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ORIGINAL ARTICLE

Subject- and Injury-Related Factors Influencing the Course of Manual Wheelchair Skill Performance During Initial Inpatient Rehabilitation of Persons With Spinal Cord Injury

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ABSTRACT. Kilkens OJ, Dallmeijer AJ, Angenot E, Twisk JW, Post MW, van der Woude LH. Subject- and injury-related factors influencing the course of manual wheelchair skill performance during initial inpatient rehabilitation of persons with spinal cord injury. Arch Phys Med Rehabil 2005;86:2119-25.

Objectives: To study changes in wheelchair skills in subjects with spinal cord injury (SCI) during rehabilitation; to determine whether changes in wheelchair skill performance are related to the subject, lesion characteristics, secondary complications, and upper extremity pain; and to investigate if wheelchair skill performance at discharge can be predicted from these features.

Design: Longitudinal. Subjects performed the Wheelchair Circuit 3 times during rehabilitation: at admission (t1), 3 months later (t2), and at discharge (t3).

Setting: Eight rehabilitation centers in the Netherlands.

Participants: One hundred twenty-one subjects with SCI.

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.

Results: All the scores of the Wheelchair Circuit improved significantly between t1 and t2, and between t2 and t3. The scores were related to age and lesion level, whereas changes in scores were related to age, sex, lesion level, and secondary complications. The variables age, body mass index, sex, lesion level, motor completeness, and secondary complications contributed significantly to the prediction of the scores at t3.

Conclusions: Wheelchair skill performance improved during rehabilitation. Personal and lesion characteristics are most important for improving wheelchair skill performance and predicting wheelchair skill performance.

Key Words: Rehabilitation; Spinal cord injuries; Wheelchairs.

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THE MAJORITY OF PEOPLE with spinal cord injury (SCI) are dependent on wheelchairs for mobility.[1] This may impact overall functioning, primarily at the level of activities, and participation as is expressed in the *International Classification of Functioning, Disability and Health* model.[2] Environmental and personal factors, as well as lesion characteristics, impact wheelchair skill performance during and after inpatient rehabilitation. The current study is the first that analyzes the complex of relationships within this conceptual model.

To function independently, manual wheelchair users must possess a variety of wheelchair skills to deal with the physical barriers they will encounter in various environments.[3] Mastering wheelchair skills can make the difference between dependence and independence in daily life,[4,5] and wheelchair skill training therefore is a major part of inpatient rehabilitation after SCI.[6] During rehabilitation, recently injured persons with SCI have to learn a completely new way of locomotion. When persons with acute SCI are discharged from inpatient rehabilitation, most are capable of performing various wheelchair skills, such as making transfers and negotiating curbs and ramps. It seems obvious that performance of wheelchair skills improves during inpatient rehabilitation as a direct consequence of practice and learning. MacPhee et al[7] found considerable improvements in wheelchair skills after a training program aimed at improving wheelchair skills during inpatient rehabilitation of wheelchair users with different neurologic and musculoskeletal disorders. However, little SCI research[8] describes the improvement of wheelchair skill performance during inpatient rehabilitation. From studies of disability in general or functional limitations or cross-sectional studies, one may deduce that wheelchair skill performance is related to subject and lesion characteristics and the prevalence of secondary complications and upper-extremity pain.[8-17]

Evidence exists for an inverse relation between age and functional outcome measures.[14,18-21] Warschausky et al[20] found that sex was a significant predictor for changes in functional outcome during rehabilitation, whereas Greenwald et al[19] stated that sex did not influence the functional outcome of rehabilitation of patients with SCI. Reports on the relation between wheelchair mobility and body mass index (BMI) are lacking, but it is plausible to hypothesize that wheelchair skill performance and BMI are related because activities that require moving or lifting the whole body, which are the essence of wheelchair mobility, are more difficult with a higher body weight.[14,22]

Lesion level and lesion completeness are related to functional outcomes.[10,11,17] Persons with tetraplegia are in general more limited in their ability to propel a wheelchair than are

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people with paraplegia, and subjects with motor complete lesions are expected to experience more difficulties in wheelchair skill performance than persons with motor incomplete lesions. Subjects who suffer from secondary complications (ie, pressure ulcers, urinary tract infections [UTIs], respiratory tract infections) may also experience a limitation in their daily physical activity. This can indirectly affect a patient's progress in rehabilitation.[21,22] Musculoskeletal pain in the upper extremities is a common problem among people with SCI who use manual wheelchairs for their mobility.[13,23-26] This pain interferes with daily activities and may lead to a decrease in independence and mobility.[13,14,24]

The influence of subject and lesion characteristics, secondary complications, and upper-extremity pain on changes in manual wheelchair skills during inpatient rehabilitation has, however, never been studied in detail. Understanding the influence of these variables is important for the planning and allocation of treatment resources and for setting realistic rehabilitation goals and prognosis. The objectives of the present research were therefore (1) to study changes in manual wheelchair skills in subjects with SCI during inpatient rehabilitation; (2) to determine whether changes in wheelchair skills are related to subject characteristics, lesion characteristics, secondary complications and upper-extremity pain; and (3) to investigate to what degree the level of wheelchair skill performance at the time of discharge from inpatient rehabilitation (t3) can be predicted from subject characteristics, lesion characteristics, secondary complications, and upper-extremity pain at the start of the inpatient rehabilitation (t1).

METHODS

Participants and Procedures

The present 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. In this prospective cohort study, subjects with an acute SCI were followed during inpatient rehabilitation. Subjects were measured 3 times: at the start of functional rehabilitation, defined as the moment that subjects were 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). Eight Dutch rehabilitation centers specialized in the rehabilitation of persons with SCI participated in this research program. Eight trained research assistants conducted the measurements, according to a standardized protocol.

Subjects were eligible to enter the project if they had an acute SCI; were between the ages of 18 and 65 years; were classified as grades A, B, C, or D on the American Spinal Injury Association (ASIA) Impairment Scale; were wheelchair dependent; did not have a progressive disease or psychiatric problem; and had enough knowledge of the Dutch language to understand the goal of the study and the testing methods. Before testing, subjects were examined by their rehabilitation physician. Potential subjects were not included if they had (1) cardiovascular diseases (the absolute contraindications as defined by the American College of Sports Medicine 2000 guidelines[27] and a resting systolic blood pressure >180mmHg or a resting diastolic blood pressure >90mmHg) or (2) severe musculoskeletal complaints of the upper extremities, neck, or back.

To avoid influencing the test results, subjects were asked to consume a light meal only, to refrain from smoking, drinking coffee, and drinking alcohol for at least 2 hours before each measurement, and to void their bladder directly before testing. All subjects completed a consent form after they were given information about the testing procedures. All tests and protocols were approved by the Medical Ethics Committee of the Institute for Rehabilitation Research (Hoensbroek, The Netherlands).

The Wheelchair Circuit Measures

Wheelchair skills were measured with the Wheelchair Circuit,[15,28] a standardized test in which the capacity to perform wheelchair skills was measured. The Wheelchair Circuit[15,28] consists of 8 different standardized tasks. The tasks are performed in a fixed sequence, on a hard and smooth floor surface and on a motor-driven treadmill.[a] To avoid using different wheelchairs over time, all subjects used an individually adjusted standard wheelchair, which was available in 2 seat widths, .42 and .46m, and was equipped with solid tires.[b]

The 8 tasks of the Wheelchair Circuit are (1) negotiating figure-of-eight shape, in which subjects propel their wheelchair, as fast as possible, in a shape of 8 around 2 markers; (2) crossing a doorstep, in which the subjects sit in their wheelchair 1m in front of a doorstep (height, .04m) situated in an otherwise level doorway and then propelling the wheelchair forward and negotiating the doorstep; (3) mounting a platform (height, .10m) placed on the floor (this task is only performed if subjects were able to cross the doorstep); (4) 15-m sprint, in which subjects propel their wheelchairs over a distance of 15m as fast as possible; (5, 6) negotiating 3% and 6% slopes on a wheelchair-adjusted treadmill; (7) propelling the wheelchair for 3 minutes on a treadmill at a constant velocity of 0.56, 0.83, or 1.11m/s, depending on the subjects' ability; and (8) transferring from the wheelchair to a treatment table, with or without the use of assistive device(s) that are normally used to perform a transfer. For a more detailed description, see Kilkens et al.[15,28]

During performance of the Wheelchair Circuit, heart rate was measured with a heart rate monitor.[c] Performance of the Wheelchair Circuit provides 3 different test scores: ability, performance time, and physical strain.

The ability score contains all 8 test items, assigned 0, 0.5, or 1 point, giving an overall ability score ranging from 0 to 8. Items that are performed adequately and independently are assigned 1 point. Crossing a doorstep, mounting platform, and transfer can also be scored partially able (0.5 points).

The performance time score is the sum of the performance times of the figure-of-eight shape and the 15-m sprint, and is available in only those subjects who are able to perform both tasks. The physical strain score provides information on the physical strain induced by propelling the wheelchair up the 3% and 6% slope and is available only for those subjects who are able to perform these tasks. The physical strain score is defined as the mean of the peak heart rates reached during each of the 2 slope items expressed as a percentage of heart rate reserve (%HRR).[29] For further details see Kilkens.[15,28]

The development and assessment of the clinimetric properties of the Wheelchair Circuit have been described,[15,28] and the test's reliability, construct validity, and responsiveness are good.

Subject Characteristics

At each measurement occasion, subjects' characteristics, age, sex, and BMI were registered. BMI was calculated as body mass divided by the square of the height of the subjects.

Lesion Characteristics

At each measurement occasion, lesion characteristics were assessed by a physician by using the International Standards for Neurological Classification of Spinal Cord Injury[30]: ASIA grades A and B were defined as motor complete, C and D as motor incomplete, and neurologic lesion levels below T1 were defined as paraplegia, whereas lesion levels at or above T1 were defined as tetraplegia.

Secondary Complications

Rehabilitation physicians reported whether subjects had suffered from pressure ulcers, UTIs, or respiratory tract infections between the admission to the rehabilitation center and t1, between t1 and t2, and between t2 and t3. They also registered whether subjects had been prescribed bedrest because they had these secondary complications. In the present study, we wanted to select subjects who might experience a limitation in their daily physical activity because of secondary complications. The variable secondary complications were therefore defined as follows: subjects did have pressure ulcers, UTIs, or respiratory tract infections and had been prescribed bedrest for at least 1 of these conditions, for at least 1 day.

Upper-Extremity Pain

Subjects were asked whether they had pain in the muscles and/or joints of the upper extremities (ie, fingers, elbows, shoulders) between the admission to the rehabilitation center and t1, between t1 and t2, and between t2 and t3.

Statistics

Descriptive statistics (mean ± standard deviation [SD]) were applied to all variables. For longitudinal analysis, multilevel analysis was used.[d] The benefits of this method are (1) that it accounts for the dependency of repeated measures within the same person, (2) that it accounts for the hierarchic nature of the longitudinal data of the present study, and (3) in contrast to traditional methods of longitudinal data analysis (ie, multivariate analysis of variance for repeated measures), the number of observations per individual may vary.[31,32] Three levels of hierarchy are present: the repeated measurements are nested within the subjects and the subjects are nested within rehabilitation centers.

The 3 outcome variables of the Wheelchair Circuit (ie, ability score, performance time score, physical strain score) were related to time, which was entered into the analyses as a categoric variable; that is, the variables were converted into dummy variables with the second measurement as reference (dummy t1−t2 was t1=1, t2=0, t3=0; dummy t2−t3 was t1=0, t2=0, t3=1).

To answer the first research question, only the time dummies were included in the model. For the second research question, we first analyzed which of the independent variables were, in addition to the time-based model, univariately related to either one of the 3 outcome measures. Apart from time, the independent variables used in the analyses were age (in years), sex (male=1, female=0), BMI (in kg/m^2), lesion level (paraplegia=1, tetraplegia=0), motor completeness of the lesion (complete=1, incomplete=0), secondary complications (yes=1, no=0), and upper-extremity pain (yes=1, no=0). We also investigated whether a significant interaction existed between all the independent variables listed earlier and the time indicator variables (t1–t2, t2–t3).

All independent variables and interaction terms with a univariate P value below .10 were subsequently included in a multivariate multilevel model. A backward elimination technique[32] was used to filter significant main relationships ($P \leq .05$). All analyses were performed separately for each of the 3 scores of the Wheelchair Circuit.

To answer the third research question (predicting the wheelchair scores at discharge by using independent variables measured at the start of active rehabilitation), all subjects who performed a measurement both at t1 and at t3 were included. Because the time variables were not included in this study, only 2 levels of hierarchy in the data were considered: the subjects who are nested within the rehabilitation centers. To predict the scores of the Wheelchair Circuit at discharge (t3), a model was built that only included the independent variables measured at t1 as predictor variables by using the same procedure as described previously.

RESULTS

Participants' Characteristics

In this study, 121 subjects performed the Wheelchair Circuit at least twice. Not all subjects performed the test at all 3 measurement occasions: 14 subjects did not perform the t1 measurement because they were wearing a halo or a brace at the time of the measurement. Thirty-one subjects did not perform a t2 measurement because their entire inpatient rehabilitation period lasted 3 months or less, and thus performed only the t1 and the t3 measurement. In addition, not all subjects were able to obtain all 3 scores of the Wheelchair Circuit: 121 subjects had at least 2 ability scores, 110 subjects had at least 2 performance time scores, and 71 subjects had at least 2 physical strain scores.

For construction of the predictive models (research question 3), the number of subjects who had an ability score, performance time score, or physical strain score at both t1 and t3 were 107, 92, and 52, respectively. The mean number of days

Table 1: Wheelchair Circuit Scores, Subject Characteristics, Lesion Characteristics, Secondary Complications, and Comorbidity at t1, t2, and t3

	t1		t2		t3	
Measurement Times	n	Value	n	Value	n	Value
Ability score	107	4.9±2.4	86	5.6±2.5	121	6.3±2.1
Performance time score (s)	92	31.6±17.5	79	26.9±13.4	115	22.4±10.7
Physical strain score (%HRR)	62	44.6±18.3	53	42.1±18.9	81	37.3±19.0
BMI (kg/m^2)	115	23.0±4.1	79	23.5±4.2	113	23.7±4.1
% paraplegia*	120	63	85	61	118	64
% motor complete†	120	69	83	66	116	61
% secondary complications	121	24	86	35	121	13
% pain upper extremities	121	51	86	54	121	49

NOTE. Values are mean ± SD or percentage unless otherwise indicated.
*Lesion level caudal to T1.
†ASIA grades A and B.

± SD between t1 and t3 was 192±127 for all subjects (those with paraplegia, 157±92d; those with tetraplegia, 254±155d).

Table 1 shows the 3 test scores of the Wheelchair Circuit, subject characteristics, lesion characteristics, and secondary complications at the different measurement occasions. The mean age of the subjects at t1 was 39.8±14.5 years, and 74% of the group was men.

Changes Over Time in Wheelchair Circuit Scores

Between t1 and t2, the ability score improved 1.1 points on average (95% confidence interval [CI], 0.8−1.4; P<.001), and between t2 and t3 it improved a significant 0.4 points (95% CI, 0.1−0.7; P=.014; fig 1). Performance time score improved significantly between t1 and t2 (mean drop, 7.0s; 95% CI, 4.7−9.4; P<.001) and between t2 and t3 (decrease, 4.1s; 95% CI, 1.9−6.3; P<.001).

The physical strain score showed a significant decrease of 7.1% HRR (95% CI, 3.0−11.2; P=.001) between t1 and t2, and a significant decrease of 2.9% HRR was found (95% CI, 1.9−9.6; P=.003) between t2 and t3. In all 3 scores of the Wheelchair Circuit, the hierarchic level "rehabilitation center" did not contribute to the explanation of variance.

Relation Between Characteristics (Subject, Lesion), Complications, and Pain and Wheelchair Circuit Scores

Ability score. Age was inversely related to the ability score: older subjects had lower ability scores than younger subjects (table 2). Persons with paraplegia performed the Wheelchair Circuit significantly better than subjects with tetraplegia. The significant negative interaction between lesion level and t2 and t3 indicates that between t2 and t3 subjects with tetraplegia improved on average .96 points more than subjects with paraplegia, thus reducing the difference in ability score between subjects with paraplegia and subjects with tetraplegia. The significant interaction between secondary complications and t1−t2 shows that between t1 and t2 subjects who had secondary complications improved on average 1.05 points less than subjects who did not have secondary complications. A significant negative interaction existed between sex and t1−t2, indicating that between t1 and t2 men improved on average .81 points more than women.

Performance time score. A significant relation existed between age and performance time, indicating that younger subjects had better performance times than older subjects, with an average difference of .28 seconds per year (see table 2). Lesion level was also significantly related to the performance time score. Persons with paraplegia were on average 10.8 seconds faster than subjects with tetraplegia. The significant interaction between lesion level and t2−t3 shows that between t2 and t3, subjects with tetraplegia improved on average 6 seconds more than subjects with paraplegia, thus decreasing the difference in performance time score between subjects with paraplegia and subjects with tetraplegia at time of discharge.

Physical strain score. Lesion level was significantly related to the physical strain score: for subjects with paraplegia, the performance of the 2 slope tasks was less strenuous than for persons with tetraplegia, with an average difference of 24% HRR (see table 2). The significant interaction between age and t2−t3 shows that between t2 and t3, younger subjects improved more than older subjects.

Predictive Models

Table 3 shows the results of the multiple multilevel analyses to predict the ability score, performance time score, and physical strain score at t3. The ability score at t1, age, and BMI proved to be the significant predictors of the ability score at t3, explaining 60% of the variance. Performance time at t1 and age best predicted performance time at t3, explaining 61% of the variance. Physical strain score t1 and BMI at t1 were significant predictors of the physical strain score at t3, explaining 45% of the variance.

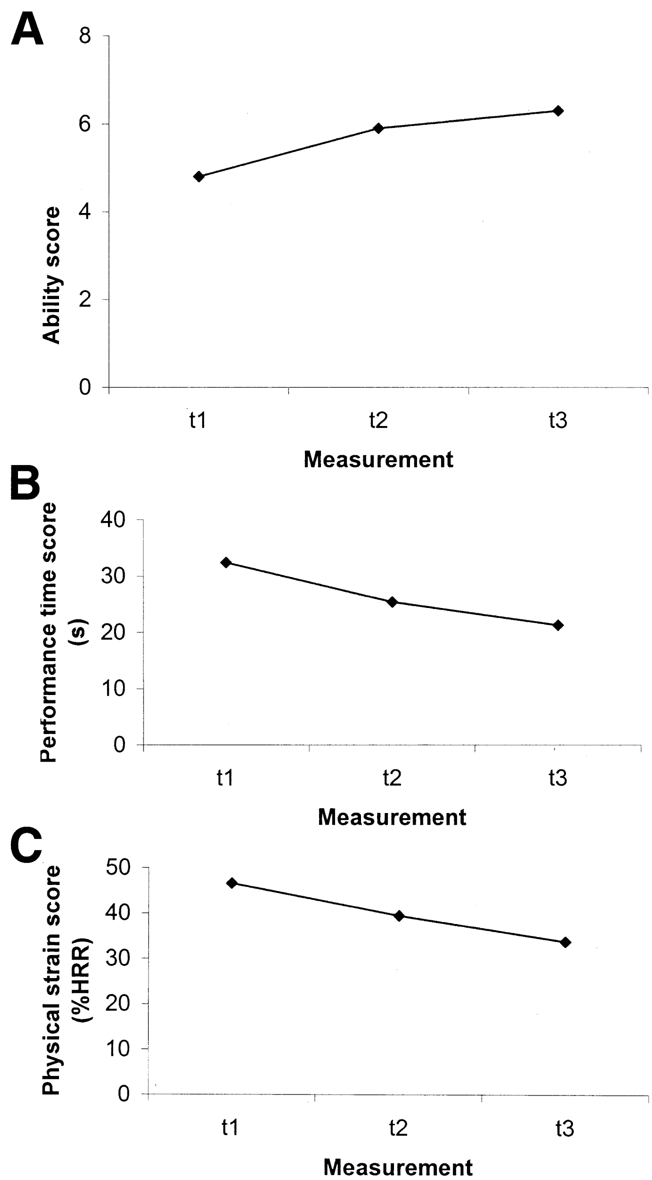

Fig 1. (A–C) The results of the multilevel analysis to describe the changes in the Wheelchair Circuit scores over time.

DISCUSSION

The inpatient rehabilitation period is an essential time for persons with SCI to learn to be independent in daily life. Very few studies have examined wheelchair skill performance during initial inpatient rehabilitation. Except for Dallmeijer[8] and MacPhee[7] and colleagues, most studies that did investigate wheelchair skills included only subjects who were already discharged from inpatient rehabilitation.[8,12,33,34]

Table 2: Results of the Multilevel Analysis of the Longitudinal Relation Between the Ability, Performance Time, and Physical Strain Scores and Subject Characteristics, Lesion Characteristics, Complications, and Comorbidity (N=121)

Factor	Ability Score		Performance Time Score		Physical Strain Score	
	β (95% CI)	P	β (95% CI)	P	β (95% CI)	P
Constant	5.29 (3.94 to 6.64)		21.40 (14.23 to 28.57)		65.66 (53.00 to 78.31)	
t1–t2*	−1.06 (−1.90 to −0.22)	.013	9.40 (5.02 to 13.77)	<.001	4.52 (−7.19 to 16.23)	.449
t2–t3†	1.02 (0.21 to 1.83)	.014	−8.24 (−12.23 to −4.26)	<.001	−18.57 (−29.88 to −7.27)	.001
Age (y)	−0.04 (−0.06 to −0.01)	.004	0.28 (0.15 to 0.40)	<.001	−0.19 (−0.48 to 0.10)	.199
Sex (men=1)	0.81 (−0.09 to 1.71)	.078	NS	NS	NS	NS
Lesion level (paraplegia=1)	2.39 (1.64 to 3.14)	<.001	−10.83 (−15.72 to −5.94)	<.001	−24.47 (−31.70 to −17.24)	<.001
Secondary complications (yes=1)	−0.33 (−0.95 to 0.29)	.294	NS	NS	NS	NS
Age* t1–t2	NS	NS	NS	NS	0.09 (−0.22 to 0.39)	.581
Age* t2–t3	NS	NS	NS	NS	0.34 (0.05 to 0.63)	.020
Sex × t1–t2	−0.81 (−1.59 to −0.02)	.044	NS	NS	NS	NS
Sex × t2–t3	−0.20 (−0.95 to 0.55)	.602	NS	NS	NS	NS
Lesion level × t1–t2	−0.41 (−0.28 to 1.10)	.246	−2.56 (−7.81 to 2.69)	.339	NS	NS
Lesion level × t2–t3	−0.96 (−1.36 to −0.02)	.043	6.07 (1.12 to 11.01)	.016	NS	NS
Secondary complications × t1–t2	1.05 (0.20 to 1.89)	.015	NS	NS	NS	NS
Secondary complications × t2–t3	−0.63 (−1.58 to 0.32)	.194	NS	NS	NS	NS

Abbreviation: NS, not significant.
*The regression coefficient of the time dummies t1–t2 and t2−t3 represent the change between t1 and t2, respectively between t2–t3, bearing in mind that t2 is the reference (0) in both; for instance the negative β of t1–t2 for the ability score indicates an average value of 5.29 at t2, an improvement of (1×1.06) compared with t1.
†The positive β for t2–t3 for the ability score, for instance, indicates a 1-point improvement over this time interval (1.02×1) at t3.

Changes in Wheelchair Circuit Scores

Because all Wheelchair Circuit scores improved significantly between t1 and t2 and between t2 and t3, with the largest improvement occurring during the first 3 months of the inpatient rehabilitation period (t1−t2) and because the multilevel analyses showed that the level "rehabilitation center" did not contribute to the clarification of variance, we may conclude that the changes in wheelchair skill performance do not differ between rehabilitation centers.

No other studies describe the longitudinal development of wheelchair skills during inpatient rehabilitation. Several researchers[8,17,35-39] have studied changes in functional status during rehabilitation after SCI by using FIM scores or parameters of physical capacity as outcome variables. Most studies[8,17,35,36] only assessed subjects once or twice during their rehabilitation period (ie, at admission, and/or at the time of discharge from the rehabilitation center). Few studies have been published on the course of improvement during rehabilitation and few assess functional status at least 3 times during rehabilitation.[37-39] Furthermore these studies include small numbers of subjects, which makes the interpretation of the results difficult. The results of the present study are in accordance with those of Bode and Heinemann[37] and Hjeltnes.[39] Hjeltnes measured the physical capacity of subjects with SCI 3 times during primary rehabilitation. Hjeltnes found that the largest improvement in physical capacity occurred during the first 6 to 8 weeks of the active rehabilitation period. During the whole rehabilitation period, Bode and Heinemann[37] weekly assessed FIM scores to examine functional improvement of subjects with SCI. They found that functional status improved linearly during inpatient rehabilitation. Future studies will also have to focus on changes that occur after discharge from rehabilitation.

Relation Between Characteristics (Subject, Lesion), Complications, and Upper-Extremity Pain and Wheelchair Circuit Scores

Age and lesion level were associated with Wheelchair Circuit scores obtained during inpatient rehabilitation. The interaction between time and age, sex, lesion level, and secondary complications, indicated that these variables influenced the rate of change in wheelchair skill performance over time.

Because only a few SCI studies have examined wheelchair skill performance during inpatient rehabilitation[8,40] and most include small numbers of subjects, we can only compare the results of the present study with the results of studies that have examined changes in FIM scores during inpatient rehabilitation. War-

Table 3: Results of the Multilevel-Analysis to Predictions of Ability, Performance Time, and Physical Strain Scores at t3 Using Independent Variables Measured at t1 (n=107)

Factor	Ability Score at t3		Performance Time Score at t3		Physical Strain Score at t3	
	β (95% CI)	P	β (95% CI)	P	β (95% CI)	P
Constant	5.78 (4.05 to 7.52)		5.25 (2.49 to 8.02)		−14.98 (−38.23 to 8.27)	
Ability/performance time/physical strain t1	0.55 (0.45 to 0.65)	<.001	0.28 (0.22 to 0.33)	<.001	0.55 (0.38 to 0.72)	<.001
Age	−0.02 (−0.04 to −0.00)	.026	0.16 (0.10 to 0.23)	<.001	NS	NS
BMI	−0.07 (−0.13 to −0.00)	.037	NS	NS	0.97 (0.06 to 1.88)	.037

schausky et al[20] examined the recovery of the FIM motor scores in 142 subjects with SCI during inpatient rehabilitation. As we did, Warschausky found that the rate of change over time was significantly influenced by sex. The results of the present study showed that both the ability score and the performance time score were significantly related to age. These results are in accordance with those of other studies that found age was inversely related to functional status after SCI.[20,41] Many researchers[10,11,17] have shown a relation between lesion level and motor completeness of the lesion and functional outcome after inpatient rehabilitation. In the present study, we found that lesion level was significantly associated with the 3 scores of the Wheelchair Circuit. Our analyses also showed that, between t2 and t3, subjects with tetraplegia had a larger improvement of their ability and performance time scores than did the subjects with paraplegia. This difference may be explained by the fact that subjects with tetraplegia had a longer inpatient rehabilitation than persons with paraplegia, resulting in a longer time period between t2 and t3. We could not show a relation between the Wheelchair Circuit scores and the motor completeness of the lesion. This may be explained by the fact that all subjects had to be wheelchair dependent to be included in the cohort. It implies also that, in subjects with incomplete lesions, the spinal cord was, nevertheless, severely damaged. The difference in functioning between subjects with motor complete lesions and those with motor incomplete lesions may therefore be less evident.

Predictive Models

From our results, one may conclude that the Wheelchair Circuit scores at the start of active rehabilitation and patients' age and BMI are the most important variables to predict the wheelchair skill performance after inpatient rehabilitation.

The model to predict the physical strain score at t3 explained substantially less variance than the models to predict the ability score and performance time score. This is most likely because only 52 subjects had a physical strain score at t1 and at t3, whereas 107 and 92 subjects had an ability or performance time score at t1 and t3, respectively.

In clinical practice, these prediction models can be used to obtain insight into patients' possible future wheelchair skill performance. This knowledge can be useful for formulating rehabilitation goals and treatment plans for wheelchair mobility. However, the patient must be able to perform the Wheelchair Circuit at t1.

Limitations of the Study

To be included in the cohort, subjects had to meet several inclusion criteria: they had to be between 18 and 65 years of age and they had to be wheelchair dependent. When, during the rehabilitation period, subjects were no longer wheelchair dependent they were at that point excluded from the cohort. Subjects who for whatever reason performed the Wheelchair Circuit only once were not included in the analyses. Because of these criteria, our subjects are a positive selection out of the complete population of persons with an acute SCI who were admitted to a rehabilitation center.

At all measurement times, all subjects who performed the Wheelchair Circuit had an ability score, but only those who performed both the figure-of-eight shape and the 15-m sprint were assigned a performance time score. Further, to be given a physical strain score, subjects had to perform both the 3%- and 6%-slope task and the maximum exercise test. Because of this, the analyses of the performance time score and the physical strain score constitute a selection of the research population, consisting of subjects with relatively good wheelchair skill performance.

Fourteen subjects were unable to perform the t1 measurement because they were wearing a halo or a brace at the measurement time. Possibly, these subjects negatively influenced the results at t2 and t3. To check for this selection bias, we performed secondary analyses, which showed that the wheelchair skill performance of these subjects at t2 and t3 did not differ from the wheelchair skill performance of the subjects who performed the Wheelchair Circuit at t1.

Not all subjects performed the Wheelchair Circuit at all 3 measurement times, which led to missing values in the database. Missing values occurred also when subjects were unable to perform parts of the Wheelchair Circuit or the maximum exercise test. These missing values consequently could not be defined as "missing at random." We did not use imputation to replace these missing values because that is not necessary when multilevel analyses are used.[42]

The length of the inpatient rehabilitation period varied considerably between subjects. This variability may have affected the results for the period between t2 and t3. The t3 measurement was performed at discharge from the rehabilitation center. However, sometimes discharge was delayed for reasons unrelated to the patient's functional status, for instance when the necessary adaptations to the home were not yet completed, or when subjects waited for placement in a nursing home. During the period between the moment that subjects were functionally ready to be discharged and the moment that they actually left the rehabilitation center, therapies continued at a lower frequency. In these subjects, the t3 measurement may not reflect the actual discharge status.

CONCLUSIONS

The scores of the Wheelchair Circuit all improved significantly between t1 and t2 and between t2 and t3. The largest improvement occurred during the first 3 months of the inpatient rehabilitation.

Personal characteristics, lesion characteristics, and secondary complications significantly influenced wheelchair skill performance during rehabilitation, whereas upper-extremity pain did not affect wheelchair skills during inpatient rehabilitation in the current study. The personal characteristics of age and BMI were the most important predictors, along with the baseline score for wheelchair skills, at the end of inpatient rehabilitation.

Future studies should include the postrehabilitation phase and should analyze modifiable characteristics such as physical fitness and muscle force. The role of wheelchair skill performance in participation needs further attention as well.

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Suppliers

a. Treadmill Giant; Bonte BV, Rechterland 25, 8024 AH Zwolle, The Netherlands.
b. Wheelchair Sopur Starlight 622; Sunrise Medical GmbH, D-69254 Malsch/Heidelberg, Germany.
c. Polar Electro Finland Oy, Professorintie 5, FIN-90440 Kempele, Finland.
d. MlwiN, version 1.10; Center for Multilevel Modeling, Institute of Education, 20 Bedford Way, London, WC1H0AL, UK.