The Wheelchair Circuit: Construct Validity and Responsiveness of a Test to Assess Manual Wheelchair Mobility in Persons With Spinal Cord Injury

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ABSTRACT. Kilkens OJ, Dallmeijer AJ, de Witte LP, van der Woude LH, Post MW. The Wheelchair Circuit: construct validity and responsiveness of a test to assess manual wheelchair mobility in persons with spinal cord injury. Arch Phys Med Rehabil 2004;85:424-31.

Objective: To assess the validity and responsiveness of the Wheelchair Circuit, a test to assess manual wheelchair mobility in persons with spinal cord injury (SCI).

Design: Longitudinal. Subjects performed the Wheelchair Circuit at the start (T1) and at the end (T3) of inpatient functional rehabilitation. Construct validity and responsiveness were assessed.

Setting: Eight rehabilitation centers in the Netherlands.

Participants: Seventy-four subjects with SCI admitted for inpatient rehabilitation.

Interventions: Not applicable.

Main Outcome Measures: The Wheelchair Circuit consists of 8 wheelchair skills and results in 3 test scores: ability, performance time, and physical strain. The construct validity of the Wheelchair Circuit was assessed by testing whether the test scores were significantly related to the subjects' functional status, physical capacity, lesion level, motor completeness of the lesion, and age. To prove the test's responsiveness, it was assessed whether the test scores had significantly improved between T1 and T3.

Results: For construct validity, 4 of the 5 hypotheses were confirmed. For test responsiveness, all 3 test scores had significantly improved during rehabilitation, and the standardized response mean values ranged from 0.6 to 0.9.

Conclusions: The Wheelchair Circuit is a valid and responsive instrument with which to measure manual wheelchair mobility in subjects with SCI.

Key Words: Rehabilitation; Spinal cord injuries; Validity of results; Wheelchairs.

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AN IMPORTANT ASPECT of daily life in the majority of persons with spinal cord injury (SCI) is their dependence on a wheelchair. In the Netherlands, approximately 82% of persons with SCI who are admitted for inpatient rehabilitation are wheelchair users, and 60% are completely wheelchair dependent.[1] For these persons, wheelchair use is conditional to achieve independent mobility. To function independently, manual wheelchair users must possess a variety of wheelchair skills, enabling them to deal with the physical barriers they will inevitably encounter in various environments.[2] Mastering wheelchair skills can make the difference between dependence and independence in daily life.[3,4] Training of these skills is therefore a vital part of the rehabilitation process. Within the scope of a longitudinal multicenter cohort study, a test to assess manual wheelchair mobility was developed: the Wheelchair Circuit.

The interrater and intrarater reliability of the Wheelchair Circuit is good.[5] The aim of the present study was to assess the construct validity and responsiveness of the Wheelchair Circuit. Construct validity is the degree to which the scores of the Wheelchair Circuit are related to variables that are hypothesized or known to be related to manual wheelchair mobility.[6] From the literature, we know that physical capacity, functional status, lesion level, motor completeness of the lesion, and age are directly related to the performance of wheelchair skills in persons with SCI.[7-19] We hypothesized that, when the construct validity of the Wheelchair Circuit is good, these determinants will be significantly associated with the test scores. Responsiveness, which is an aspect of validity,[20] indicates the ability of a measurement tool to detect functional change over time.[6,21] The responsiveness of the Wheelchair Circuit was assessed by comparing the scores achieved by subjects with SCI at the beginning of their inpatient rehabilitation period with the scores these persons attained at the end of their inpatient rehabilitation period. We hypothesized that a person's wheelchair skills would significantly improve during his/her rehabilitation period.

The aim of our study was to test the following 6 hypotheses: (1) the functional status of persons with SCI—assessed by the FIM™ instrument mobility score and peak power output during a maximum wheelchair exercise test—is significantly related to the scores of the Wheelchair Circuit; (2) the physical capacity (expressed as peak oxygen consumption) of persons with SCI is significantly related to their scores in the Wheelchair Circuit; (3) subjects with paraplegia perform better on the Wheelchair Circuit than subjects with tetraplegia; (4) subjects with motor incomplete lesions perform better on the Wheelchair Circuit than subjects with motor complete lesions; (5) age is inversely associated with the scores of the Wheelchair Circuit; and (6) scores of the Wheelchair Circuit improve significantly between T1 and T3.

METHODS

Participants

Our study was part of the Dutch research program Physical Strain, Work Capacity, and Mechanisms of Restoration of Mobility in the Rehabilitation of Persons with Spinal Cord Injuries.[22] In this program, persons with an acute SCI are being followed up during clinical rehabilitation. Subjects are eligible to enter the program if they have an acute SCI; are between the ages of 18 and 65 years; are categorized as class A, B, C, or D on the American Spinal Injury Association Impairment Scale (AIS); are wheelchair dependent; do not have a progressive disease or psychiatric problem; and have enough knowledge of the Dutch language to understand the goal of the study and the testing methods. Eight Dutch rehabilitation centers specializing in the rehabilitation of persons with SCI participate in this research program. Eight trained research assistants conduct the measurements, according to a standardized protocol. Subjects are assessed at 3 moments during inpatient rehabilitation: at the start of functional rehabilitation, defined as the moment that subjects are just able to sit in their wheelchair for (at least) 3 consecutive hours (T1); 3 months later (T2); and at the time of discharge from inpatient rehabilitation (T3).

For the study described in our report, only the results of T1 and T3 were used. This study was based on 74 subjects who participated in both measurements. Mean time between T1 and T3 was 177±87 days (range, 15–454d). Subjects' mean age at T1 was 40.5±14.5 years (range, 18–65y), and 51 subjects (69%) were men. There were 53 subjects with paraplegia, including 18 subjects with a motor incomplete lesion, and 21 subjects with tetraplegia, including 9 subjects with a motor incomplete lesion.

Procedure

The measurements for our study assessed the main lesion characteristics, the subjects' physical capacity, and the subjects' functional abilities. Tests were performed on 2 different days (at the same time of the day, no more than 1wk apart). To avoid influencing test results, subjects were asked to consume only a light meal; to refrain from smoking, drinking coffee, and drinking alcohol at least 2 hours before each measurement; and to void their bladder directly before testing. All subjects completed a consent form after they had been given information about the test procedures. All tests and protocols were approved by the Medical Ethics Committee of the Institute for Rehabilitation Research, Hoensbroek.

Two contraindications for the Wheelchair Circuit and the maximum exercise test were (1) cardiovascular diseases: the absolute contraindications as stated in the American College of Sports Medicine's 2000 guidelines[23] and a resting diastolic blood pressure greater than 90mmHg or a resting systolic blood pressure greater than 180mmHg and (2) severe musculoskeletal complaints of the upper extremities, neck, or back.

After inclusion in the cohort, subjects were examined by their rehabilitation physician to check for any of these contraindications.

Measurements

On the first test day, subjects' lesion characteristics were assessed and subjects performed the Wheelchair Circuit. On day 2, the FIM was assessed and subjects performed the maximum wheelchair exercise test (including a wheelchair drag test).

Lesion Characteristics

Lesion characteristics were assessed by a physician according to the International Standards for Neurological Classification of Spinal Cord Injury[24]: the AIS classifications A and B were defined as motor complete and classes C and D as motor incomplete. Neurologic lesion levels at or caudal to the T1 vertebra were defined as paraplegia, and lesions cranial to the T1 vertebra were defined as tetraplegia.

The Wheelchair Circuit

The Wheelchair Circuit[5] consists of 8 different standardized items that are conditional to achieve independent wheelchair mobility. The items used in the circuit were adapted from the mobility-related tasks used by Dallmeijer,[8] Janssen,[12] and Harvey[25] and colleagues. Items of varying difficulties were selected to make the circuit suitable to assess the wheelchair skills of persons with different competence levels. Appendix 1 provides a detailed description of instructions and scoring for each test item. The items were performed in a fixed sequence, on a hard and smooth floor surface or on a motor-driven treadmill, all using a standard test wheelchair (see below). During the performance of the circuit, the ability to perform the test items, the performance time of the figure-of-8 shape and the 15-m sprint, and the peak heart rates during the 3% and 6% slope items on the treadmill were recorded.

The main score of the Wheelchair Circuit is the ability score. All items that can be performed adequately and independently are assigned 1 point. There are 3 items that can also be scored as partially able (crossing a doorstep, mounting platform, transfer) and can then be assigned half a point. All points are summed to give an overall ability score. The ability score ranges from 0 to 8, is easy to calculate, and provides information about the ability of subjects to perform the various test items.

Besides the ability score, 2 other scores express subjects' performance on the Wheelchair Circuit: (1) the performance time score and (2) the physical strain score. The performance time score is the sum of the performance times of the figure-of-8 shape and the 15-m sprint. Subjects were instructed to perform these 2 tasks at their maximum speed. The physical strain score provides information on the physical strain induced by the performance of the 3% and 6% slope items. These items are performed on the treadmill with the same belt velocity for all subjects (.56m/s) and have a fixed performance time. The physical strain score can be expressed in 2 ways. First, it is expressed as the mean of the peak heart rates (in beats/min) reached during each of the 2 slope items. This scale can be used when subjects' performances are compared longitudinally. In our study, the mean heart rate was used to assess the responsiveness of the physical strain score. Second, it is expressed as the mean of the peak heart rates reached during each of the 2 slope items, which is expressed as percentage heart rate reserve (%HRR). The HRR is the difference between the maximum heart rate (HRpeak) (in beats/min) and the heart rate at rest (HRrest) (in beats/min).[26] The %HRR is calculated according to the formula

$$\%HRR = (HRslopes–HRrest)/(HRpeak–HRrest) \times 100\%$$

HRpeak was assessed during a maximum wheelchair exercise test (described below), and HRrest was measured after 5 minutes of rest, with the subjects sitting quietly in the wheelchair.

The heart rate response expressed relative to the HRR is used when comparisons between subjects are performed. The %HRR provides a relative measure to estimate physical strain because a correction is made for interindividual differences in HRpeak and HRrest.[12,27] In our expanded study, the %HRR will be used when relations between the physical strain score and other variables are studied.

The 2 additional scores of the Wheelchair Circuit can be used to further differentiate wheelchair skill performance or to detect changes in test performance in those subjects who have attained the maximum ability score.

Functional Independence Measure

On the second day, subjects' functional status was measured using the FIM (Dutch version 5.0).[28] For our study, only 4 items of mobility and locomotion were taken into account (transfer bed, chair, wheelchair; transfer toilet; transfer tub and shower; walk and/or wheelchair). Each item in the FIM has a range of 1 (complete dependence) to 7 (complete independence). The scores of the 4 FIM items were summed to retrieve a score that we called the FIM mobility score. The FIM ratings were based on the observations of research assistants trained in the use of the FIM.

Wheelchair Drag Test

Before the maximum wheelchair exercise test, the wheelchair drag force for the wheelchair user combination on the treadmill was recorded in a drag test.[29] These force measurements were used to calculate the power output for each angle of inclination on the treadmill, according to F_{drag} (ie, drag force in Newtons) multiplied by belt velocity (in m/s). During this measurement, the subject sat passively in a wheelchair that was attached by a rope to a force transducer fixed to the frame of the treadmill. The velocity of the belt was set equal to the velocity at which the maximum exercise test would be performed, and subsequently the slope was raised from 0° to 3.6° in 10 steps of .36°. The results were stored on a computer.

Maximum Exercise Test

After a 5-minute rest and a subsequent 2-minute warm-up, two 3-minute submaximal exercise periods were performed, separated by 2-minute rest intervals. The first 3-minute period was performed with the belt in horizontal position, the second with a slope of .36°. After the submaximal exercise periods and a 2-minute rest, the workload was increased every minute by increasing the slope of the belt by 1 unit. During the entire test, the velocity of the belt was held constant at .56, .83, or 1.11m/s, depending on the subject's ability. The test was terminated when the subject could no longer maintain his/her position on the belt. Throughout the test, oxygen consumption ($\dot{V}O_2$; in L/min) was recorded continuously, and heart rate (in beats/min) was measured at a 5-second storage interval. The highest mean value over 30 seconds of $\dot{V}O_2$ measured during the entire test was defined as VO_2peak. The HRpeak measure was the highest heart rate recorded during the test. Peak power output (in watts), derived from the drag test, was defined as the power output that corresponded to the highest slope level that had been maintained for at least 30 seconds during the maximum exercise test.

Testing Equipment

The Wheelchair Circuit and the maximum exercise test were performed in a test handrim rigid-frame wheelchair, which was available in 2 seat widths, .42m and .46m, and was equipped with solid tires.[a] Three items of the Wheelchair Circuit (3% and 6% slope and wheelchair propulsion) and the maximum exercise test were performed on a treadmill[b] (width, 1.20m; length, 2.60m). The slope of the belt was adjustable from 0° to 9° in 25 steps of .36°. Maximum velocity of the belt was 5m/s, adjustable in 180 steps of .028m/s. To measure the drag force, the treadmill was modified with a force transducer[c] mounted on a height-adjustable horizontal crossbar at the front of the frame of the treadmill to measure the forces exerted on the subject-wheelchair combination during the separate drag test. Static calibration of the force transducer was performed regularly with reference weights. Heart rate was monitored with a Polar Sport Tester Vantage NV.[d] Data were stored on a computer with the Polar Sport Tester interface and software. Oxygen uptake (in L/min) was continuously measured with an Oxycon Delta instrument.[e] Data were stored on a computer with the concomitant software program. Before each test, a calibration was performed with reference gases. Equipment needed to perform the Wheelchair Circuit, apart from the treadmill and the sport tester, were a treatment table, a wooden doorstep (height, .04m; width, .15m; length, 1.20m), a wooden platform (height, .10m; width, 1.20m; length, 1.20m), a stopwatch, and 3 markers.

Statistical Analysis

Construct validity. A Mann-Whitney *U* test for 2 independent samples was used to test for differences in ability scores due to lesion level (paraplegia vs tetraplegia) and motor completeness of the lesion (complete vs incomplete). To assess whether lesion level and motor completeness of the lesion significantly influenced performance time scores (in seconds) and mean physical strain scores (%HRR), independent samples *t* tests were used. To determine the relation between the ability score and age, FIM mobility score, VO_2peak (in L/min), and peak power output (in watts) we calculated Spearman correlations. Pearson correlations were calculated to determine the relation between the performance time score and the physical strain score on the Wheelchair Circuit and age, VO_2peak, and peak power output, while Spearman correlations were calculated to determine the relation between these scores on the Wheelchair Circuit and FIM mobility score.

Responsiveness. Responsiveness was assessed through 2 methods. The first method assessed the changes in the Wheelchair Circuit scores between T1 and T3. We used the Wilcoxon signed-rank test to assess whether the ability score had improved significantly between T1 and T3. Paired Student *t* tests were used to evaluate changes in performance time scores and physical strain scores (in beats/min).[30] The second method involved calculating the standardized response mean (SRM).[20] The SRM is a standardized measure of change calculated by dividing the mean change score by the standard deviation (SD) of this change score.[20,30] An SRM of 0.8 or higher is considered large, a value between 0.5 and 0.8 is regarded as moderate, and lower values are considered small.[31]

All values are described as mean ± SD. The level of significance was set at *P* less than .05. For the construct validity, which was assessed using multiple comparisons, the level of significance was adjusted using the Bonferroni adjustment ($P<.0083$).

RESULTS

Participants

Not all 74 subjects included in the project performed the Wheelchair Circuit. At T1, 12 subjects did not perform the Wheelchair Circuit (n=62). Nine subjects were still wearing a halo or a brace at the time of the measurement, and 3 subjects

Table 1: Values of FIM Mobility Score, Peak Power Output, and $\dot{V}O_2$peak at T1 and T3

		FIM Mobility Score			Peak Power Output (W)			Peak Oxygen Uptake (L/min)		
		n	Mean ± SD	Range	n	Mean ± SD	Range	n	Mean ± SD	Range
T1	Total group	62	13.2±7.0	4–28	43	37.4±22.1	10.9–124.1	43	1.10±0.42	0.52–3.15
	Paraplegia	45	14.0±7.2	4–28	36	41.0±22.3	15.7–124.1	36	1.15±0.43	0.70–3.15
	Tetraplegia	17	11.0±6.2	4–25	7	19.0±6.9	10.9–30.8	7	0.85±0.22	0.52–1.23
	Incomplete	25	14.6±7.4	4–27	20	36.8±26.0	10.9–124.1	20	1.16±0.53	0.52–3.15
	Complete	37	12.3±6.7	4–28	23	37.9±18.7	14.4–70.1	23	1.05±0.29	0.70–1.57
T3	Total group	68	21.4±6.6	4–28	52	46.5±24.5	4.6–117.5	52	1.29±0.47	0.55–2.90
	Paraplegia	50	22.4±5.4	9–28	41	51.0±24.7	4.6–117.5	41	1.33±0.49	0.57–2.90
	Tetraplegia	18	18.7±8.8	4–28	11	29.8±15.4	11.7–65.2	11	1.14±0.36	0.55–1.61
	Incomplete	24	23.3±5.0	10–28	21	50.1±26.8	13.7–117.5	21	1.42±0.60	0.60–2.90
	Complete	44	20.4±7.2	4–28	31	44.1±23.0	4.6–94.0	31	1.21±0.35	0.55–1.91

had a contraindication. At T3, 5 subjects did not perform the Wheelchair Circuit (n=69). Three had a contraindication, 1 had a pressure ulcer and was not allowed to sit in a wheelchair, and 1 subject did not want to perform the Wheelchair Circuit.

Maximum Exercise Test

Of the 62 subjects who performed the Wheelchair Circuit at T1, 43 were physically able to perform the maximum exercise test. At T3, 54 of the 69 subjects were able to perform the maximum exercise test. During T3, the oxygen uptake measurement failed in 2 subjects, and in 2 other subjects the power output was not measured correctly. Mean values, SDs, and ranges of peak power output and peak oxygen uptake values measured at the 2 measurement times are in table 1.

FIM Mobility Scores

FIM mobility scores were available for all subjects who performed the Wheelchair Circuit at T1. At T3, the FIM mobility score was missing for 1 subject. Mean values, SDs, and ranges of FIM mobility scores at T1 and T3 are in table 1.

Wheelchair Circuit

Ability score. At T1, 6 of the 62 subjects were unable to perform any of the items of the circuit and had an ability score of zero; 3 subjects were able to perform all 8 items and achieved the maximum score of 8. At T3, 3 subjects scored zero and 22 subjects achieved the maximum score of 8. Descriptive figures are displayed in table 2.

Performance time score. Performance time scores were only available for those subjects who were able to perform both the figure-of-8 shape and the 15-m sprint. At T1, 52 subjects had a performance time score, and at T3 65 subjects performed both tasks (table 2).

Physical strain score. Physical strain scores (%HRR) could only be given to subjects who had performed both slope items and from whom both HRrest and HRpeak were available. At T1 and T3, 38 and 47 subjects, respectively, could be assigned a physical strain score. At T3, the peak heart rate reached during the 3% slope item was lower than the heart rate at rest in 1 subject. This resulted in a negative HRR for the 3% slope item. The physical strain score of this subject was not taken into account in the statistical analyses and was not included in tables 2 or 3. Table 2 displays the mean physical strain scores at T1 and T3.

Construct Validity

Ability score. At T1 and T3, the ability scores differed significantly for both lesion levels; subjects with paraplegia scored significantly higher than subjects with tetraplegia. No differences existed between the ability scores of subjects with motor complete and those with motor incomplete lesions at any of the measurement times (see table 2). At T1, age did not correlate significantly with the ability score, and at T3 there was an inverse relation between age and ability score: older subjects scored lower than younger subjects. The ability score correlated positively with the FIM mobility score, peak power output, and $\dot{V}O_2$peak at both measurement times, with the highest correlation for peak power output (table 3).

Performance time score. At T1, no differences existed between the performance time scores of subjects with tetraple-

Table 2: Scores on the Wheelchair Circuit at T1 and T3

		Ability Score				Performance Time Score (s)				Physical Strain Score (%HRR)			
		n	Mean ± SD	Range	*P* Value	n	Mean ± SD	Range	*P* Value	n	Mean ± SD	Range	*P* Value
T1	Total group	62	4.9±2.4	0–8		52	30.6±16.1	12.0–83.0		38	43.8±17.8	13.9–74.6	
	Paraplegia	45	5.7±1.8	0–8	<.001*	43	28.7±15.4	12.0–83.0	.055	34	41.3±16.8	13.9–71.2	.010
	Tetraplegia	17	2.7±2.4	0–6.5		9	40.0±17.3	19.0–69.0		4	56.0±11.4	50.0–74.6	
	Incomplete	25	5.0±2.2	0–8	.718	21	34.1±20.5	12.0–83.0	.206	17	44.2±15.3	18.2–66.7	.907
	Complete	37	4.8±2.5	0–8		31	28.3±12.2	13.0–63.0		21	43.5±20.0	13.9–74.6	
T3	Total group	69	6.2±2.2	0–8		65	22.0±10.6	11.0–64.0		46	35.4±17.5	8.4–77.0	
	Paraplegia	50	6.7±2.0	0–8	.004*	48	19.4±7.7	11.0–51.0	<.001*	37	31.0±14.4	8.4–72.1	<.001*
	Tetraplegia	19	5.1±2.6	0–8		17	29.5±13.8	14.0–64.0		9	53.2±18.6	22.9–77.0	
	Incomplete	25	6.7±1.6	3–8	.696	25	23.2±11.6	12.0–64.0	.489	18	38.1±18.1	15.8–72.9	.397
	Complete	44	6.0±2.5	0–8		40	21.3±1.0	11.0–60.0		28	33.6±17.3	8.4–77.0	

*$P<.0083$.

Table 3: Correlation Coefficients (*r*) of the Ability Score, Performance Time Score, and Physical Strain Score

	Ability Score				Performance Time Score (s)				Physical Strain Score (%HRR)			
	T1		T3		T1		T3		T1		T3	
	N	*r*	N	*r*	N	*r*	N	*r*	N	*r*	N	*r*
Age (y)	62	−.216	69	−.322*	52	.397*	65	.383*	38	.067	46	.365
FIM mobility score	62	.517*	68	.519*	52	−.466*	64	−.396*	38	−.398	46	−.139
Peak power output (W)	43	.824*	52	.762*	43	−.628*	51	−.719*	38	−.678*	45	−.692*
VO_2peak (L/min)	43	.674*	52	.572*	43	−.425*	51	−.563*	38	−.560*	45	−.490*

*$P<.0083$.

gia and those with paraplegia, and at T3 subjects with paraplegia were significantly faster than subjects with tetraplegia. There were no differences in the performance time scores due to motor completeness of the lesion at any of the measurement times (see table 2). At both measurement times, age, FIM mobility score, peak power output, and peak oxygen uptake were related to the performance time score, showing the highest correlation for peak power output (see table 3).

Physical strain score. At T3, subjects with tetraplegia had significantly higher levels of physical strain during the performance of the slope items. At T1, no differences existed in physical strain scores due to lesion level (see table 2). At none of the measurement times was there differences in the physical strain scores due to the motor completeness of the lesion, age, or the FIM mobility score. Peak power output and peak oxygen uptake were inversely related to physical strain at both measurement times, again showing the highest mean correlation for peak power output (table 3).

Responsiveness

Fifty-eight subjects performed the wheelchair circuit at both T1 and T3. For this subject group, the mean time between T1 and T3 was 172±87 days (range, 35–454d). Fifty-one subjects had a performance time score (in seconds) at both measurement times, and 33 subjects had a physical strain score (in beats/min) at T1 and at T3. Table 4 shows that all 3 scores of the Wheelchair Circuit showed strong significant improvements between T1 and T3. The SRM ranged from 0.6 to 0.9 (moderate to large effect).

DISCUSSION

Construct Validity

Five different hypotheses were tested to assess construct validity.

Hypothesis 1. Subjects with paraplegia perform better than subjects with tetraplegia. This hypothesis was confirmed for the ability scores at T1 and T3 and for the 2 additional scores at T3. The literature provides little information about the relation between lesion level on the one hand and wheelchair mobility on the other hand. Our findings are in agreement with those of Janssen et al,[12] who studied physical strain during the performance of wheelchair tasks in persons with long-standing SCI and found that subjects with tetraplegia experienced significantly higher levels of strain during task performance than subjects with paraplegia.

Hypothesis 2. Subjects with motor incomplete lesions perform better than subjects with motor complete lesions. Motor completeness of the lesion was not associated with any of the test scores at any of the measurement times. There are 2 possible explanations for this result. First, all subjects were wheelchair dependent. This implies that, in subjects with incomplete lesions, the spinal cord was nevertheless severely damaged. The distinction in functioning between subjects with motor complete and subjects with motor incomplete lesions is therefore less evident. Second, we did not take the lesion level into account in these analyses. Among subjects with tetraplegia, motor completeness of the lesion may be a more important predictor of the performance of manual wheelchair tasks than in subjects with paraplegia. Because of the small percentage of subjects with tetraplegia in our study group, we did not perform subgroup analyses. In their study on subjects with longstanding SCI, Janssen[12] could not show an effect of completeness of the lesion on physical strain during the performance of wheelchair skills and activity of daily living (ADL) tasks.

Hypothesis 3. Age is inversely related to manual wheelchair mobility. A small but significant inverse correlation existed between age and the ability score at T3, and a positive correlation existed between age and the performance time score at both measurement times, but age did not correlate with the physical strain score. Kirby et al[11] tested the same hypothesis to assess the construct validity of the Wheelchair Skills Test (WST) in wheelchair users with different disabilities who had on average been wheelchair dependent for 1 year. In their study population, they also found a small inverse relation between subjects' age and the test scores (reflecting test ability). Our inability to show a relation between age and the ability score at T1 may reflect the subjects' inexperience with wheelchair skill performance at that measurement time: all subjects were early in their rehabilitation after SCI, and at this measurement time the impairment itself may have had a much more general impact than did age.

Jebsen et al[10] found that older subjects (age, ≥50y) performed the wheelchair tasks significantly more slowly than

Table 4: Responsiveness T1 to T3

	n	T1 (mean ± SD)	T3 (mean ± SD)	Change Score (mean ± SD)	*P* Value	SRM
Ability score	58	5.1±2.2	6.3±2.2	1.2±2.0	<.001	0.6
Performance time score (s)	51	30.7±16.3	20.2±8.1	10.5±11.0	<.001	0.9
Physical strain score (beats/min)	33	111.7±15.9	100.3±10.6	11.4±13.6	<.001	0.8

younger subjects, which is in accordance with our findings on performance time. Regarding physical strain during wheelchair skill performance, Mattison et al[32] also could not show a relation between age and physical strain during wheelchair propulsion in subjects performing a wheelchair test circuit. A possible explanation might be that the characteristics of the spinal injury influence physical capacity to a larger extent than age.

Hypothesis 4. Subjects' functional abilities are positively associated with wheelchair skill performance. The FIM mobility score and peak power output (reached during a maximum exercise test) were used as parameters of functional ability. The FIM mobility score was indeed positively related to the ability score and the performance time score at both T1 and T3. No relation existed between the FIM mobility score and the physical strain score. Like Duran et al,[9] who studied subjects with paraplegia, we found that FIM scores were positively associated with functional ability and the performance time of wheelchair tasks. A strong inverse relationship existed between peak power and all 3 scores of the Wheelchair Circuit at both measurement times. Janssen et al[33] studied the performance of ADL tasks (including a number of wheelchair skills) in subjects with an SCI at 2 occasions (average, 35mo apart). They found strong indications for a positive relationship between peak power output and the ability to perform ADL tasks. Janssen et al[12,33] also found that peak power output was the most important predictor of physical strain during task performance.

Hypothesis 5. Physical capacity ($\dot{V}O_2$peak) is positively related to wheelchair skill performance. This hypothesis proved true for all 3 scores at both measurement times. Janssen[33] found strong indications for a positive relationship between physical capacity and the ability to perform tasks. Regarding physical strain during task performance, Janssen[12,33] and Dallmeijer et al[19] also showed that physical capacity was inversely related to physical strain during a wide array of ADL tasks, both in subjects with a longstanding SCI as well as in subjects during and after rehabilitation, both cross-sectionally and longitudinally.

Summarizing, 4 of the 5 hypotheses—all but hypothesis 2—were confirmed. This confirmation supports the view that the Wheelchair Circuit is a valid test to assess wheelchair skill performance during inpatient rehabilitation.

Responsiveness

To assess the responsiveness of the Wheelchair Circuit, we examined whether the 3 test scores had significantly improved between T1 and T3 and calculated the SRM for each score. The responsiveness was good: all scores had significantly improved between T1 and T3, and the SRM values ranged from moderate to large. Evaluating the responsiveness of a test should ideally involve 3 measurement times: 2 baseline measurements and 1 follow-up measurement. In our study, only 1 baseline measurement was performed, which may have limited the value of the responsiveness.[20]

Wheelchair Tests

The results show that the Wheelchair Circuit is a reliable test[5] and has construct validity. Along with being valid, it is also a responsive instrument to assess manual wheelchair mobility in persons with SCI. It can be used in scientific studies as well as in clinical practice. The ability score and the performance time score can be simply obtained from the performance of the Wheelchair Circuit. To acquire the physical strain score, a heart rate monitor is required. Only when groups of subjects with SCI are compared is the performance of a maximum exercise test necessary to calculate the heart rate reserve.

A number of tests are available to evaluate manual wheelchair mobility.[34] The majority, however, have not been evaluated on reliability, validity, or responsiveness. There are 2 tests that exceed the others: the test of Harvey et al[25] and the WST of Kirby et al.[11]

Harvey[25] designed a tool to assess mobility in wheelchair-dependent persons with paraplegia. The scoring system, a 6-point scale, resembles that of the FIM and takes into account the level of assistance and the time required to complete the tasks. The incorporated tasks are fundamental to the mobility of wheelchair users, the test does not require special equipment, and it can be performed in only 15 minutes. The main disadvantage of this test is the scoring system: it requires a subjective evaluation of the rater, which may result in less objective results.[35] The test's interrater reliability is good; its validity has not been assessed.

The WST includes the performance of 33 skills. The skills concern the handling of the wheelchair itself (eg, brakes, footrests, armrests), transfers to and from the wheelchair, maneuvering the wheelchair, and negotiating obstacles. All skills are scored on a 3-point scale (0, failure; 1, partial completion; 2, successful and safe completion). The time required to administer the WST is 30 minutes. The reliability and the validity of the WST are good. The WST provides a very detailed view of the ability of a person to use his/her wheelchair. The WST does, however, have 1 major drawback: only 15 of the 33 items directly concern wheelchair mobility.

Neither the Harvey assessment tool nor the WST provide any concrete information on the time needed to perform a task and the physical strain induced by the tasks. These variables can, however, provide valuable and more detailed information in addition to the ability score. It is important to note that the coherence between the 3 test scores was significant, as shown in the calculations of the Spearman correlation coefficients. At T1, the correlations were –.765 (ability score and performance time score), –.540 (ability score and physical strain score), and .655 (performance time score and physical strain score). At T3, these correlations, respectively, were –.680, –.635, and .666. The range of correlations between the 3 scores showed both conceptual coherence, and each score provides information additional to that of the other scores. The scores must be viewed as highly complementary to each other.

When a person is able to perform a certain wheelchair skill but requires a disproportionately long amount of time to do it, the performance of this skill will probably not be practicable in the person's daily life. The same applies to the physical strain attained during the performance of a wheelchair skill. The 2 additional scores of the Wheelchair Circuit make it possible to include these considerations into the test results.

Another advantage of the additional scores is that they make it possible to detect changes in wheelchair skill performance in subjects who have achieved the maximum ability score of 8 or had the same ability score at 2 successive measurement times.

CONCLUSIONS

The Wheelchair Circuit is a complete and compact measurement, has an objective scoring method, and is a valid and responsive test to assess manual wheelchair mobility in persons with SCI. The ability score is easy to retrieve and provides information on a person's ability to perform wheelchair skills. If desired, the 2 additional scores (performance time score, physical strain score) can provide more detailed information on wheelchair-related performance.

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APPENDIX 1: DESCRIPTION AND SCORING PROCEDURE OF THE WHEELCHAIR CIRCUIT

Item 1: Figure-of-8 Shape

Three markers are placed on the floor, in a straight line and 1.50-m apart. The subject sits in the wheelchair, front casters behind the first marker and turned backward. At the starting signal, the subject propels the wheelchair as fast as possible in a shape of 8 around the other 2 markers. Time is recorded from the moment the subject starts until the front casters pass the first marker again.

Ability score 0: The subject cannot perform this item within 60s.

Ability score 1: The subject performs this item correctly within 60s.

Performance time: Time needed to perform this item.

Item 2: Crossing a Doorstep

A wooden doorstep (height, .04m) is placed in an otherwise level doorway. One meter in front and behind the doorstep a marker is placed on the floor. The subject sits in the wheelchair, front casters behind the first marker and turned backward. At the starting signal, the subject propels the wheelchair forward, negotiates the doorstep, and propels farther forward onto the second marker. Time is recorded from the moment he/she starts until the front casters pass the second marker.

Ability score 0: The subject cannot perform this item within 120s.

Ability score 0.5: The subject is able to cross the doorstep with the front casters (within 120s) but cannot pass the doorstep with the rear wheels.

Ability score 1: The subject performs this item correctly within 120s.

Item 3: Mounting a Platform

A wooden platform (height, .10m) is placed on the floor, 1 side against a wall. Two meters in front of the platform, a marker is placed on the floor. The subject sits in the wheelchair, front casters behind the first marker and turned backward. At the starting signal, the subject propels the wheelchair forward and mounts the platform. Time is recorded from the moment he/she starts until all 4 wheels are on the platform.

Note: This item is only performed if the subject was able to cross the doorstep (ability score, 1).

Ability score 0: The subject cannot perform this item within 120s.

Ability score 0.5: The subject is able to mount the platform with the front casters (within 120s) but cannot pass the doorstep with the rear wheels.

Ability score 1: The subject performs this item correctly within 120s.

Item 4: 15-m Sprint

Two markers are placed on the floor, 15m apart. The subject sits in the wheelchair, with the front casters behind the first marker and turned backward. At the starting signal, the subject propels the wheelchair toward the second marker as fast as possible. Time is recorded from the moment he/she starts until the front casters pass the second marker.

Ability score 0: The subject cannot perform this item within 60s.

Ability score 1: The subject performs this item correctly within 60s.

Performance time: Time needed to perform this item.

Item 5: 3% Slope

This item is carried out with the subject propelling the wheelchair on a wheelchair-adjusted treadmill. At the starting signal, the velocity of the belt is set at .56m/s; 10 seconds later the slope is raised to 3% (which takes 12s), and when this inclination is reached, the subject keeps propelling the wheelchair for another 10 seconds before the inclination is returned to 0% (which again takes 12s). The test ends when the treadmill has returned to horizontal position.

Ability score 0: The subject cannot perform this item.

Ability score 1: The subject performs this item correctly.

Strain: The maximum heart rate reached during the performance of the item.

Item 6: 6% Slope

This item is exactly the same as the 3% slope item, except for the inclination of the slope, which is increased to 6%. Both the increasing and decreasing of the slope take 23 seconds.

Note: This item is only performed if the subject was able to perform the 3% slope item (ability score, 1).

Ability score 0: The subject cannot perform this item.

Ability score 1: The subject performs this item correctly.

Strain: The maximum heart rate reached during the performance of the item.

Item 7: Wheelchair Propulsion

This item is carried out with the subject propelling the wheelchair on a wheelchair-adjusted treadmill. At the starting signal, the velocity of the belt is set at .56, .83, or 1.11m/s, depending on the subject's ability. The subject propels the wheelchair for 180 seconds.

Ability score 0: The subject cannot perform this item.

Ability score 1: The subject performs this item correctly for 180s.

Item 8: Transfer

A line is placed on the floor 1m from a treatment table and parallel to it; the table is set at the same height as the top of the seat cushion in the wheelchair. The subject sits in the wheelchair with the front casters behind the line and turned backward. At the starting signal, the subject performs a transfer from the wheelchair to the table. First he/she drives up to the table and puts the wheelchair in position, then he/she makes a transfer, with the legs hanging over the edge of the table, and finally he/she places his/her legs on the table, while remaining seated. The subject is allowed to use the assistive device(s) he/she normally uses to perform a transfer. Time is recorded from the moment the subject starts until the subject sits on the table with both legs lying on the table.

Note: This item is not carried out if the subject has a score less than 3 on the FIM transfer item bed/chair/wheelchair. The research assistant is not allowed to lift any part of the subject's body to help in performing the item.

Ability score 0: The subject cannot perform this item within 300s.

Ability score 0.5: The subject is able to perform a transfer (within 300s) but cannot do this in the manner described above.

Ability score 1: The subject performs this item correctly within 300s.

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Suppliers

a. Sopur Starlight 622; Sunrise Medical GmbH, D-69254 Malsch/Heidelberg,Germany.
b. Treadmill Giant; Bonte BV, Rechterland 25, 8024 AH Zwolle, The Netherlands.
c. KAP-E; AST GmbH, Marschnerstr 26, 01307 Dresden, Germany.
d. Polar Electro Finland Oy, Professorintie 5, FIN-90440 Kempele, Finland.
e. Jaeger Toennies, Nikkelstraat 2, 4823 AB Breda, The Netherlands.