Spinal Cord (2015) 53, 561–564

www.nature.com/sc

ORIGINAL ARTICLE

Relationships between wheeling parameters and wheelchair skills in adults and children with SCI

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Study design: Cross-sectional.

Objectives: To determine the relationships between (1) wheeling parameters using the SmartWheel Clinical Protocol (SCP) and wheelchair skills (wheelchair skills test 4.1 (WST)) and (2) push effectiveness (m per push) and the WST, among individuals with spinal cord injury.

Setting: Biomechanics Laboratory, Canada.

Methods: Sixteen adults and eight children participated in this study. Multiple regression analyses were used to determine significant SCP predictors (that is, weight-normalised peak force, speed, push frequency and mechanical effectiveness) of WST score. To determine relationships between push effectiveness and WST scores, Pearson's correlations were calculated.

Results: SCP-TILE: speed and mechanical effectiveness explained 36% of the variance in the WST score. SCP-RAMP and SCP-CARPET: speed explained 58% and 37% of the variance in the WST score, respectively. Push effectiveness was significantly correlated with the WST score on all three surfaces (tile, ramp and carpet).

Conclusion: Wheeling speed was a significant predictor of the WST score for all surfaces tested. Regression analyses demonstrated that SCP-RAMP had the strongest relationship with WST score. Therefore, when time is restricted, the SCP-RAMP may be the most predictive test and speed may be the most useful variable to evaluate. However, the authors do not believe that one single variable should ever replace a full assessment of skills.

Spinal Cord (2015) **53,** 561–564; doi:10.1038/sc.2015.29; published online 17 February 2015

INTRODUCTION

Assessing an individual for the most appropriate wheelchair and wheelchair set-up is important for effective and safe use of the wheelchair. Appropriate assessment tools can result in a well fit and configured manual wheelchair for individuals with spinal cord injury (SCI), which could help reduce shoulder pain and improve wheelchair skills and function. The development and use of clinical tools to help evaluate wheeled mobility is essential, given that 65 million people around the world require a wheelchair for their mobility.[1]

Two of the most studied methods of evaluating manual wheeling capacity used by clinicians and therapists in prescribing wheelchairs are as follows: (1) the wheelchair skills test (WST)[2] from Dalhousie University, which assesses specific wheelchair skills, and (2) the SmartWheel Clinical Protocol (SCP), which uses an instrumented wheel to measure kinetic and temporal–spatial variables. The WST (4.1) is a reliable measure of capacity of skill (test–retest intraclass correlation coefficient = 0.90); however, it is less reliable for evaluating whether a skill is performed safely (test–retest intraclass correlation coefficients = 0.25).[3,4] The WST has been used by researchers as an outcome measure of total skill, as well as a clinical tool to evaluate individual skills in various adult[4] and paediatric[5] populations. Many studies have been published on the use of wheelchair skills assessments to evaluate an individual's capacity to propel and manoeuvre a manual wheelchair in different environmental conditions.[6–9] The skills included in the WST were modelled on activities of daily living and not surprisingly have been shown to predict quality of life and community integration.[10]

In addition to wheelchair skills tests that have gained popularity among researchers and clinicians, instrumented measurement wheels have been used by researchers and rehabilitation centres to record and evaluate handrim kinetic and temporal-spatial data during wheeling.[11,12] Commercially available instrumented wheels (for example, SmartWheel[11] and Optipush[12]) have been developed with software to enable clinicians to obtain biomechanical data about how a client propels their wheelchair. The SCP evaluates biomechanical variables while a client wheels on three surfaces (tile, carpet and 5° ramp). A normative clinical database was created from SCP data to describe wheelchair propulsion in adults with SCI.[11]

The SCP is a reliable tool for wheelchair users with SCI.[13] High intersession reliability was determined for force, push frequency, push angle and speed (for a single trial) with intraclass correlation coefficients ranging from 0.70 to 0.85. Intersession reliability increased when an average of five trials were computed. The SCP average of five trials on the 5° ramp surface increased the reliability to a range of 0.97–0.98.[13]

Askari *et al.*[14] created the wheelchair propulsion test (WPT) in an attempt to be more inclusive of all wheelchair users including hand and foot propellers, and young children whose small diameter wheels

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Received 23 June 2014; revised 6 January 2015; accepted 15 January 2015; published online 17 February 2015

may not be compatible with an instrumented wheel. The WPT was created to be a 'low tech' measurement tool, which could be used in less-resourced settings as it only requires a tape measure and stop-watch to calculate speed (m s^{-1}), push frequency (#pushes s^{-1}) and push effectiveness (m per push) over 10 m of wheeling. This tool has a high inter-rater reliability (intraclass correlation coefficients = 0.96, 0.83 and 0.80 for speed, push frequency and push effectiveness, respectively). However, intersession (that is, test–retest) reliability for the WPT has not yet been determined. The authors compared the WPT to an instrumented wheel and found that speed and push frequency, measured with a tape measure and stop-watch, correlated well with the values obtained from their instrumented wheel. Interestingly, push effectiveness was significantly lower when evaluated with the stop-watch method compared with the values obtained with an instrumented wheel, thus an instrumented wheel may be more accurate.[14]

Although there are reliable and valid tools for evaluating wheelchair propulsion, it is unclear whether they are related to each other. The primary objective of this study was to examine the relationship between the SCP variables (weight-normalised peak force, speed, push frequency and mechanical effectiveness) and the WST score among a population of adults and children with SCI. The secondary objective was to examine the relationship between the WST score and the WPT's push effectiveness in this same population. We hypothesised that SCP variables would be predictive of overall skill and specifically that the WST score and push effectiveness would be highly correlated.

MATERIALS AND METHODS

Participants

Individuals who had an SCI (traumatic/non-traumatic) and used a manual wheelchair for >50% of their daily mobility were recruited to participate in this study. Participants were recruited via advertisements at adult and paediatric outpatient rehabilitation centres. Inclusion criteria included the following: 10–65 years of age, able to understand English, follow directions and have a wheelchair with 22′, 24′ or 25′ wheels with quick release axles. We certify that all applicable institutional and governmental regulations concerning ethical use of human volunteers were followed during the course of the study. Demographic and clinical background information were obtained from participants. This information included age, sex, diagnosis/ level of injury, height, weight and type of wheelchair used (Table 1).

Table 1 Participant demographics ($n = 24$)

Age	Sex	Diagnosis/lesion level	Weight (kg)	Height (cm)	Type of wheelchair
10	F	Spina bifida	31	158	Colours
11	M	T2/3	61	166	Quickie GT
12	M	SCI (lesion unknown)	79	165	Quickie Q7
13	M	T10	27	152	Quickie zippie
15	M	T4/5	60	168	Crossfire invacare
17	M	Spina Bifida	71	182	Ti
17	F	SCI (lesion unknown)	32	165	Ti lite YG
17	F	Spina bifida	64	157	Invacare
19	M	Spina bifida	61	168	Ti lite
20	M	SCI (lesion unknown)	112	180	Ti lite
23	F	L1	45	165	2 RA
23	F	T12	73	163	Quickie GTA
25	M	T12	60	166	Ti lite TRC
27	M	T2	79	191	Quickie GT
30	M	Spina bifida	45	163	Invacare
30	M	SCI (lesion unknown)	72	173	Elevation
34	M	C4/5	66	178	Top end
34	M	C5/6 (incomplete)	72	180	Elevation
35	M	T12	62	175	Quickie GT
35	M	T5/6	88	178	Quickie terminator
35	M	C6 (complete)	82	185	Ti lite arrow Z
42	F	T5	68	165	Invacare A4
52	F	C4/5 (complete)	57	173	Quickie TI
55	M	T7	68	185	Ti lite folder
61	M	T11	104	178	Quickie 2

Abbreviations: F, female; M, male; SCI, spinal cord injury.

Data collection—WST (4.1)

The WST Version 4.1 is an objective test of wheelchair skills.[4] The WST evaluates performance and safety for 32 skills including indoor skills (for example, forward and backward wheeling), community skills (for example, wheeling over potholes) and more advanced skills (for example, skills involving wheelies). Scoring of the WST involves calculation of a total percentage score where the numerator is the total raw score (that is, the number of skills awarded a pass) and the denominator is the number of applicable skills for both capacity and safety. To ensure safety during all skills, an additional person acting as a spotter used a spotter strap attached to the wheelchair's rear axle to prevent tips. Testing was conducted by one of the two co-investigators trained in implementing the WST. Our analysis of the WST excluded three skills, including (1) gets from ground into wheelchair, (2) ascends stairs and (3) descends stairs. These skills were not performed because of time constraints or lack of adequate spotting for safety.

Data collection—SmartWheel

The SmartWheel (OutFront, Mesa, AZ, USA) was affixed to the participant's wheelchair on the side of their dominant arm. Participants were provided up to 5 min to familiarise themselves with the weight of the SmartWheel. The instrumented wheel uses six strain gauges to measure three-dimensional forces and moments applied to the handrim. The SCP requires participants to wheel at a self-selected speed for 10 m or 10 s, whichever occurs first, on three surfaces: tile, carpet and a 5° ramp. The SCP software calculated several biomechanical variables including weight-normalised peak force (%body weight), speed (m s^{-1}), push frequency (#pushes s^{-1}) and mechanical effectiveness (tangential force per total force).[11] In addition, the WPT's push effectiveness (m per push) was determined using the SmartWheel data for distance travelled and number of pushes applied to the handrim.

Statistical analysis

All statistical analyses were performed with the statistical software R (version 3.0.2, R Foundation for Statistical Computing, Vienna, Austria).[15] Multiple regression analyses were used to determine which SCP variables were predictive of the WST score, with separate analyses for each of the three surfaces (tile, carpet and ramp). Pearson's correlations were performed between push effectiveness and the WST score for each of the three surfaces. Significance was set to $P < 0.05$. Independent sample t-tests were used to compare variables between adult and paediatric participants to ensure that they were homogeneous and could be combined into one group.

Two of the SCP variables, peak force (%body weight) and speed (m s^{-1}), are often highly correlated and not surprisingly demonstrated multicollinearity, with the variation inflation factor values exceeding 2.0. Therefore, we opted to exclude peak force from the variable selection phase of the model building. To develop a parsimonious model, we removed the variable(s) with the highest (nonsignificant) P-value(s) and compared the nested models using analysis of variance. Tolerance level for variable selection was set to $\alpha = 0.1$.

RESULTS

Demographics for the 24 participants including age, sex, diagnosis/ level of lesion and wheelchair type are shown in Table 1. Kinetic, temporal-spatial wheeling variables and WST scores for both adult (18–52 years) and paediatric (10–17 years) participants showed no differences between age groups except for peak force (N) and push

Table 2 Wheeling parameters from the SmartWheel Clinical Protocol (tile) and wheelchair skills test scores for paediatric and adult groups

Variable	Paediatric group (n = 8), mean (s.d.)	Adult group (n = 16), mean (s.d.)	P-value
Age (years)	14.0 (2.9)	32.4 (10.4)	**0.000**
Number of pushes	7.6 (1.3)	7.0 (3.4)	0.628
Speed ($m s^{-1}$)	1.5 (0.3)	1.6 (0.4)	0.450
Push frequency ($push s^{-1}$)	0.95 (0.15)	0.91 (0.12)	0.456
Push angle (°)	67.3 (20.7)	80.0 (8.3)	**0.041**
Peak force (% body weight)	7.7 (2.5)	10.2 (3.8)	0.117
Peak force (N)	40.3 (22.4)	65.8 (18.1)	**0.006**
Push effectiveness (m per push)	1.4 (0.3)	1.6 (0.4)	0.152
Mechanical effectiveness (%)	72.8 (17.1)	72.9 (14.6)	0.978
Skill (%)	90.6 (6.9)	89.0 (12.1)	0.729

Critical $P = 0.05$.

Table 3 The relationship between SmartWheel Clinical Protocol variables and WST score (df = 23)

Multiple regression: SCP variables on tile vs WST	β	t-value	P
Dependent variable = WST; adjusted $R^2 = 0.36$; RMSE = 0.084; P = 0.003			
Speed	0.135	2.694	0.000
Mechanical effectiveness	0.249	2.091	0.048
Multiple regression: SCP variables on ramp vs WST			
Dependent variable = WST; adjusted $R^2 = 0.58$; RMSE = 0.070; P = 0.000			
Speed	0.180	5.807	0.000
Multiple regression: SCP variables on carpet vs WST			
Dependent variable = WST; adjusted $R^2 = 0.37$; RMSE = 0.083; P = 0.001			
Speed	0.188	3.852	0.001

Abbreviations: df, degree of freedom; RMSE, root mean square error; SCP, SmartWheel Clinical Protocol; WST, wheelchair skills test.

Table 4 Correlations between WST score and push effectiveness (df = 23)

Pearson's moment correlation: push effectiveness vs WST score	r	t-value	P
Tile	0.501	2.776	0.011
Ramp	0.632	3.914	0.000
Carpet	0.627	3.858	0.000

Abbreviations: df, degree of freedom; WST, wheelchair skills test.

angle (°), which were significantly larger in the adult group compared to the paediatric group (Table 2). The average number of pushes from the SCP included in the multiple regression analyses was 7.1 (range 5–10), 8.6 (range 5–11) and 9.3 (5–10) for tile, ramp and carpet, respectively.

For the relationship between SCP-TILE and WST, speed and mechanical effectiveness explained 36% of the variance in the WST score (Table 3). For the SCP-RAMP and SCP-CARPET, speed alone explained 58 and 37% of the variance in WST score, respectively (Table 3). Push effectiveness and WST score were strongly ($r > 0.5$) correlated for all surfaces (Table 4).

DISCUSSION

This study is the first to our knowledge that explores the relationships between SCP outcomes and wheelchair skills. The primary purpose of this study was to evaluate the relationship between the SCP variables and the WST score among manual wheelchair users with SCI. Our models showed that regardless of wheeling surface, speed was a significant predictor of WST score. Pradon *et al.*[16] also showed correlations between WST score and self-selected wheeling speed ($r = 0.57$; $r^2 = 0.32$) and maximal wheeling speed ($r = 0.72$; $r^2 = 0.51$). Although the ramp and carpet wheeling trials may not require maximal effort, they do require increased effort and power output compared with the tile trials. Wheeling on a ramp or carpet may be closer in intensity to the maximal wheeling speed test on the tile surface. If a clinician needed to minimise time spent on the SCP, using only the ramp or carpet trials could be feasible in a clinical setting and may also be predictive of a client's wheelchair skills.

The WPT may be a useful tool especially for less-resourced settings; however, the outcome's sensitivity to change is important to consider. Knowing the minimal detectable change of the WPT, specifically the push effectiveness, will be useful in determining whether it will be adopted as a valuable outcome measure for evaluating the impact of an intervention.

Previous research has shown that wheeling biomechanics is dependent upon wheeling surface (for example, tile, ramp, and carpet).[17] Koontz *et al.*[17] found that when wheeling up a ramp, wheelchair users travelled shorter distances per push, used more pushes and had a slower average velocity, which they postulated to be the result of increased deceleration between pushes. Thus, it must be acknowledged that wheeling biomechanics performed on ramp or carpet are different from wheeling on tile.

Our study is one of the first to include adult and paediatric populations in the same cohort. Research in this field is often plagued with small sample sizes, and this study is no exception. However, we believe that the combined adult and paediatric data ($n=24$) is sufficient to show relationships between the SCP and WST for individuals with SCI who are over 8 years of age. Surprisingly, this is the largest sample of data that evaluates both adults and children using the same protocol. There is not an abundance of literature on wheelchair propulsion in children. One study from the mid 1990's evaluated propulsion in 10 adults and 10 children,[18] whereas two other studies in 2013 only assessed children ($n=13$),[19] ($n=2$).[20]

We showed surprising similarities in wheeling parameters and skills between adult and paediatric wheelchair users with SCI (Table 2). Only peak force (N) and push angle (°) were different between the two populations with adults using significantly greater peak force (N) and longer push angles. Adults appear to use greater peak force on the basis of their larger mass considering that there were no differences in weight-normalised peak force. Our findings support the work by Bednarczyk *et al.*[18] who concluded that kinematics and kinetics were similar in adult and paediatric populations with SCI. Our paediatric SCI population was fortunate to have ultra lightweight wheelchairs, which were generally well fit. In addition, many children had participated in wheelchair sports, which allowed them to learn higher level skills. The two youngest participants (10 and 11 years old) had the smallest push angles (39.2º and 58º, respectively); however, their wheeling speeds (1.0 and 1.2 $m\,s^{-1}$, respectively) were not different compared with the adult speeds. Despite the age differences between the two populations evaluated in this study, the data support combining these two groups for the purpose of our analyses (Table 2). Although we standardized tyre pressure by pumping participants' tyres to the maximum recommended pressure, there may be confounding variables that we did not control for, such as wheelchair training experience, self-efficacy, level of SCI and wheelchair type or maintenance.[21] Four participants (one paediatric) received 100% on the WST, which may have introduced a ceiling effect into our results; however, there were no violations of any of the model assumptions that would bring into question the validity of our results. The ceiling effect was partially due to our exclusion of two very difficult skills (ascending and descending stairs). Future studies should evaluate all skills from the WST in order to reduce this ceiling effect and incorporate the newest version of the WST (4.2).[2]

In conclusion, there appear to be predictive relationships between wheeling parameters and wheelchair skills for individuals with SCI. Speed on tile and carpet and speed and mechanical effectiveness on ramp were significantly predictive of the WST score. Push effectiveness was also highly correlated ($r>0.5$) with WST score and may be a valuable outcome if skills testing is not available. Depending on the time or financial resources available to a clinician, performing a speed test on a ramp or carpet may be a valid and reliable method to follow a patient's wheelchair propulsion progress. However, the authors believe that the evaluation of biomechanical variables cannot replace a comprehensive evaluation of skills and that each tool has value in evaluating wheelchair propulsion.

DATA ARCHIVING

There were no data to deposit.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGEMENTS

This paper was partly funded by the Natural Sciences and Engineering Research Council of Canada (RGPIN 249489-07).

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