. Of these, 26 were manual wheelchair and 13 were power wheelchair users. We collected wheelchair-related mobility data using wheelchair data-logging devices. Participants were significantly more active using manual wheelchairs during the games than when using their wheelchairs in their homes in terms of distance traveled (4,466.2 vs 1,367.4 m, $p < 0.001$) and average speed of propulsion (0.76 vs 0.64 m/s, $p < 0.001$). The trend was the same for power wheelchair users, with respect to distance (7,306.2 vs 3,450.5 m, $p = 0.004$) and average speed (0.9 vs 0.7 m/s, $p = 0.002$). This study demonstrates an objective method of evaluating wheelchair use in community-dwelling older adults.

Key words: community participation, data logger, environment, manual wheelchair use, National Veterans Wheelchair Games, older adults, physical activity, power wheelchair use, wheelchair mobility, wheelchair provision.

INTRODUCTION

The rate of participation in "regular physical activity" is reported to be only 22 percent in individuals ≥65 years, while this percentage drops to 8 percent for those >85 years of age [1]. "Regular physical activity" is defined by the U.S. Surgeon General as engaging in moderate intensity activities for at least 30 minutes five times a week [2]. When aging is coupled with the presence of disability, restriction of physical activity becomes a significant problem [3]. Physical inactivity is also considered a major contributing factor for increased level of disability and mortality in older adults [4].

Generating a physical activity profile of older adults has inspired several measurement methods, including observations by healthcare professionals, use of self-report physical activity questionnaires, pedometers that count numbers of footsteps, heart rate monitors for recording physiological response, accelerometers, and calorimetry for computing physiological energy expenditure [5]. In spite of significant pros and cons, pedometers have been used for screening and assessment, outcome measurements, and intervention with the ambulatory population [5–7]. Evidence suggests that using pedometers as interventional tools is associated with improved levels of physical activity, reduced body mass index, and positive changes in blood pressure levels [8].

Abbreviations: HERL = Human Engineering Research Laboratories, MWC = manual wheelchair, NVWG = National Veterans Wheelchair Games, PVA = Paralyzed Veterans of America, PWC = powered wheelchair, SCI = spinal cord injury, VA = Department of Veterans Affairs.

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A significant limitation of the research just mentioned is its emphasis on measuring walking, which therefore excludes individuals using manual wheelchairs (MWCs) or other mobility devices. Most research focused on recording wheelchair-related mobility has relied on subjective assessments using questionnaire and survey methods to capture information related to level of physical activity and participation among wheelchair users. However, extensive research monitoring physical activities involving MWC users has not been done.

Warms and Belza reported use of the Actiwatch (Mini Mitter; Bend, Oregon), a commercially available product for recording gross motor movements among individuals with spinal cord injury (SCI) who use MWCs [9]. This method, although useful, only detected the motions occurring in the upper limbs, rather than comprehensively measuring the extent of wheelchair use and the interaction between the users and their wheelchairs. A report by Wilson et al. demonstrated efficacy of the activPAL, a customized device (PAL Technologies Ltd; Glasgow, United Kingdom), for measuring MWC-related mobility (distance covered, speed of travel, and time spent in wheelchair) in individuals with SCI within their natural living settings [10].

Previous work in quantifying wheelchair use has demonstrated the effectiveness of our customized data-logging device for measuring driving characteristics of powered wheelchairs (PWCs) over the course of 5 days for athletes participating in the National Veterans Wheelchair Games (NVWG) and compared them with driving characteristics of PWC use in the home [11]. More recently, a study reported the use of data loggers for monitoring MWC-related mobility, comparing distance traveled, amount of continuous travel (without stopping), and hours of wheelchair use for wheelchair athletes during organized sporting events versus MWC use within their community [12]. Use of wheelchair data-logging devices has also been reported as a method for determining the effectiveness of pushrim-activated power-assist wheelchairs in improving the mobility of individuals with SCI compared with use of traditional MWCs [13]. Cooper et al. have also used customized data-logging devices to measure both MWC- and PWC-related mobility among children using MWCs and PWCs within the community [14]. Another instrument, the wheelchair activity-monitoring instrument, has been developed for recording wheelchair usage (indoor and outdoor: distance traveled and the number of bouts of acceleration) and overall occupancy time for PWC users [15].

The objective of our study was to quantify MWC and PWC mobility characteristics for older adults during an organized sporting event, the NVWG, and during community use of their MWCs and PWCs.

METHODS

Study Design

The study design was prospective and observational in nature and conducted at the 28th NVWG in Omaha, Nebraska (July 2008). The NVWG is an organized wheelchair sporting competition for veterans held every year and sponsored by the Department of Veterans Affairs (VA) and Paralyzed Veterans of America (PVA). These games started in 1981 and offered 17 sporting events for veterans using wheelchairs [16].

Participants

All study participants were veterans participating in the 28th NVWG. A total of 42 individuals were recruited, 39 of whom completed the study protocol. One MWC user did not return the data logger and was excluded from the study. The study investigators did not put data loggers on two PWC users (after consenting for the study) because of noncompatibility issues with the wheelchairs. Twenty-six were MWC users (n = 26), and thirteen were PWC users (n = 13). The inclusion criteria for this study were aged 50 years and older and current independent wheelchair users. The exclusion criterion for the study was pressure ulcers on their buttocks that limited sitting tolerance. We only recruited PWC users who confirmed their ability to change caster data loggers (with or without assistance). Demographic information of all participants is presented in **Table 1**.

Instrumentation

We collected data related to MWC mobility using a customized data-logging device (**Figure 1**) that was developed at the Human Engineering Research Laboratories (HERL), part of the VA Pittsburgh Healthcare System. The data-logging device is self-powered and can record up to 3 months of wheelchair mobility data on a flash memory chip. The device measures wheel rotations through the use of three reed switches mounted 120° apart on a circuit board and a magnet mounted at the bottom of

Table 1.
Subject demographics of manual and power wheelchair users.

Demographic	Manual Wheelchair Mean ± SD (range) or No. (*n* = 26)	Power Wheelchair Mean ± SD (range) or No. (*n* = 13)
Age (yr)	62.5 ± 5.7 (53–84)	66.9 ± 7.5 (58–81)
Body Weight (kg)	89.7 ± 19.2 (51.2–134.2)	84.2 ± 16.8 (52.1–113.4)
Disability Duration (yr)	25.3 ± 14.8 (3.3–53.6)	33.5 ± 17.0 (2.0–57.6)
Sex		
Male	26	11
Female	0	2
Ethnicity*		
African American	5	3
Caucasian	16	9
Other	4	1
Diagnosis*		
C-SCI	5	7
T-SCI	10	1
LS-SCI	3	1
Other	7	4

*Indicates missing data.
C-SCI = cervical-level SCI, LS-SCI = lumbosacral SCI, No. = number, SCI = spinal cord injury, SD = standard deviation, T-SCI = thoracic-level SCI.

a pendulum sensor. Every time the wheelchair wheel rotates more than 120° (either forward or backward), the magnet triggers one of the reed switches. As each reed switch is triggered, a date and time stamp for that event is recorded in the device. For this study, we instrumented each participant's MWC with data-logging devices for 1 month. The wheel circumference, which was used during the data-reduction process, was also recorded during instrumentation. The data-logging devices were placed between spokes of the wheels and did not interfere with participants' routine use of wheelchairs.

For measuring PWC use, we used caster data loggers, also designed and developed at HERL (**Figure 2**). Front or back casters of PWC for each participant were replaced by customized caster data loggers. The caster data logger records wheel rotation using a magnet and switches similar to those of the manual data logger just described.

Protocol

All participants were recruited during the 2008 NVWG. After obtaining informed consent, we collected demographic information and attached a data-logging device to each participant's MWC. Participants were given written instructions on how to remove the data logger, along with a prepaid envelope to mail it to investigators 2 weeks after the end of the games.

Figure 1.
Manual wheelchair data-logging device: **(a)** view when placed between spokes of wheels and **(b)** close-up.

For PWC users, we replaced the front or back original casters of their wheelchairs with customized casters with built-in data loggers (**Figure 2**). Participants were given their original wheelchair casters and a prepaid envelope and were instructed to change the casters with the built-in data logger back to their original wheelchair casters 2 weeks after the end of the games. PWC participants used the prepaid envelope to mail the casters with built-in data loggers to the study investigators.

Data Reduction

After receiving the manual- and power-caster data loggers from the participants, we downloaded all data onto a computer. We then decompressed the raw data using a customized MATLAB (The MathWorks; Natick, Massachusetts) program. The customized program extracted the following average wheelchair-related mobility variables:

- Distance traveled each day using the wheelchair (distance).

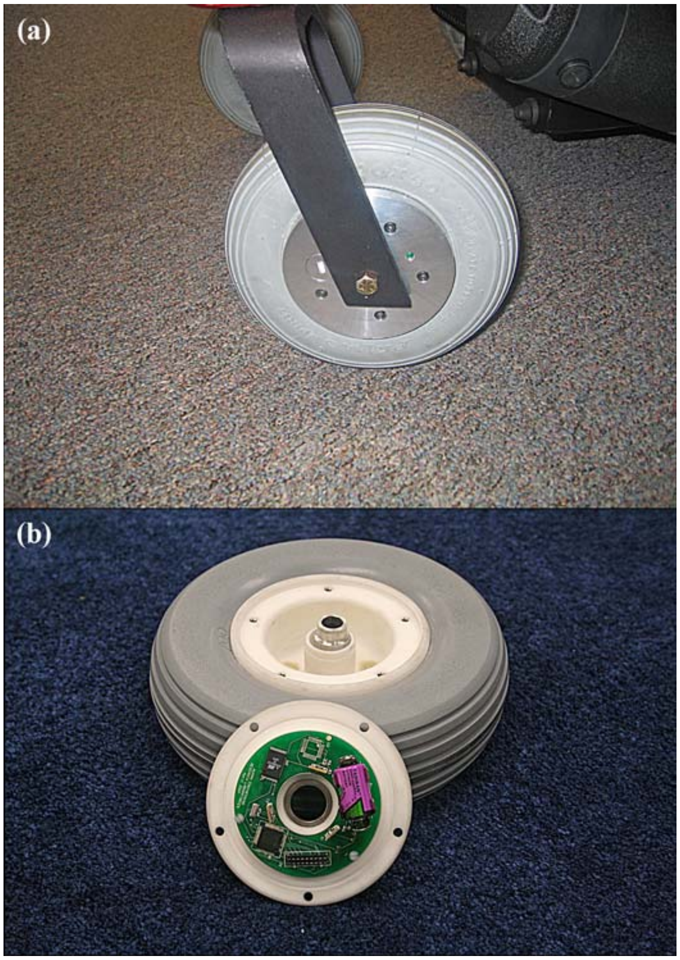


Figure 2.
Power wheelchair data-logging device: **(a)** view when placed either on back or front of wheels and **(b)** close-up.

- Velocity of wheelchair propulsion (driving) each day (velocity).
- Maximum continuous distance traveled without a stop (endurance distance).
- Number of stops taken for every 500 m traveling with wheelchair (stops/500 m).
- Continuous time traveled without a stop (endurance time).

A secondary mobility variable included subanalysis of wheelchair velocity to determine the time participants spent using their wheelchairs at various velocities: >1.0 m/s, between 0.5 and 1.0 m/s, and <0.5 m/s. Detailed information (including mathematical equations) related to data reduction has been described previously by Tolerico et al. [17].

Data Analyses

We used descriptive statistics for demographics and wheelchair characteristics for MWC and PWC groups separately. Because of nonnormal distribution and small sample size, wheelchair mobility data (distance, velocity, continuous distance, continuous time, and number of stops every 500 m) were compared within subjects (NVWG vs home) using the Wilcoxon signed rank test for both MWC and PWC groups. We performed all statistical analyses using SPSS 16.0 software (SPSS Inc; Chicago, Illinois), with a significance level set a priori at 0.05.

RESULTS

Participants' Demographic Characteristics

Compared with the mean ± standard deviation age of 63 ± 6 yr for the MWC group, the mean age of participants in the PWC group was 67 ± 8 yr. The MWC group presented with a slightly higher body weight (90 ± 19 kg) compared with 84 ± 17 kg for the PWC group. For years with disability, the PWC group was slightly higher at 34 ± 17 than the MWC group at 25 ± 15. A few female participants were in the PWC group, and none were in the MWC group. The ethnic distribution was similar in both groups. SCI was the most prevalent medical condition for both groups (MWC = 72%, and PWC = 70%), with the MWC group having the highest number of individuals with SCI at the thoracic level (40%). The proportion of participants with SCI at the cervical level was highest for the PWC group (53%) (**Table 1**).

Wheelchair Characteristics

The MWC group primarily used the Quickie 2 wheelchair (Southwest Medical; Phoenix, Arizona), while the PWC group mostly used the Action Arrow wheelchair (Invacare Corporation; Elyria, Ohio) (**Table 2**). The wheelchair total years used was slightly higher for the PWC group (26 yr) than for the MWC group (21 yr).

Manual Wheelchair Usage

The results of this study indicated that MWC mobility of participants was significantly higher during the NVWG than in their home and community. Participants were significantly more active with their wheelchairs at the NVWG regarding distance traveled (4,466.2 vs 1,367.4 m, $p < 0.001$), wheelchair propulsion velocity (0.76 vs 0.64 m/s, $p < 0.001$), continuous wheelchair drive

Table 2.
Characteristics of users' manual and power wheelchairs.

Characteristic	Manual Wheelchair Mean ± SD or No. (*n* = 26)	Power Wheelchair Mean ± SD or No. (*n* = 13)
Years of Using Wheelchair	21.0 ± 15.1 (3–60)	26.3 ± 17.2 (2–53)
Most Commonly Used		
Make	Quickie	Invacare
Model	2	Action Arrow
Number (%)	6 (22.2)	7 (53.8)
Age of Primary Wheelchair (yr)	4.9 ± 7.4 (0–40)	2.5 ± 2.0 (0–7)

No. = number, SD = standard deviation.

distance (328.6 vs 182.2 m, $p < 0.002$), continuous wheelchair drive time (5.2 vs 2.5 min, $p < 0.001$), and number of stops every 500 m (17.4 vs 32.6, $p < 0.001$). The proportion of time participants were propelling their wheelchairs with velocity >1 m/s was higher during the NVWG than in their home and community (29.8 vs 13.9, $p = 0.013$) (**Table 3**).

Power Wheelchair Usage

The results of this study indicated that PWC mobility of participants was significantly higher during the NVWG than in their home and community. Participants were significantly more active with their wheelchairs regarding distance traveled (7,306.2 vs 3,450.5, $p = 0.004$), wheelchair driving velocity (0.9 vs 0.7, $p = 0.002$), continuous wheelchair travel distance (613.2 vs 344.1, $p = 0.006$), continuous wheelchair drive time (7.1 vs 4.2, $p = 0.005$), and number of stops/500 m (18.6 vs 36.5, $p = 0.002$). The proportion of time participants were driving their wheelchairs with velocity >1.0 m/s was higher during the NVWG than in their home and community (58.4 vs 29.5, $p = 0.003$) (**Table 4**).

Organized Sports Participation

We observed no difference in our MWC and PWC groups in number of events participated for all sports activities (4.0 vs 3.5, $p = 0.12$). Participation in the track and field events was highest for both groups, followed by participation in other sports (nine ball, bowling, etc.) (**Table 5**).

Relation Between Variables

Results for the MWC group showed a significant negative correlation coefficient between age and wheelchair propulsion velocity ($r = -0.40$, $p = 0.04$) (**Figure 3(a)**). For the PWC group, a significant positive correlation coefficient was observed between age and wheelchair driving velocity ($r = 0.68$, $p = 0.01$) (**Figure 3(b)**).

DISCUSSION

Use of prescribed wheelchairs is critical for understanding the benefits attained from their optimal use and the risks associated with their limited use. Wheelchair datalogging devices have been successfully established as an objective measurement for determining use of wheelchairs within the users' natural environment [11,13–14,17]. However, this method has not been used for community-dwelling older adults for understanding the extent of their wheelchair use. Our study recruited older adults participating in the annual NVWG who were full-time MWC or PWC users and were community dwellers. We recruited two cohorts of MWC and PWC users. The results showed no major differences in demographic characteristics

Table 3.
Manual wheelchair use comparison of users at National Veterans Wheelchair Games (NVWG) and in home.

Measure	NVWG Use, Mean ± SD (*n* = 26)	Home Use, Mean ± SD (*n* = 26)	*p*-Value*
Distance Traveled (m)	4,466.2 ± 1,192.0	1,367.4 ± 624.2	<0.001
Propulsion Velocity (proportional time, m/s)	0.76 ± 0.08	0.64 ± 0.13	<0.001
>1.0	29.8 ± 26.1	13.9 ± 17.8	0.013
0.5–1.0	66.4 ± 25.5	39.2 ± 21.0	0.001
<0.5	3.7 ± 4.2	42.0 ± 26.7	<0.001
Continuous Drive			
Distance (m)	328.6 ± 111.9	182.2 ± 190.4	<0.002
Time (min)	5.2 ± 1.4	2.5 ± 1.9	<0.001
Stops/500 m (No.)	17.4 ± 3.7	32.6 ± 10.6	<0.001

*Indicates statistically significant difference between NVWG and home use.
No. = number, SD = standard deviation.

Table 4.
Power wheelchair use comparison of users at National Veterans Wheelchair Games (NVWG) and in home.

Measure	NVWG Use, Mean ± SD (n = 13)	Home Use, Mean ± SD (n = 13)	p-Value
Distance Traveled (m)	7,306.2 ± 2,592.1	3,450.5 ± 2,596.0	0.004*
Driving Velocity (proportional time, m/s)	0.9 ± 0.3	0.7 ± 0.3	0.002*
>1.0	58.4 ± 34.5	29.5 ± 32.3	0.003*
0.5–1.0	30.6 ± 31.4	42.3 ± 20.9	0.17
<0.5	11.0 ± 23.0	27.5 ± 19.8	0.04*
Continuous Drive			
Distance (m)	613.2 ± 344.0	344.1 ± 324.9	0.006*
Time (min)	7.1 ± 2.8	4.2 ± 2.8	0.005*
Stops/500 m (No.)	18.6 ± 9.1	36.5 ± 16.6	0.002*

*Indicates statistically significant difference between NVWG and home use.
No. = number, SD = standard deviation.

Table 5.
Total number of events in which manual and power wheelchairs users participated at National Veterans Wheelchair Games.

Activity	Manual Wheelchair Mean ± SD (n = 26)	Power Wheelchair Mean ± SD (n = 13)	p-Value
Track and Field	1.3 ± 1.3	1.2 ± 1.0	0.90
Shooting	0.6 ± 0.8	0.4 ± 0.7	0.39
Organized Sports	0.9 ± 0.7	0.7 ± 0.6	0.27
Event with Primary Wheelchair Use	2.8 ± 1.6	3.4 ± 1.6	0.29
Other*	1.2 ± 0.9	1.2 ± 0.9	0.82
Total	4.0 ± 1.2	3.5 ± 1.2	0.12

*Examples of other events include nine ball, bowling, etc.

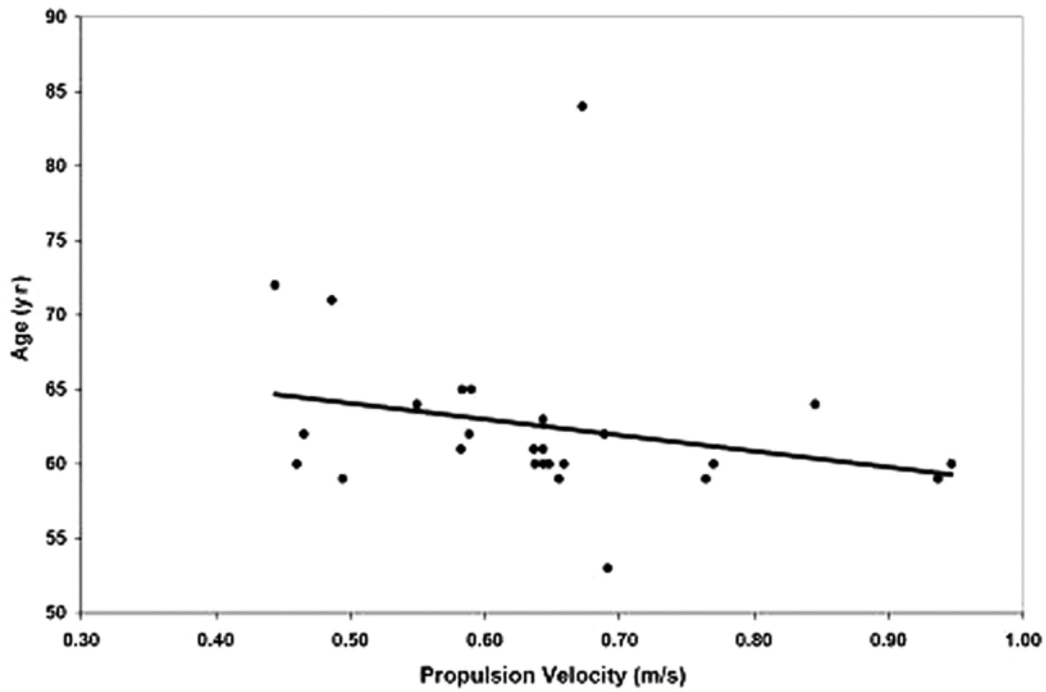
between these two groups. We compared wheelchair use separately for MWC and PWC users between their use at the NVWG and in their homes.

For the MWC group, the differences in basic wheelchair-related mobility (distance traveled and velocity of propulsion) during the NVWG were significantly higher than those in their home. Our results resembled those reported by Tolerico et al., who suggested significantly higher use of MWCs during the NVWG than in the home [17]. However, our cohort was less active during both the NVWG and during their use in their home environments than the participants in Tolerico et al.'s study: distance during the NVWG was 4.4 vs 6.7 km and during home use, 1.3 vs 2.4 km. A difference was also identified in the velocity of wheelchair propulsion, with our cohort being slightly slower than participants in Tolerico et al.'s study: velocity during the NVWG was 0.76 m/s vs 0.96 m/s and during home use, 0.64 vs 0.79 m/s [17]. Results from the secondary analyses of data indicated a significant negative relationship between age of the wheelchair user and velocity of wheelchair propulsion. This trend has been commonly observed in ambulatory older adults, who often walk at a slower pace (velocity) than younger individuals [18]. This pattern was also observed with wheelchair propulsion velocities (for MWC users). When in their homes, our participants were for the most part pushing their MWCs at velocities <0.5 m/s. This finding could suggest use of short and uneven pushrim strokes. However, it is not conclusive enough, because the home environment (floor plan, furniture arrangement) for these participants was not evaluated.

For PWC users, our study found significantly greater driving distance during the 28th NVWG compared with home use (7.3 km vs 3.4 km). Our results were consistent with those reported by Cooper et al., who also reported higher use of PWCs during the 28th NVWG compared with use in the home (community) [11]. Our cohort was traveling faster with their PWCs during games than they traveled with their PWCs in their homes, which is also consistent with previous findings [11]. Our results were also consistent with those by Sonenblum et al., who found that the environment significantly affected the PWC mobility patterns for individuals with disabilities [15].

Understanding indoor and outdoor wheelchair use is important for older adults, who constitute one of the largest consumer groups for powered mobility devices (~50 k) [19]. The evidence to support selection of the most appropriate mobility device (PWC) and how it might benefit people's participation and quality of life is very limited [20]. This result could be because the research done in this area

(a)



(b)

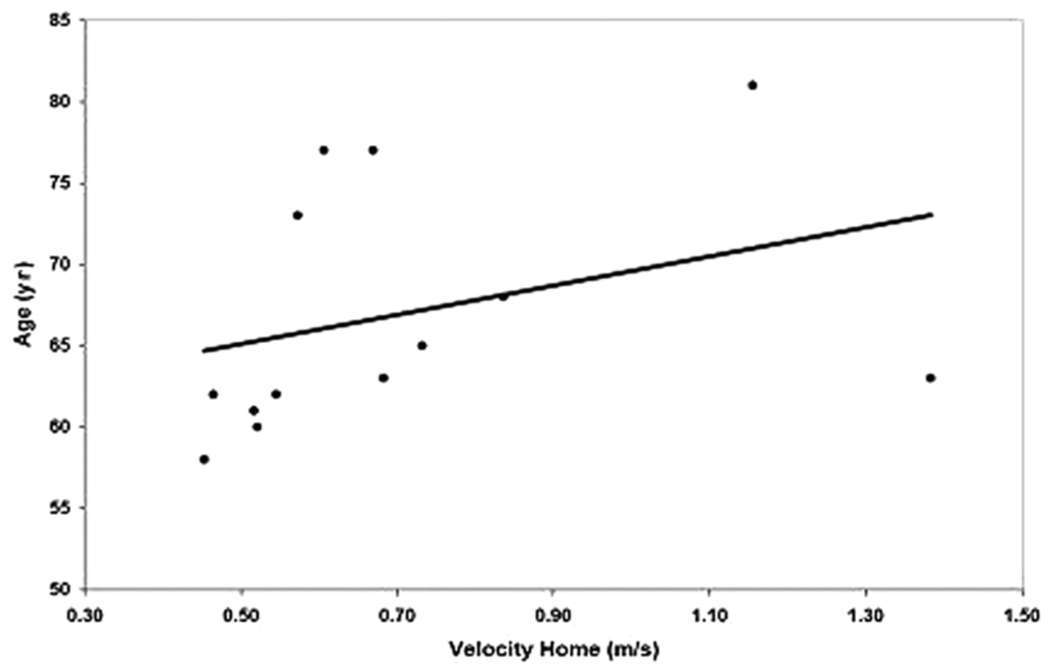


Figure 3.
Relationship between variables for **(a)** manual wheelchair (age and propulsion velocity) and **(b)** power wheelchair groups (age and driving velocity)

has been based on self-reports from users, without objective usage data, which has limited strength of the evidence [21].

Our study found a moderate negative relationship between age and propulsion velocity in MWC users. This finding may also raise several concerns, particularly with respect to increased repetitions in propulsion patterns, which can lead to overuse injuries [22–23]. Future research using biomechanical and physiological methods to examine these issues within a controlled environment is required for evaluating this assumption. Understanding that older adults propel wheelchairs at a slower speed is also important for future research, since some of the previously conducted studies (in laboratory environments) have had selected propulsion velocities that are much higher than the rates of natural propulsion patterns of older adults [22,24].

For the PWC cohort, our results showed a significant positive correlation between age and wheelchair driving velocity. While we cannot derive any conclusions from this finding, a future line of work may warrant examining mobility patterns for older adults transitioning from MWCs to PWCs and determining their relationship to functional independence and quality of life.

Our study recruited a convenience sample of older veterans attending organized sporting events (NVWG). We realize that this cohort does not represent a typical wheelchair-using older adult living in the community or in an institutional setting (assisted-living or nursing home). Therefore, generalization of the results to the civilian population, as well as to those veterans who do not participate in such events, could be limited. Wheelchair usage data are lacking for older adults living within various communities and in institutional settings. This, in turn, has limited the evidence that supports providing customized wheelchairs to older adults. This limitation could be overcome by conducting studies that recruit both the older adult population living in the community as well as those living in institutional settings.

Most of our participants (21 out of 26 for MWCs; and 9 out of 13 for PWCs) reported owning a backup, or secondary, wheelchair. We attached a data logger only onto their primary wheelchairs, which could have resulted in underestimating their overall wheelchair mobility. Future research should include attaching data loggers to secondary wheelchairs so researchers can determine the interchangeability of wheelchair use.

Another limitation pertains to the data-logging devices themselves. Data regarding wheelchair-related activities (for MWC group) could have reflected both active use (participants using their wheelchairs) and passive use (someone propelling the wheelchairs for the participants). Although one of the inclusion criteria for the study was independent wheelchair use, instances may have occurred when wheelchair mobility involved both active and passive uses. The data loggers were not sensitive enough to make this distinction. In the future, a data reduction program using machine-learning algorithms could develop a model capable of distinguishing between active and passive uses. Wheelchair data loggers measure one dimension of wheelchair-related mobility and do not compute energy expenditure or exertion levels. Future research should consider a relationship between these two dimensions (mobility and energy expenditure) for a more complete picture of wheelchair-related mobility in the MWC group.

CONCLUSIONS

Results from our study suggest that "context/environment" affects the extent of wheelchairs use among older adults. Wheelchair data-logging is very effective and unbiased in objectively evaluating wheelchair use. Understanding wheelchair usage will enable clinicians to better match older adults with the appropriate wheeled mobility device to meet their (mobility) needs.

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Acquisition of data: A. M. Karmarkar, H. Wang, A. Kelleher, R. Cooper.
Analysis and interpretation of data: A. M. Karmarkar, R. A. Cooper.
Drafting of manuscript: A. M. Karmarkar, R. A. Cooper.
Critical revision of manuscript for important intellectual content: A. M. Karmarkar, R. A. Cooper, H. Wang, A. Kelleher, R. Cooper.
Statistical analysis: A. M. Karmarkar.
Obtained funding: R. A. Cooper.
Administrative, technical, or material support: R. Cooper.
Study supervision: R. A. Cooper.

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Institutional Review: The VA Pittsburgh Healthcare System Institutional Review Board approved the study, and all participants signed a consent form to enroll in the study.

Participant Follow-Up: The authors do not plan to inform the participants of the publication of this study. However, the authors will post the citation of the study on the HERL Web site.

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