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ORIGINAL ARTICLE

Wheelchair Propulsion Test: Development and Measurement Properties of a New Test for Manual Wheelchair Users

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Abstract

Objective: To develop and assess some of the measurement properties of a simple and inexpensive test that can be used to evaluate the wheelchair mobility of manual wheelchair users.

Design: The initial phase of the study was developmental and descriptive. For the assessment of reliability and validity, correlations and comparisons were carried out using within-participant and subgroup comparisons.

Setting: Rehabilitation center.

Participants: Manual wheelchair users (N=58), a sample of convenience.

Intervention: The Wheelchair Propulsion Test (WPT) consists of wheeling 10m while time is recorded with a stopwatch, and the number of cycles and propulsion methods are recorded by observation. The WPT was administered once to each participant. Participants in subgroups involved in the assessment of reliability, construct, and concurrent validity had an additional WPT on the same occasion.

Main Outcome Measures: Derived measures—speed (m/s), push frequency (cycles per second) and effectiveness (meters per cycle)—from the WPT and, for concurrent validity, an instrumented rear wheel.

Results: Regarding intra- and interrater reliability, intraclass correlation coefficients ranged from .72 to .96. Content validity was qualitatively good. For construct validity, on univariate or multivariate analyses, we found statistically significant relations between WPT measures and age, sex, duration of wheelchair use, type of wheelchair frame, and rolling surface. For concurrent validity, the WPT and instrumented wheel variables were highly correlated (*r* range, .92−.99), and there were no clinically significant differences between them.

Conclusions: The WPT appears to be a simple and inexpensive test with good measurement properties that can be used for people who use hand and/or foot propulsion. However, further study is needed before widespread implementation can be recommended.

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Wheelchairs provide mobility and independence for many people with disabilities.[1] However, wheelchairs are not without their problems, including the frequent need for repairs,[2] a high incidence of injuries because of tip-overs,[3] and a high prevalence of upper-limb overuse problems.[4-7] A number of studies have been carried out on 2-hand propulsion in the able-bodied population and on people with spinal cord injury.[8-16] It has been suggested that optimizing propulsion mechanics could reduce the incidence of upper-limb problems.[17]

However, wheeled mobility is about more than the propulsion mechanics of people who use 2-hand propulsion and upper-limb overuse symptoms. Of at least equal importance is a wheelchair user's ability to get around in his/her environment and participate fully. There has been growing interest about people (eg, those with hemiplegia) who propel their wheelchairs with 1 or both feet in addition to or instead of their arms.[18-21] For instance, for people

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using the hemiplegic-propulsion pattern (1 arm and 1 leg), propelling the wheelchair backward may be helpful when resistance is encountered (eg, ascending inclines or negotiating soft surfaces).[21]

Despite the importance of wheelchair mobility in all its forms, what seemed to us to be missing was a simple and inexpensive test of intermediate granularity for the assessment of manual wheelchair mobility. Such a test would provide more detail than data loggers (that provide data, eg, distance traveled per day)[22,23] and skill profiles, such as the Wheelchair Skills Test (that provides data on success or failure when attempting each of a set of skills),[24,25] but less detail than that provided by instrumented wheels (eg, peak forces applied to the hand-rims)[26] and three-dimensional motion analysis (eg, elbow movement during the propulsion cycle).[14] Many clinicians and researchers do not have the time, expertise, space, or equipment to use these otherwise useful measures.

The objectives of this study were to develop and assess some of the measurement properties of a simple and inexpensive test that could be used by clinicians and researchers to evaluate the wheelchair propulsion of manual wheelchair users. Such a test would complement the existing measures of manual wheelchair mobility.

Methods

Study design

The initial phase of the study was developmental and descriptive. For the assessment of reliability and validity, correlations and comparisons were carried out using within-participant and subgroup comparisons.

Ethical issues

This study was approved by the Research Ethics Board of the Capital District Health Authority. All wheelchair-using participants provided informed consent.

Test development

The design criteria for the Wheelchair Propulsion Test (WPT) were that it should be simple and rapid to administer, be inexpensive, require little or no equipment, exhibit good measurement properties, require minimal training for the tester, require minimal time to analyze the data and generate a report, and be applicable to different rehabilitation populations (including hand and foot propellers). The results of the test should provide data regarding whether the test subject is able to safely and successfully complete the prescribed distance, direction of travel (forward or backward), limbs contributing to propulsion, steering or braking, time to complete the distance, total number of propulsive cycles, speed (meters per second), push frequency (cycles per second), push effectiveness (meters per cycle), nature of the hand and/or foot contact phases, and the nature of the hand and/or foot recovery phases. From these design criteria, we used pilot work to develop a preliminary WPT. The pilot work included videotaping some trials to confirm the ease with which the data could be validly collected by simple observation and a stopwatch.

We then held a focus group of 6 experienced people from diverse rehabilitation backgrounds (occupational therapy, physical therapy, physiatry, kinesiology, and rehabilitation engineering) to assist in content validation. We restricted the size of the group to facilitate discussion. None of the focus group members were members of the research team for this study. We made a brief presentation to the focus group regarding the objective of the test, distributed the draft WPT, and demonstrated it. In addition to the open-ended discussion, we posed a set of 11 questions (eg, "Should we use a standing or moving start…"). The 90-minute session was audio recorded and transcribed. On the basis of the focus group discussion, we refined the preliminary WPT, resulting in the version of the WPT that we used in this study (subsequently described).

List of abbreviations:

ICC	**intraclass correlation coefficient**
WPT	**Wheelchair Propulsion Test**

Wheelchair Propulsion Test

The WPT form and detailed instructions are shown in appendix 1. Briefly summarized, the wheelchair user is asked to wheel 10m on a smooth level surface from a stationary start. For safety, the tester serves as a spotter. For forward propulsion, the main safety concern is a rear tip when the wheelchair user begins to move forward. For backward propulsion, the main concern is a rear tip when the wheelchair user brings the wheelchair to a stop. To allow a single tester to serve as both a tester and a spotter, the tester positions him/herself within an arm's length of the back of the wheelchair, but slightly to 1 side to allow the data to be collected.[27]

The collected raw data were success in completing the 10m, the direction of travel (forward or backward), the limbs contributing to propulsion, steering or braking, the limb used for counting cycles, time (to the nearest s), number of cycles (in whole cycles completed), and whether proper propulsion techniques were used.

For participants who used $\geq$1 hands to propel forward, a correct contact phase was defined as when each hand generally began its contact with the hand-rim behind the top dead center of the rear wheel and remained on the hand-rim until ahead of the top dead center.[10] A correct recovery phase was defined as when each hand generally returned to the hand-rim using a path that was primarily beneath the hand-rim.[10] If using $\geq$1 feet for propulsion and going forward, a correct foot propulsion cycle was defined as when the participant generally made initial foot contact with the knee flexed $<90°$ from full extension and finished with the knee flexed $>90°$ (or the opposite if going backward).[19] Data were collected by observation and a stopwatch. Comments were recorded. Derived measures were speed (meters per second), push frequency (cycles per second), and effectiveness (meters per cycle).

Participants

We studied 58 manual wheelchair users, a sample of convenience. Because the WPT was a new test, there were no prior data on which to base a power analysis for the formal estimation of an appropriate sample size. However, our sample size was similar to that used to assess the measurement properties of another wheelchair mobility instrument.[24,25]

Recruitment and screening

Wheelchair-using participants were recruited by clinicians with whom they worked. Each participant was ≥17 years of age, was able to independently propel a manual wheelchair, had used a manual wheelchair for ≥14 days, used a manual wheelchair for ≥1 hour per day, was willing to participate, was competent to provide informed consent, and did not have any unstable medical conditions. We used these highly inclusive criteria because we were interested in the wheeled mobility of anyone who used a manual wheelchair regularly, even if a wheelchair was not his/her primary or long-term means of mobility. Each participant was screened for inclusion and exclusion criteria by a physician working with him/her.

Demographic and clinical data

Demographic and clinical data for each participant were collected by interview and chart review. We recorded age (y), sex (man/woman), setting (inpatient/outpatient), diagnosis accounting for wheelchair use, latency (time in years) from the onset of this diagnosis to WPT data collection, and the number of major comorbidities.

Wheelchair-usage and wheelchair data

By interview, we recorded how long each participant had used a wheelchair (y) and the hours of wheelchair use per day (<2, 2−5, 6−8 or >8). Except for the assessment of concurrent validity (as subsequently described), participants used their own manual wheelchairs. We recorded the frame type (folding/rigid), seat type (sling/dropbase), whether a cushion was used (present/absent), seat height (in centimeters to the top of the cushion, if any), and the number of footrests (0−2).

Measurement properties

Reliability

For a subset of 20 wheelchair users (10 who used 2-hand propulsion and 10 who used at least 1 foot for propulsion), we had a single rater administer the test twice (trials 1 and 2), with no more than 5 minutes between administrations. This provided data to assess intrarater reliability. During the first administration, a second rater simultaneously but independently recorded the raw data (trial 3) for the assessment of interrater reliability. Both raters were investigators and well versed in the test administration.

Validity

There are a variety of types of validity that can be assessed (and a variety of terms used),[24,28] of which we evaluated 3, which will be subsequently discussed.

Content validity is assessed by looking at the extent to which the measurement tool deals with the area of interest. This was assessed qualitatively, based on the literature, pilot work, and input from the focus group. We also qualitatively evaluated the extent to which the WPT met our design criteria.

We assessed construct validity by seeing if the WPT-derived measures (speed, push frequency, and effectiveness) identified expected differences.[20,21,24] We hypothesized that WPT-derived measures would be affected by age, sex, duration of wheelchair use, whether people used rigid-frame versus cross-brace folding wheelchairs, and whether they propelled on tile versus carpet surfaces. Most of these comparisons were possible by using WPT data collected from all participants during trial 1. The final question (tile vs carpet surfaces) was assessed using a subset of 20 wheelchair users who had the test administered twice, first on a smooth surface and then on an intermediate-pile carpet.

Concurrent validity is assessed by comparing the assessment method under study with an existing criterion standard. We compared the WPT against an instrumented rear wheel,[a] using a subgroup of 11 wheelchair users. For this component of the study, each participant needed to use a 2-hand propulsion method, to be able to fit in the single wheelchair that had been instrumented, and to be independent for transfers from his/her own wheelchair to the one that we used. The test wheelchair[b] was instrumented on the left with a 61-cm-diameter instrumented rear wheel and a matching wheel on the right side. The participant was transferred to the instrumented wheelchair, and the participant was given a few moments to get used to it. A WPT was performed while data were simultaneously collected using the instrumented wheel. The instrumented rear wheel wirelessly provided data on all cycles. These data were used to calculate speed, push frequency, and effectiveness to compare with the same variables determined from the WPT data.

Procedure

Each participant attended a single session that lasted <60 minutes. After informed consent, we collected the demographic, clinical, and wheelchair data. A standard WPT was administered to all participants. Members of the subgroups for specific aspects of the study (ie, reliability, carpet, and instrumented wheel) had the additional WPTs administered after a short rest.

Statistical analysis

All data were entered into a database,[c] and we used SAS statistical software (Version 9.2).[d] Descriptive statistics were calculated for all data. For the main focus of the article (the WPT derived parameters), there were no missing data. For the other parameters reported descriptively, there were relatively few instances of missing data. Our way of handling missing data was to indicate clearly in the results reported the number of participants for any parameter for which we did not have complete data. Nonparametric or parametric statistical tests were used depending on the normality of the continuous data. We used intraclass correlation coefficients (ICCs) to compare the derived measures (speed, push frequency and effectiveness) from trials 1 and 2 for intrarater reliability and to compare trials 1 and 3 for interrater reliability.

For the construct-validity assessments, to look at the relation between the WPT-derived measures and age or duration of wheelchair use, we used Spearman correlation coefficients. We used Wilcoxon 2-sample tests to compare the WPT-derived measures of men versus women and to compare participants who used rigid versus folding frame wheelchairs. For the tile versus carpet comparisons, we used Sign tests.

As part of our assessment of construct validity, we also conducted an analysis of variance, using the rank-ordered WPT-derived measures as the dependent measures and 4 other characteristics (age, sex, duration of any wheelchair use, and wheelchair frame type) as the independent measures. A strong relation was found between wheelchair frame type and age; therefore, only age was included in the final model. The independent variables were chosen based on our a priori expectations of factors likely to affect the WPT-derived measures. The number of independent variables was limited by the sample size. A logarithmic transformation was applied to the duration of wheelchair use to improve the fit of the model because of its positively skewed distribution. All variables were tested for multicollinearity, and model fit was assessed using fit and regression diagnostics.

For concurrent validity, to compare the measures derived from the instrumented-wheel data and the WPT-derived measures, we used Sign tests and Spearman correlation coefficients. Because the reliability and validity analyses were based on independent a priori hypotheses, we used alpha levels of .05.[29]

Results

Demographic and clinical data

The demographic and clinical data are shown in table 1. The participants' ages ranged widely (18–91y). Generally, participants were inpatients, they had a variety of diagnoses accounting for wheelchair use, and they had a few comorbidities.

Wheelchair usage and wheelchair data

These data are shown in table 2. The participants' median duration of any wheelchair use was 3 months, but the range was wide. Over half of participants used their wheelchairs for >5 hours per day. Most of the wheelchairs used had folding frames and were fitted with cushions. Only about one third of wheelchairs had bilateral footrests.

WPT data

Each administration of the WPT required ≤50 seconds to perform and record the data. The WPT data for trial 1 are shown in table 3. All participants were successful at completing the 10-m distance safely with no need for spotter intervention. All but 1 performed the task in the forward direction. An arm was more often monitored than a leg for the cycle count. We observed 7 of the 8 possible combinations of hand and foot steady-state propulsion patterns. Fifty-three (91%) participants used the hands alone or in combination with 1 or both feet. Twenty-one (36%) participants used 1 or both feet alone or in combination with 1 or both hands. For the 53 hand propellers, about one third had correct contact phases, and fewer than 10% had correct recovery phases. For 19 of the 21 foot propellers for whom we had data, a slight majority used correct contact phases. The variances (the magnitudes of the SDs in comparison with the mean values) of the speed and push frequency were high, as was the range of values for effectiveness.

Table 1 Demographic and clinical data (n=58)

Parameter	Data Type*	Values
Age (y)	Mean ± SD	58.1±17.9
Sex (male)	n (%)	35 (60.3)
Setting (inpatient)	n (%)	56 (96.6)
Diagnosis		
Amputation	n (%)	18 (31.0)
Spinal cord injury	n (%)	5 (8.6)
Stroke	n (%)	13 (22.4)
Traumatic brain injury	n (%)	2 (3.5)
Other	n (%)	20 (34.5)
Latency from diagnosis onset to WPT (y)	Median (range)	0.25 (0.04–49.91)
Comorbidities (no.)	Median (range)	3.00 (0.00–12.00)

* Mean ± SD data are reported when the data were normally distributed; otherwise, the median value and range of values are reported.

Table 2 Wheelchair-usage and wheelchair data

Parameter	n	Data Type*	Values
Duration of wheelchair use (y)	57	Median (range)	0.25 (0.03–50.0)
Hours of use per day			
<2h	57	n (%)	3 (5.3)
2–5h	57	n (%)	20 (35.1)
6–8h	57	n (%)	12 (21.1)
>8h	57	n (%)	22 (38.6)
Wheelchair components			
Folding frame	56	n (%)	50 (89.3)
Sling seat	56	n (%)	27 (48.2)
Dropbase	56	n (%)	21 (37.5)
Seat height (cm)	55	Mean ± SD	49.5±3.9
Cushion	56	n (%)	54 (96.4)
Seatbelt present	58	n (%)	29 (50.0)
Bilateral footrests	53	n (%)	17 (32.1)

NOTE. When the n values were <58, this was because of missing data.
* Mean ± SD data are reported when the data were normally distributed; otherwise, the median value and range of values are reported.

Reliability

The reliability results are shown in table 4. There were no clinically significant differences among trials. The ICCs ranged from .72 to .96 for intrarater reliability and from .80 to .96 for interrater reliability. The highest ICCs for both the intrarater and interrater reliability were seen for speed, followed in order by push frequency and effectiveness.

Validity

Content validity was qualitatively good, based on the literature, pilot work, and input from the focus group, as previously described. The suggestions of the focus group regarding specific elements of the WPT (eg, using a standing start) were included in the version of the WPT used for this study. Qualitatively, the WPT appeared to meet all of the design criteria, except that we did not assess the time needed to train testers.

For construct validity, using univariate statistics, we found that higher speeds were seen in younger participants ($P=.009$), participants with rigid-frame wheelchairs ($P=.015$), and when propelling on tile ($P<.001$). Lower push frequencies were seen with more experienced participants ($P=.044$) and on carpet ($P=.031$). Higher effectiveness was seen in younger participants ($P=.011$), participants using rigid-frame wheelchairs ($P=.022$), and on tile ($P<.001$). On multivariate analysis, we found

Table 3 WPT data (trial 1) (n=58)

Parameter	Data Type*	Values
Recorded data		
Able to successfully complete the 10m	n (%)	58 (100.0)
Direction of travel		
Forward	n (%)	57 (98.3)
Backward	n (%)	1 (1.7)
Limb monitored for cycle count		
Arm	n (%)	46 (79.3)
Leg	n (%)	12 (20.7)
Propulsion method		
2 hands	n (%)	37 (63.8)
1 hand	n (%)	0 (0.0)
1 hand and 1 foot	n (%)	8 (13.8)
2 hands and 2 feet	n (%)	4 (6.9)
2 hands and 1 foot	n (%)	3 (5.1)
1 hand and 2 feet	n (%)	1 (1.7)
2 feet	n (%)	4 (6.9)
1 foot	n (%)	1 (1.7)
Time (s)	Median (range)	15 (6−38)
Cycles	Median (range)	13.5 (2−41)
Hand—proper contact phases†	n (%)	19 (35.9)
Hand—proper recovery phases†	n (%)	4 (7.6)
Foot—proper contact phases‡	n (%)	11 (57.9)
Derived data		
Speed (m/s)	Mean ± SD	0.73±0.29
Push frequency (cycles/s)	Mean ± SD	0.98±0.30
Effectiveness (m/cycle)	Median (range)	0.74 (0.24−5.00)

* Mean and SD data are reported when the data were normally distributed; otherwise, the median value and range of values are reported.
† There were 53 hand propellers.
‡ There were 21 foot propellers, for whom data on the contact phases were missing for 2.

that speed was higher for younger participants (P=.003). Effectiveness was higher in younger participants (P<.001) and participants who were men (P=.031).

The concurrent validity results are shown in table 5. There were no statistically significant differences between the WPT and instrumented rear wheel data for speed or push frequency. There was a small (9%) difference for effectiveness (P=.039). The WPT and instrumented wheel variables were highly correlated.

Discussion

We accomplished our objective of developing a test of intermediate granularity that qualitatively appears to meet all of our design criteria except for ease of tester training, which we did not assess. The main advantages of the WPT are its simplicity, low cost, and usability for both hand and foot propellers. Although we did not do so with this study, the WPT could be used for distances greater than 10m and on a variety of surfaces (eg, rough ground and inclines).

A limitation of the WPT is that the cycle-count data are recorded from 1 side of the body. Persons with asymmetrical weakness in the upper limbs who use the 2-hand propulsion method might require more frequent pushes by the weaker limb than the stronger one. Similarly, for a person who uses both hands and feet to propel, the number of cycles might differ. Also, a wheelchair user could use a different combination of hands and feet to initiate motion than to maintain it.

Variations in how the WPT is carried out would be reasonable in such circumstances. For instance, a video recording could be used to capture both sides, or a second tester could be used. Also, if the focus of the assessment was on steady-state propulsion, it would be reasonable to use a moving, rather than a stationary, start. Variations in propulsion style within the 10-m task can be recorded in the comments section of the WPT form.

Another limitation of the WPT is that it assumes that correct propulsion technique has been conclusively demonstrated. Although some excellent work has been done to date,[8-16] it is likely that our understanding of the optimal 2-hand propulsion technique will evolve. Only about one third of the hand propellers in our study demonstrated correct contact phases, and fewer than 10% had correct recovery phases. If our understanding of correct propulsion is valid, this suggests the need for further training. Similarly, because only a slight majority of the foot propellers used what we had defined as correct contact phases (about which even less is known than about 2-hand propulsion), a case could be made for further training for this subgroup as well.

However, it should not be assumed that the same propulsion technique is equally appropriate for all wheelchair users. For instance, a person with limited shoulder range or with a more rearward position of the rear wheels may not be able to easily reach back behind the top dead center of the rear wheels. Encouraging such a person to use the “correct” propulsion pattern could lead to overuse symptoms rather than preventing them. Similarly, for foot propulsion, the nature of the seat and the characteristics of the footrests may limit the range through which the knee can effectively function.

We view the WPT as being potentially useful in both clinical and research settings. In the clinical setting, where space and time are often limited, the facts that the WPT can be carried out in less than a minute and in any uncluttered hallway make it very practical. Also, if a wheelchair user is undergoing wheelchair skills training and the

Table 4 Intrarater and interrater reliabilities for derived WPT values (n=20)

Variable	Trial 1	Trial 2	Trial 3	Intrarater* ICC (95% CI)	Interrater† ICC (95% CI)
Speed (m/s)	.78±.32	.80±.35	.82±.32	.96 (.91−.98)	.96 (.91−.98)
Push frequency (cycles/s)	.92±.31	.94±.30	.99±.33	.90 (.77−.96)	.83 (.63−.93)
Effectiveness (m/cycle)	.90±.44	.88±.34	.86±.31	.72 (.43−.87)	.80 (.58−.91)

NOTE. Values are mean ± SD or as otherwise indicated.
Abbreviation: CI, confidence interval.
* Trial 1 vs Trial 2.
† Trial 1 vs Trial 3.

Table 5 Concurrent validity—WPT vs instrumented wheel (n=11)

Derived Parameter	WPT	Instrumented Wheel	Sign Test *P*	Spearman Correlation Coefficient (*P*)
Speed (m/s)	0.62±0.29	.61±.27	.549	.99 (<.001)
Push frequency (cycles/s)	1.03±0.28	.92±.23	.065	.98 (<.001)
Effectiveness (m/cycle)	0.60±0.25	.66±.27	.039	.92 (.020)

NOTE. Values are mean ± SD or as otherwise indicated.

focus of the training is on improving propulsion technique, the WPT can be used to assess the wheelchair user's baseline characteristics and document improvement. In the context of research, the WPT has sufficiently good measurement properties to warrant its use as an outcome measure, depending on the objectives of the research study. The data that we collected on all participants (see table 3) represent the beginning of a normative data bank for the WPT.

We also accomplished our objective of assessing some of the measurement properties of the WPT. Regarding the reliability assessments, there were no clinically significant differences between trials, and the ICCs ranged from .72 to .96. For the intrarater reliability, because the 2 administrations of the test were carried out within 5 minutes of each other, we were reasonably confident that the wheelchair propulsion characteristics used by the participants would not have changed in any meaningful way during the interval. However, it is possible that subtle differences were present between the 2 test administrations. A slightly higher ICC value for intrarater reliability would probably have been found if the tester had recorded the data for both tests from a video recording of the test. The interrater reliability assessment had no such limitations—the 2 raters recorded the raw data during the same administration of the WPT.

Content validity was high, especially in relation to the defined design criteria for the test. Regarding the training of testers, we did not formally assess this criterion. However, learning to perform the WPT as investigators required only a few administrations. We estimate that a clinician or researcher, using only the materials provided on our website,[30] could learn to perform this test within 15 to 30 minutes. If the WPT is used in the future in clinical and research settings, it is likely that there will be refinements in how the test is carried out; this will add to the content validity.

Regarding construct validity, the extent to which expected differences were seen on univariate or multivariate analyses varied depending on the parameters assessed. Some of the expected differences were seen, and others were not. We interpret these findings as representing good, but not excellent, construct validity. Concurrent validity (comparing the WPT with an instrumented rear wheel) was very good—there were no clinically significant differences between the derived parameters, and the Spearman correlation coefficients ranged from .92 to .99.

Study limitations

This study had a number of limitations, some of which have already been discussed. Our sample size was small for some purposes. This may have led to type 2 errors for some of the statistical tests, and the small sample size limited the number of independent variables that could be assessed during multivariate analysis. The diversity of demographic and clinical characteristics of our participants undoubtedly added to the variability of the data, but this heterogeneity represents a strength with respect to the generalizability of our findings. Given that the median duration of wheelchair use of our participants was only 3 months and all participants were inpatients, our participants would have to be considered relatively inexperienced.

For the assessment of reliability and validity, we confined ourselves to the derived values (speed, push frequency, and effectiveness) rather than looking at all of the raw data elements (eg, correctness of the propulsion style). For the assessment of measurement properties, we complicated the analysis by simultaneously looking at all 3 derived measures rather than confining ourselves to a single outcome. However, all 3 derived measures performed well enough to warrant being retained within the WPT. For our assessment of test-retest reliability, we did not permit much time (5min) between test administrations. It would also be of interest to better understand the test-retest consistency over a longer interval. We suspect that wheelchair users may vary their propulsion styles depending on factors such as pain, fatigue, and environmental challenges.

Further research is needed to address the study limitations and to extend inquiries about the nature of manual wheelchair mobility. Some areas for future work have already been noted. Although a new test has been developed and its measurement properties have been assessed in a preliminary way, we do not yet know if clinicians and researchers will perceive a role for the WPT to complement existing assessment measures. Having other groups use the WPT in their own settings would provide valuable feedback that could be used to refine the instrument. We have placed the WPT form and sample video recordings on our website[30] to make it easy for others to use it. Taking a more formal approach to tester training should allow us to assess that design criterion more thoroughly. Other future work will include using the WPT on a wide range of manual wheelchair users to further assess usefulness and collect additional normative data.

Despite the study limitations and the need for further research, this study was successful in developing a new test and documenting some of its measurement properties. The WPT holds promise to provide insights into the various forms of manual wheelchair mobility. We hope that these insights will facilitate optimization of manual wheelchair propulsion in the future.

Conclusions

The WPT appears to be a simple and inexpensive test with good measurement properties that can be used for people who use hand and/or foot propulsion, and that complements existing measures. However, further study is needed before widespread implementation can be recommended.

Suppliers

a. SmartWheel; Out-Front, 1826 W Broadway Rd, Ste 43, Mesa, AZ 85202.

b. Quickie LXI; Sunrise, 7477 E Dry Creek Pkwy, Longmont, CO 80503.
c. Microsoft Access 2003; Microsoft Canada Co, 1950 Meadowvale Blvd, Mississauga, ON, Canada L5N 8L9.
d. SAS software, Version 9.2; SAS Institute, 100 SAS Campus Dr, Cary, NC 27513-2414.

Keywords

Outcome assessment (health care); Rehabilitation; Wheelchair

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WPT Version 1.0 Directions

A. Equipment and setup:
- Means of recording the time (to the nearest second).
- A 10-m path at least 1.2-m wide on a smooth level surface is needed, with at least 2m before the starting line and at least 2m beyond the finish line. The starting lines and path width should be clearly indicated. Note that longer distances (eg, 100m) can be used with the same methodology, depending on the purpose of the test.

B. Starting position: Wheelchair user seated in wheelchair at rest, with the wheel locks off, behind the starting line, facing forward or backward, at the wheelchair user's preference. The casters should be oriented as they will be for moving in the selected direction. The tester positions himself/herself where it is best possible to view the limb being used to record the number of cycles and to view the leading wheel as it crosses the finish line.

C. Safety: The tester is attentive to and in a position to spot for rear tips or forward falls from the wheelchair, especially during the starting and stopping stages of the test.

D. Instructions:
- The test subject may do a practice attempt to familiarize him/her with the instructions and to provide the tester with an indication of what limb should be used for counting the cycles and propulsion method.
- Orally or in writing, the tester instructs the test subject as follows: "When you are ready, please propel your wheelchair to the finish area using your usual method and speed." The tester should indicate the finish area beyond the finish line. If it becomes clear that the wheelchair user did not understand the instructions (eg, stopping before the finish line rather than beyond it), the test may be repeated.

E. What the tester records: The tester uses the form on the previous page to record the following data:
- Success at completing the 10-m task (yes/no).
- Direction of travel (forward/backward).

Appendix 1 WPT version 1.0 form

Subject No.: ____________________ Date: ____________ Time: ____________ Test No. ___________

Recorded Data*

1. Able to successfully complete the 10m distance?	Yes ☐ No ☐
2. Direction of travel	Forward ☐ Backward ☐
3. Limbs contributing to propulsion, steering or braking (tick all that apply)	Left: Hand ☐ Leg ☐ Right: Hand ☐ Leg ☐
4. Limb monitored for timing propulsion cycles (tick 1 limb)	Left: Hand ☐ Leg ☐ Right: Hand ☐ Leg ☐
5. Time (to nearest second)	_______ s
6. Total number of propulsive cycles (to nearest full cycle)	_______ cycles
7. If using ≥1 hands for propulsion in the forward direction, during the contact phases, did the subject generally begin the contact between the hands and the hand-rims behind the top dead center of the rear wheel?	Yes ☐ No ☐ Not applicable ☐
8. If using ≥1 hands for propulsion in the forward direction, during the recovery phases, did the subject generally use a path of the hands that was predominantly beneath the hand-rims?	Yes ☐ No ☐ Not applicable ☐
9. If using ≥1 feet for propulsion and going forward, did the subject make initial foot contact with the knee flexed <90° from full extension and finish with the knee flexed >90° (or the opposite if going backward)?	Yes ☐ No ☐ Not applicable ☐
10. Comments:	

Derived Wheelchair-Propulsion Data*

1. Speed: 10m/______ no. of seconds =	_______ m/s
2. Push frequency (cadence): _____ no. of cycles/______ no. of seconds =	_______ cycles/s
3. Effectiveness: 10m/_____ no. of cycles =	_______ m/cycle

Tester signature: ____________________ Tester name (print): ________________.

* Directions on next page.

- Limbs contributing to propulsion, steering, or braking (left arm, right arm, left leg, and/or right leg). Tick all that apply.
- Limb monitored for timing propulsion cycles (left arm, right arm, left leg, or right leg). Tick one. For people with hemiplegia using an arm and a leg, generally use the leg for counting the cycles.
- Time (to the nearest second) from when the leading wheels cross the starting line until they cross the finish line. The tester should not be obvious about timing the test, to avoid encouraging speed.
- Total number of propulsive cycles in 10m (to nearest full cycle). A cycle is defined as beginning when the limb being monitored makes the initial contact with the hand-rim (if an arm) or the ground (if a leg). The end of the cycle is when this event occurs the next time.
- If using $\geq$1 hands for propulsion in the forward direction, during the contact phase, did the subject generally begin the contact between the hands and the hand-rims behind the top dead center of the rear wheel? (yes/no/not applicable).
- If using $\geq$1 hands for propulsion in the forward direction, during the recovery phases, did the subject generally use a path of the hands that was predominantly beneath the hand-rims? (yes/no/not applicable).
- If using $\geq$1 feet for propulsion, did the subject make initial foot contact with the knee flexed $<90°$ from full extension and finish with the knee flexed $>90°$ (or the opposite if going backward)? (yes/no/not applicable).
- Comments: The tester notes anything relevant (eg, position on seat, trunk and arm posture, hand grip, foot contact, consistency, need for training, footwear, equipment worn, wheelchair issues).

F. What the tester calculates: The tester calculates the following derived parameters:
- Speed: 10m/no. of seconds = no. of meters per second
- Push frequency (or cadence): no. of cycles/no. of seconds = no. of cycles per second
- Effectiveness: 10m/no. of cycles = no. of meters per cycles

Note:
- No permission is needed to use the WPT, nor are there any charges.

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