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Pilot study for quantifying driving characteristics during power wheelchair soccer

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Abstract—This study determined the driving characteristics of wheelchair users during power wheelchair soccer games. Data for this study were collected at the 28th and 29th National Veterans Wheelchair Games. Nineteen veterans who were 18 years or older and power wheelchair soccer players completed a brief demographic survey and provided information about their power wheelchairs. A customized data-logging device was placed on each participant's wheelchair before power soccer game participation. The data logger was removed at the end of the final game for each participant. The average distance traveled during the games was 899.5 +/– 592.5 m, and the average maximum continuous distance traveled was 256.0 +/– 209.4 m. The average wheelchair speed was 0.8 +/– 0.2 m/s, and the average duration of driving time was 17.6 +/– 8.3 min. Average proportion of time spent at a speed >1 m/s was 30.7% +/– 33.8%, between 0.5 and 1 m/s was 16.2% +/– 34.4%, and <0.5 m/s was 21.4% +/– 24.3%. The information from this descriptive study provides insight for future research in the field of adapted sports for people with high levels of impairments who use power wheelchairs for their mobility.

Key words: activity, adapted sports, data logger, disability, mobility, National Veterans Wheelchair Games, power wheelchair, rehabilitation, veterans, wheelchair users.

INTRODUCTION

Participation in adapted sports has contributed significantly to the quality of life of veterans with disabilities [1–2]. Sports and recreation are of the utmost importance for maintaining or increasing functional capacity and psychological well-being for people with physical disabilities [3–4]. Regular physical activity has been found to reduce the risk of secondary complications and comorbidities associated with injury or disease and to increase functional capacity [3,5]. However, individuals with higher levels of physical impairment have difficulty participating in regular physical activity because of various limitations [6]. Therefore, individuals who rely on a power wheelchair (PWC) are at risk for adopting a sedentary lifestyle because of a lack of recreation and limited physical activity [6]. A paucity of literature exists on PWC use during sports and other mobility-related activities.

Power soccer is a team-based sport for people with severe disabilities that is gaining popularity among individuals who rely on a PWC for mobility [5,7]. The performance

Abbreviations: CP = cerebral palsy, HERL = Human Engineering Research Laboratories, MWC = manual wheelchair, NVWG = National Veterans Wheelchair Games, PWC = power wheelchair, SCI = spinal cord injury, VA = Department of Veterans Affairs.

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and quality of the play depends on a fast response, speed, turning radius, sound braking control, and strategic passing and positioning abilities [7–8]. Power soccer is a contact sport and each player's wheelchair is equipped with a foot guard to protect the player from impact injury. Little information is available on the mobility patterns and demographic characteristics of individuals who play power soccer. This type of information could be vital for customizing PWCs and their associated components, battery designs, and other specifications to enhance athletic performance and reduce risk of injury during PWC sports [9–10].

In the past, the majority of research was conducted on wheelchair use during sport or activity with nondisabled participants. For example, Reid and Prupas conducted a literature review of 436 articles from 1986 to 1996 related to disability sports [11]. After analyzing the literature, they found that the majority of research was conducted with nondisabled athletes and the results were then compared with individuals with disabilities [11]. Participation in adapted sports has been rising steadily as a result of new innovations and the growth of science and technology, with better assistive devices to enhance functional capacity in individuals with disabilities [2,12]. Advancements in science and technology have produced adapted equipment that allows individuals with disabilities to achieve or even surpass records held by nondisabled athletes [2,12–13]. The role of technology in measuring performance in adapted sports is growing, which could enhance the training efficiency.

Limited research has been conducted on the driving characteristics of PWC users in adapted sports. Several studies have been conducted on the driving characteristics of PWC users during community activities. Sonenblum et al. [14], in a 2008 study of persons who used PWCs in their homes and communities, found that the participants traveled a median of 1.085 km over 58 min. Daily distance traveled and time spent wheeling varied widely between and across study participants. The measure of wheelchair occupancy presented with the least variation [14]. Cooper et al. found that veterans participating in the National Veterans Wheelchair Games (NVWG) traveled longer distances at higher speeds than civilians traveling in their communities [9]. In addition, this study found that participants traveled at a speed considerably less than the wheelchair's maximum speed (approximately 2.7 m/s) most of the time. In another pilot study, Cooper et al. used customized data loggers to quantify the mobility patterns of children using manual wheelchairs (MWCs) and PWCs in community settings [15]. Data analyzed from the customized data-logging devices revealed that the children who used PWCs drove 1,752.42 m/d at a speed of 0.75 m/s. Ferretti also used wheelchair data loggers to measure the mobility patterns of people using either MWCs or PWCs [16]. Significant correlations between average driving minutes and community participation were found among people using PWCs. A study by Sporner et al. quantified the activity of MWC users during wheelchair basketball and rugby [17]. During the sports activities, wheelchair rugby athletes were found to travel approximately 2,300 m at 1.33 m/s and the wheelchair basketball players traveled approximately 2,700 m at 1.48 m/s [17].

The U.S. Paralympics Committee has given high priority to research on disability sports [18]. An evidence-based approach is needed to determine factors that may affect the performance of power soccer players. Data derived from this approach may improve the prescription criteria and ensure that appropriate PWC designs are being issued to the individuals with disabilities engaged in organized competitive sports. To support the evidence-based approach, the purpose of this pilot investigation was to characterize wheelchair-related mobility patterns of athletes during power soccer games.

METHODS

Participants

The Human Engineering Research Laboratories (HERL), a joint research venture between the Department of Veterans Affairs (VA) Pittsburgh Healthcare System and the University of Pittsburgh, has permission to collect research data during the NVWG. Centrally located booths were set up for subject recruitment. Veterans who approached the booths were told about the research being conducted at the NVWG and were invited to participate.

The data for this study were collected at the 28th NVWG held in Omaha, Nebraska, in 2008 and the 29th NVWG held in Spokane, Washington, in 2009. To be eligible, participants had to be 18 years or older and participate in power wheelchair soccer at the NVWG.

Instrumentation

A custom data-logging device (**Figures 1** and **2**) was used to monitor PWC usage during soccer games. These caster data loggers were designed and developed at HERL and have been used in multiple studies to assess movement (**Figure 2**). The front or back casters of participants' PWCs were replaced with a caster wheel with a data logger in its

Figure 1.
Custom data-logging device used to monitor power wheelchair usage during soccer games.

Figure 2.
Custom caster data-logger designed to assess power wheelchair movement.

hub. The device measures wheel rotations through use of three reed switches mounted 120° apart on a circuit board and magnets mounted on the side of a custom-designed axle insert. Every time the wheelchair wheel rotated more than 120°, the magnet triggered one of the reed switches. As each reed switch was triggered, a date and time stamp of that event was recorded in the device.

As a participant exited the tournament, the caster containing the data logger was removed and the participant's original caster was put back on his or her wheelchair. Time stamp data from the data-logging devices were used to calculate the following variables: (1) average distance traveled, (2) average speed, (3) maximum continuous distance traveled, (4) duration of driving, and (5) proportion of time spent at different speed levels. For this study, only the first two recorded games were used, because each participant played a different number of games. However, not all participants were able to stay in the tournament to record two or more games worth of data.

Terms used in this analysis are defined as follows: "duration of driving" is the total amount of time the wheelchair was in motion, "stop" is a pause in motion lasting 2 s or more, "average speed" is the figure represented by the duration of driving divided by the total distance driven, "maximum continuous distance" is the maximum distance traveled between two stops, and "maximum continuous speed" is the maximum speed traveled between two stops.

Study Protocol

Demographic information was collected on each participant by means of a survey that asked the participant's age, disability, years since injury or diagnosis, PWC type, training habits, and participation in other organized sports. A customized data-logging device was placed on each participant's PWC before his or her respective power soccer games. The start and end times of the power soccer games were recorded and used to calculate the mobility patterns for each game.

Data Analysis

For the analysis of the demographic data, categorical variables such as disability, sex, and race/ethnicity were represented with frequencies and percentages and continuous variables such as age and years since diagnosis or injury were represented with means and standard deviations. Activity levels during power soccer games could not be calculated on the basis of different users' interfaces, since only one participant used a chin-control joystick. Based on the results of previous studies that characterized the mobility patterns of wheelchair users in the community and during sports, the proportion of time spent by participants at three different speed levels was classified into high, medium, and low levels. Speeds more than 1 m/s were classified as high, speeds between 0.5 and 1 m/s were classified as medium, and speeds less than 0.5 m/s were classified as low. The analyses were done with SPSS version 15 (SPSS Inc; Chicago, Illinois).

RESULTS

The average (mean ± standard deviation) participant age was 56.8 ± 9.1 yr, and the average time since injury or the onset of disability was 26.6 ± 13.8 yr. Of the

19 participants, 18 (94.7%) were male. Thirteen (68.4%) had a spinal cord injury (SCI), three (16.0%) had multiple sclerosis, and three (16.0%) had had a stroke. Sixteen participants (84.0%) used rear-wheel drive PWC, and three (16.0%) used mid-wheel drive PWC. Demographic characteristics are presented in detail in **Table 1**.

The total duration of a power soccer game is 40 min, consisting of two 20 min periods. **Table 2** provides details of each participant's mobility patterns during the power soccer games. The overall average distance traveled by the 19 athletes was 899.5 ± 592.5 m, with a maximum distance traveled of 2,055.87 m. The average speed of all participants during games was 0.8 ± 0.2 m/s. The average maximum continuous distance traveled was 256.0 ± 209.4 m. The average driving time of participants during games was 17.6 ± 8.3 min. **Figure 3** shows the proportion of time each participant spent at the three different speed levels. The average proportion of time spent at the high speed (>1 m/s) was 30.4 ± 33.9 percent, the average proportion of time spent at the medium speed (0.5–1 m/s) was 16.3 ± 34.4 percent, and the average proportion of time spent at the low speed (<0.5 m/s) was 21.5 ± 24.3 percent.

Table 1.
Summary of demographic characteristics for 19 power wheelchair soccer players at 2008 and 2009 National Veterans Wheelchair Games.

Variable	Value
Age, Mean ± SD	56.8 ± 9.1
Years Postinjury or Onset of Disability, Mean ± SD	26.6 ± 13.8
Disability, *n* (%)	
SCI ($C_{3-4=6}$, $C_{5-6=7}$)	13 (68.4)
Multiple Sclerosis	3 (15.8)
Other	3 (15.8)
Race/Ethnicity, *n*	
White	15
Nonwhite	4
Sex, *n* (%)	
Male	18 (94.7)
Female	1 (5.3)
Wheel Drive, *n* (%)	
Rear-Wheel Drive	16 (84.0)
Mid-Wheel Drive	3 (16.0)
Residence, *n*	
Rural	4
Urban	5
Suburban	10
Type of Joystick, *n*	
Hand Control	18
Chin Control	1
Training Time, h	4.6

C = cervical (subscript numbers represent level), SCI = spinal cord injury, SD = standard deviation.

DISCUSSION

The results of our pilot study quantify the mobility patterns of power soccer athletes using data-logging devices on their wheelchair. The data gathered by these devices allowed us to calculate average distance traveled, speed, maximum continuous distance, and proportion of time traveled at three different speed levels during power soccer games.

To our knowledge, this is the first study to measure the mobility characteristics of PWC during power soccer game participation. Results of this study show that the mobility characteristics varied between power soccer participants. These results are consistent with previous data collected on the driving characteristics of PWC users in the community [14–16]. The current study found that the distance traveled by power soccer players ranged from 69.15 to 2,055.87 m, with a mean of 899.5 ± 592.5 m. Power soccer players were found to travel at an average speed of 0.8 ± 0.2 m/s for an average driving time of 17.6 ± 8.3 min (range 2.52 to 31.27 min). The results of the power soccer mobility characteristics are not consistent with the activity measured during wheelchair basketball and rugby [17]. Participants in the wheelchair rugby and basketball games tended to travel farther and faster than the power soccer players. Future studies should investigate the factors that influence mobility characteristics during wheelchair sports.

Barfield et al. monitored heart rate among people with SCI, cerebral palsy (CP), and muscular dystrophy competing in a national power soccer tournament [5]. They determined that disability type did influence heart rate responses during PWC sports, since the median heart rate responses for athletes with CP was significantly higher ($p < 0.01$) than athletes with SCI. In future research studies, it would be interesting to collect both heart rate and mobility characteristics of athletes using PWCs during sports to investigate whether heart rate is related to mobility patterns. Further, the PWC data logger may be an effective measuring device to monitor training

Table 2.
Participant characteristics and average mobility patterns during power wheelchair soccer games.

ID	Age (yr)	Body Weight (kg)	Games Played (No.)	Wheel Drive	Diagnosis	Distance (m)	Speed (m/s)	Max Continuous Distance (m)	Drive Time (min)
1	62	225	2	RWD	SCI	1,053.84	0.60	187.36	28.56
2	52	120	2	MWD	MS	902.33	0.48	176.35	31.27
3	48	180	2	RWD	SCI	819.24	0.74	279.71	17.74
4	54	150	1	RWD	MS	1,620.39	1.09	591.77	24.77
5	38	195	2	RWD	SCI	69.15	0.45	15.32	2.52
6	63	164	2	RWD	MS	341.52	0.78	111.50	6.64
7	77	150	2	RWD	Other	2,055.87	1.29	464.20	26.48
8	61	250	2	MWD	SCI	484.73	0.70	140.65	11.42
9	53	165	2	RWD	SCI	825.62	0.96	192.04	14.37
10	60	177	2	RWD	SCI	1,926.07	1.16	516.86	27.69
11	51	155	1	RWD	SCI	1,426.54	1.28	779.66	18.49
12	67	135	2	RWD	SCI	1,629.65	1.22	442.17	25.01
13	68	230	2	RWD	SCI	519.31	0.73	126.71	11.53
14	53	180	1	RWD	Other	428.34	0.51	79.37	13.83
15	62	250	1	MWD	SCI	333.86	0.75	176.61	7.36
16	53	190	2	RWD	SCI	1,046.71	0.77	218.11	22.28
17	62	240	2	RWD	Other	401.85	0.47	55.75	14.01
18	50	140	2	RWD	SCI	602.41	0.69	156.29	14.20
19	45	239	2	RWD	SCI	604.32	0.59	155.12	16.73

Note: Total duration of time for each game is 40 minutes.
ID = identification, Max = maximum, MS = multiple sclerosis, MWD = mid-wheel drive, RWD = rear-wheel drive, SCI = spinal cord injury.

and provide a method to investigate whether a correlation exists between data-logger data and game performance.

Bumpers are applied to the PWCs to protect the feet of athletes from collisions with the soccer ball or other wheelchairs during the games. Measurement of the PWC speed during the games is an important consideration for bumper design to reduce the risk of injury and improve safety measures for the athletes [10]. Results indicate that during the soccer games most athletes maintained an average speed greater than 1 m/s. During the game, none of the participants exceeded the speed limit of power soccer, which was 2.8 m/s (6.2 mi/h) [7]. This speed limit was set by the Federation Internationale de Powerchair Football Association. For future research, the data logger can be vital in determining the duration of training hours and ease of maneuverability of PWCs, especially for individuals with higher levels of SCI, more involved physical disabilities, and progressive disabilities. Coaches could use speed and acceleration data to formulate training regimens based on per game requirements and the physical and functional capacities of athletes. In turn, this information may improve and refine the process of prescribing the most appropriate PWC design to power soccer athletes based on their mobility characteristics.

The limitations of this study are that all the participants were veterans and only one female consented to participate. Therefore, the results of the present study cannot be generalized to the entire PWC population participating in power soccer. Also, it might be interesting to collect speed data before the game and after the game (something we did not measure in this study), which could provide some valuable insight into how day-to-day travel in the home and community differs from PWC sporting events. Further studies are required to determine whether the distances traveled during the power soccer games differ based on the type of input control, chin-controlled versus hand-controlled joystick, or even wheelchair type. If such differences exist, then the need for classifying power soccer games on the basis of user interface may be necessary. Since 16 of the 19 study participants used PWCs with

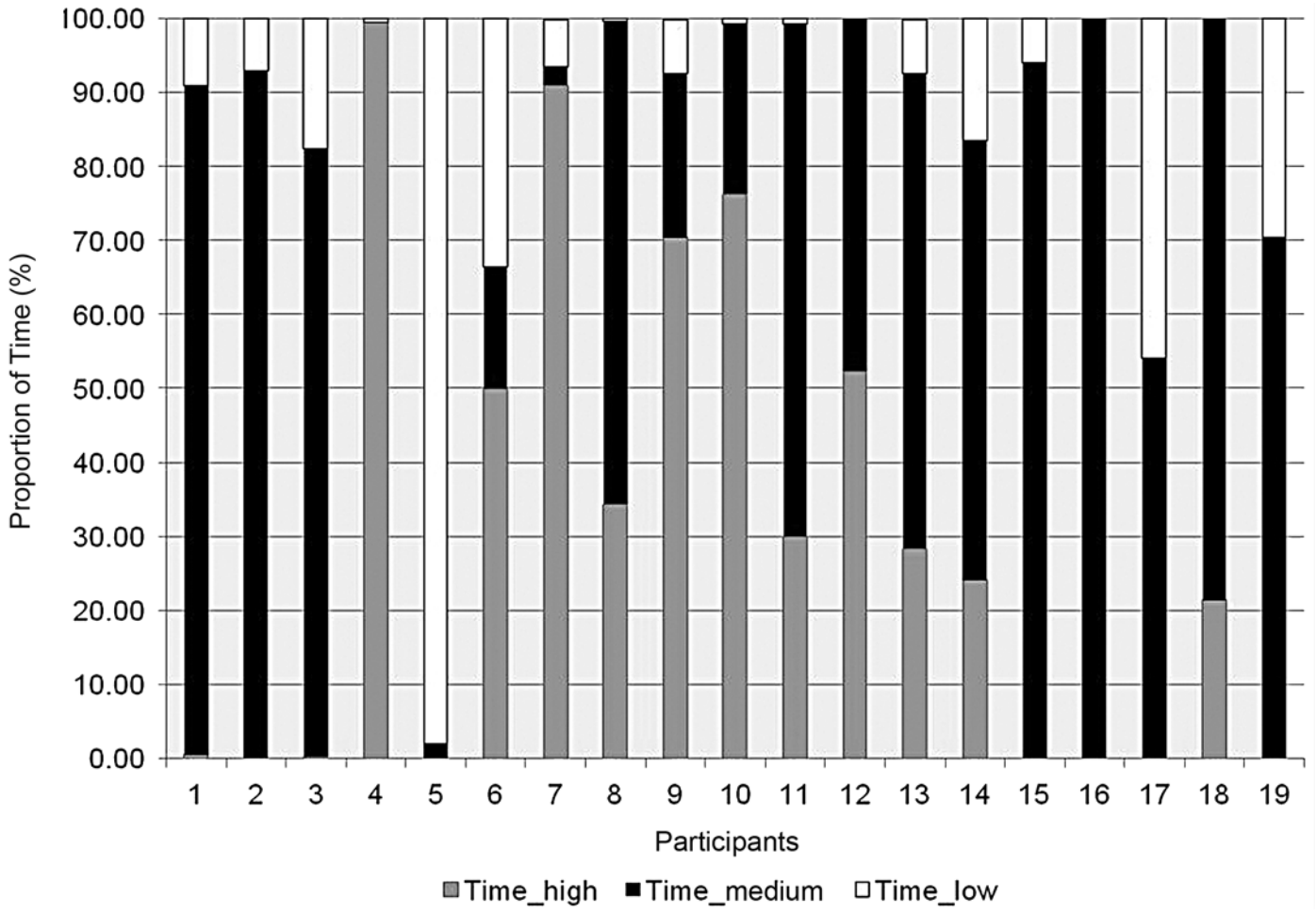

Figure 3.
Proportion of time (%) each participant spent at three different speed levels: high (>1 m/s), medium (0.5–1 m/s), and low (<0.5 m/s).

rear-wheel drive, no conclusive statements can be made about the effect of PWC drive wheel on the mobility characteristics collected in this study. We did not collect data from any front-wheel drive PWCs because the data-logger-equipped caster could not be fitted to front-wheel drive PWCs. Future studies should investigate the existence of differences in mobility patterns based on drive type of PWC.

CONCLUSIONS

Despite the growth in adapted sports in the United States, little information is available regarding activity monitoring or participation of athletes with higher level impairments, specifically those using PWCs for mobility in sports and recreation. In summary, this pilot study established the efficacy of PWC data loggers to quantify the mobility characteristics of PWC use during soccer games. The results of this descriptive study may provide future insights to researchers in the field of adapted sports for people with high-level physical impairments. Also, data loggers may play a significant role in optimizing sports performance through the design of customized PWCs, programmable controls (joysticks), and types of wheelchair drive (i.e., front-wheel, mid-wheel, or rear-wheel) to meet the demands of PWC games. Future studies may include electronic devices that quantify the level of increased or diminished participation in PWC sports or risks of adapted sports-related injuries such as seat shear during sports participation.

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Participant Follow-Up: The authors plan to inform participants of the publication of this study. They will include notification in the HERL Newsletter, which goes out to all of research participants who have expressed an interest in receiving it.
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