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Hand-rim wheelchair propulsion capacity during rehabilitation of persons with spinal cord injury

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Abstract—This paper describes the course of wheelchair propulsion capacity (WPC) during rehabilitation of persons with spinal cord injury (SCI) and its relationship with personal and injury characteristics. We investigated 132 subjects with SCI (37 with tetraplegia) at the start of active rehabilitation (t1), 3 months later (t2), and at the end of clinical rehabilitation (t3). WPC was measured as the maximal power output that can be achieved in a maximal wheelchair exercise test on a treadmill. Results were analyzed with the use of generalized estimating equations, with time of measurement, lesion level, motor completeness of the lesion, age, and gender as independent variables. Overall, WPC increased from 30.5 W at t1, to 39.5 W at t2, and 44.2 W at t3. Persons with paraplegia, persons with incomplete lesions, men, and younger persons had higher values for WPC compared with persons with tetraplegia, persons with complete lesions, women, and older persons. Rate of improvement was lower in older persons and women compared with younger persons and men. This paper identifies factors that affect the level (lesion level, completeness of the lesion, age, gender) and rate of improvement (age, gender) of WPC during rehabilitation. These findings should be considered when wheelchair capacity training is applied in SCI rehabilitation.

Key words: functional ability, hand-rim wheelchair, maximal power output, paraplegia, physical capacity, rehabilitation, spinal cord injury, tetraplegia, training, treadmill.

INTRODUCTION

The majority of persons who suffer from spinal cord injury (SCI) become partly or completely wheelchair-dependent for their activities of daily living (ADLs). Wheelchair propulsion capacity (WPC) is an important factor for achieving an optimal level of functioning in daily life and for enabling independent living and therefore is assumed to be a relevant outcome of physical rehabilitation in wheelchair-dependent persons with SCI [1–4]. Improving the capacity to propel the wheelchair is

Abbreviations: ADL = activity of daily living, F_{drag} = drag force, GEE = generalized estimating equation, PO_{max} = maximal power output, RC = Rehabilitation Center, SCI = spinal cord injury, t1 = start of active rehabilitation, t2 = 3 months after start of active rehabilitation, t3 = end of clinical rehabilitation, WPC = wheelchair propulsion capacity.

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therefore an important issue during the rehabilitation process. WPC can be measured as maximal power output (PO_{max}) (in watts) that can be achieved in a maximal wheelchair exercise test on a treadmill or on a wheelchair ergometer [5]. One can easily measure PO_{max} during hand-rim wheelchair propulsion on a treadmill using a method described by van der Woude et al. in which a measurement of the drag force (F_{drag}) is combined with the velocity of the treadmill belt to determine PO [6]. With this method, the F_{drag} is measured with a force transducer that has to be connected with a rope to the wheelchair while the subject is seated passively in the wheelchair. WPC can also be measured with more sophisticated wheelchair ergometers that have been developed over the last decades [5]. Both methods (treadmill and wheelchair ergometer) allow for an objective and highly standardized measurement of WPC.

The most frequently investigated physical capacity parameter in persons with SCI is peak oxygen uptake ($\dot{V}O_{2peak}$). $\dot{V}O_{2peak}$ is a useful measure for determining fitness levels of persons with SCI, but it does not provide insight in the actual capacity to propel a hand-rim wheelchair. Other factors, such as the mechanical efficiency and wheelchair propulsion skills, determine the actual PO that can be reached in the wheelchair [5]. Also important is that PO_{max} depends on the propulsion mechanism of the wheelchair [7–8]. Although hand-rim wheelchair propulsion is the dominant form of daily manual wheelchair propulsion, arm-crank ergometry is typically used for evaluating physical fitness [9–13]. This mode of exercise differs from hand-rim propulsion in that it shows a higher efficiency and consequently reveals higher values for PO_{max} [7–8]. Arm-cranking therefore lacks specificity of testing and does not provide information about the actual wheelchair capacity.

Previous primarily cross-sectional studies investigated the PO_{max} during wheelchair propulsion in persons with long-standing SCI [14–15] and wheelchair athletes [8,16–17]. As expected, lesion level was the most important determinant of PO_{max}: the amount of active muscle mass decreases with a higher level of injury, resulting in considerably lower levels of PO_{max} for persons with tetraplegia compared with those with paraplegia [14–17]. However, large variations in WPC within lesion groups were found [15]. The remaining variance can partly be explained by other person-dependent characteristics, such as age and gender. Women with SCI demonstrate significantly lower values than men [15–17], and values decrease with older persons [15,17]. Apart from these nonmodifiable personal characteristics, research has also shown that a considerable amount of the variance of PO_{max} can be explained by the level of physical activity or sport participation [15]. In addition, training studies indicated that physical training can improve WPC [11,18–19]. These encouraging findings indicate that training interventions may improve physical (wheelchair) capacity, regardless of the level of injury or personal characteristics.

Rehabilitation training programs can be individually guided and adjusted according to individual measurements of improvements in WPC. To monitor the course of WPC during rehabilitation, one needs systematic, objective, and standardized measurement methods. However, few studies investigated the course of WPC during the rehabilitation process [20–21]. These studies reported overall improvements of 20 to 39 percent, but groups were heterogeneous regarding lesion and personal characteristics. To use the measurement of WPC in rehabilitation for systematically evaluating progress during rehabilitation, clinicians require normative data to evaluate and adjust therapeutic interventions. Normative values have been described cross-sectionally by Janssen et al. for men with tetraplegia and paraplegia [15], but data with respect to the course of rehabilitation and its relationship with age and gender are not available yet.

This current study describes the course of hand-rim WPC (PO_{max}) during rehabilitation of persons with SCI and its relationship with personal and injury characteristics. In addition, estimated values for subgroups with different lesion and personal characteristics are given.

METHODS

Subjects and Procedure

This current study was part of a Dutch cohort study on restoration of mobility in the rehabilitation of persons with SCI.* We recruited 132 persons with a recent SCI from eight rehabilitation centers that specialize in SCI rehabilitation in the Netherlands. Subjects were included in the study if they had an acute SCI; were between 18 and 65 years of age; were classified as A, B, C, or D on the American Spinal Injury Association (ASIA) Impairment Scale; were wheelchair-dependent; had no progressive disease or psychiatric problem; and knew the Dutch language well enough to understand the purpose of the study and the testing methods.

*www.fbw.vu.nl/onderzoek/A4zon/ZONenglish

Prior to testing, a physiatrist and a physical therapist extensively screened subjects. Potential participants were excluded if they had cardiorespiratory disorders or other contraindications for exercise testing according to American College of Sports Medicine (ACSM) guidelines or had a resting diastolic blood pressure above 90 mm Hg or a resting systolic blood pressure above 180 mm Hg. Subjects were also excluded if they had severe musculoskeletal complaints of the upper limbs, neck, or back.

Subjects were tested at the start of active rehabilitation (t1), defined as the moment that subjects were just able to sit in their wheelchair for at least 3 consecutive hours; 3 months later (t2), and at the end (discharge) of clinical rehabilitation (t3). PO_{max} was measured at each occasion in a maximal wheelchair exercise test. Subjects were asked to consume a light meal only, to refrain from smoking and from drinking coffee and alcohol at least 2 hours before testing, and to void their bladder directly before testing. They were tested in the rehabilitation centers in which they were inpatients. Some subjects did not perform all three tests because of temporary medical complications or because the test was too difficult for them. If the length of stay in clinical rehabilitation was less than 3 months, subjects were tested only at t1 and t3 (at discharge). All subjects completed an informed consent form after they were given information about the testing procedure. The medical ethics committee approved the project.

Protocol Maximal Exercise Test

PO_{max} was investigated during a maximal exercise test of subjects in a hand-rim wheelchair on a motor-driven treadmill. Eight paramedical research assistants, who worked in the eight participating rehabilitation centers, conducted the tests. All research assistants received extensive training on how to administer the tests.

The maximal exercise test consisted of two 3 min exercise blocks with a 2 min rest in between, followed by 1 min exercise blocks in which the workload was increased every minute. Before the test, subjects performed a familiarization and warm-up session of 2 to 3 min. Subjects performed the first 3 min exercise block with the treadmill belt in a horizontal position and the second 3 min block at a 0.36° incline. After the two submaximal exercise blocks and a 2 min rest, research assistants increased the workload every minute by increasing the incline of the belt 0.36°. During the entire test, the velocity of the belt was held constant at 0.56, 0.83, or 1.11 m/s, depending on the lesion level and the ability of the subject. The test was terminated when the subject could no longer maintain his or her position on the belt. Subjects were excluded (for that test occasion only) when they were not able to perform the first 3 min exercise block.

Subjects performed all exercise blocks in the same wheelchair model (Sopur Starlight with a 42 × 42 cm frame or a 46 × 46 cm frame, respectively, and a total mass of 11.4 kg), with height, fore-and-aft position, and footrest adjusted for each subject.

The assistants performed a drag test [6] to determine the F_{drag} of the wheelchair-user system on the treadmill. During the drag test, the subject was passively seated in the wheelchair, which was connected with a rope to a force transducer. At a constant speed, which was the same as the exercise test velocity, the angle of the treadmill was increased from 0° to 3.6° in 10 steps of 0.36°, and at each angle, the F_{drag} was determined. These force measurements were used for calculating the PO for each angle of inclination on the treadmill. Assistants calculated PO by multiplying the F_{drag} with velocity according to PO (W) = F_{drag} (N) · belt velocity (m/s) (**Figure 1**). PO_{max} was defined as the PO that corresponded to the highest slope of the belt that had been maintained for at least 30 s during the maximal exercise test.

Statistics

We performed generalized estimating equation (GEE) analysis to investigate the longitudinal development of PO_{max} and its determinants. The GEE method considers the dependency of repeated measures within one person and allows a variable number of observations per person

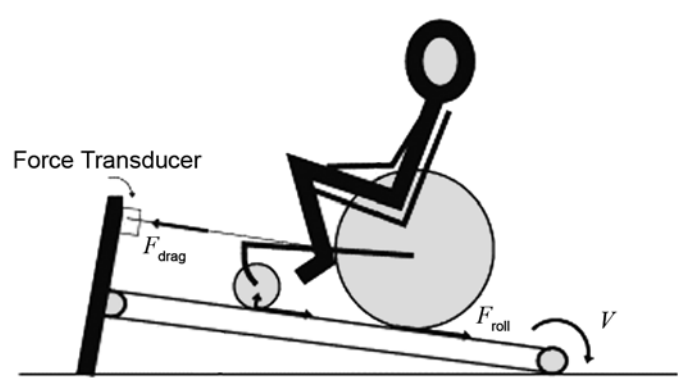

Figure 1.
Schematic representation of drag test. Power output = $F_{drag} \cdot V$. F_{drag} = drag force, F_{roll} = roll force, and V = velocity.

[22]. The analysis was performed in two steps. First, the longitudinal development of PO_{max} was modeled with the use of time as a categorical variable (dummy) for t2 and t3, with t1 as reference. The regression coefficient for the t2 and t3 dummies described the (mean) change in PO_{max} between t1 and t2, and t1 and t3, respectively. Second, the longitudinal relationship between PO_{max} and lesion and personal characteristics was investigated. Lesion level (tetraplegia = 0, paraplegia = 1), motor completeness of the lesion (complete = 0, incomplete = 1), age (years), and gender (women = 0, men = 1) were used as independent variables. In addition, a subject's ability to perform the maximal exercise test at t1 (defined as being able to propel the wheelchair for at least 3 min on the treadmill) was included as a control variable (no = 0, yes = 1). To investigate whether changes in PO_{max} were related to the independent variables, we also investigated the interaction of lesion level, completeness of lesion, age, and gender with the time dummies. All independent variables were added one by one to the basic model (including time dummies only). Independent variables with *p*-values < 0.1 were included in the final multivariate model. Finally, we ended with a backward selection procedure, excluding nonsignificant determinants ($p > 0.05$), to create the final model.

RESULTS

Subjects

At least at one of the measurement occasions, 132 subjects performed the maximal exercise test. The group included 37 persons with tetraplegia and 39 persons with incomplete lesions. Mean age ± standard deviation was 39.4 ± 14.1 years and mean body mass was 72.9 ± 13.9 kg. At t1, 91 subjects performed the test; at t2, 78 subjects; and at t3, 112 subjects. Twenty-six patients physically were not able to perform the test at t1, but were able to do so at the other test occasions. Mean time since injury at t3 was 269 ± 126 days. Mean time between t1 and t3 was 172 ± 105 days. Subject characteristics are shown in **Table 1**.

Longitudinal Development of WPC

By adding the time dummies to the model only, we described the longitudinal development of PO_{max} during the rehabilitation period. The mean (modeled) PO_{max} for the whole group was 30.6 W at t1, and 39.3 W and 44.3 W, at t2 and t3, respectively (**Table 2**). PO_{max} increased significantly with 8.7 W (28%) between t1 and t2. The overall improvement during rehabilitation (between t1 and t3) was 13.7 W (45%).

Longitudinal Relationship of WPC with Lesion and Personal Characteristics

All independent variables showed a univariate relationship with PO_{max}. Age and gender showed a significant interaction with time, while lesion level and completeness of the lesion showed no significant interaction with time. All independent variables and the age and gender time interactions were included in the final model (**Table 3**). The significant relationships of lesion level ($\beta = 21.9$) and completeness of the lesion ($\beta = 5.4$) indicate that persons with paraplegia had (on average) a 21.9 W higher PO_{max} than persons with tetraplegia and that persons with incomplete lesions had (on average) a 5.4 W higher PO_{max} than persons with complete lesions. The significant interactions of age (negative relationship) and gender with the time dummies indicate that changes in PO_{max} depend on age and gender; younger and male persons showed larger increases in PO_{max} than older and female participants.

Some subjects were not able to perform the test at t1 because they were physically not able to propel the wheelchair on the treadmill for at least 3 min (at 0.56 m/s [2 km/h]). If these subjects were able to perform the test at

Table 1.
Subject characteristics: number of subjects with tetraplegia and paraplegia by motor completeness of lesion and gender.

Group	Total	No. Motor Complete/Incomplete	No. Female/Male
Paraplegia	95	72/23	24/71
Tetraplegia	37	21/16	8/29
Total	132	93/39	32/100

Table 2.
Results of generalized estimating equation analysis, including only time dummies for t2 (3 months after start of active rehabilitation) and t3 (end of clinical rehabilitation).

Estimated Model Parameter	β	Error
Constant	30.642*	1.856
t2	8.707*	1.309
t3	13.658*	1.345

*p-value = 0.000

Table 3.
Results of generalized estimating equation analysis: final model, including all significant independent variables.

Estimated Model Parameter	β	Error	*p*-Value
Constant	5.548	5.498	0.313
t2	11.146	3.852	0.004
t3	18.580	4.505	0.000
Age	–0.254	0.114	0.026
Gender	7.235	3.146	0.021
Lesion Level	21.874	2.813	0.000
Complete	5.401	2.668	0.043
Feasibility at t1	14.526	2.450	0.000
Gender × t2	3.413	2.534	0.178
Gender × t3	6.607	2.795	0.018
Age × t2	–0.112	0.072	0.120
Age × t3	–0.245	0.079	0.002

t1 = start of active rehabilitation
t2 = 3 months after start of active rehabilitation
t3 = end of clinical rehabilitation

t2 or t3, they were included in the analysis. To avoid an overestimation of PO_{max} at t1 as a result of missing these subjects with low abilities at t1, we controlled for the ability to perform the test at t1. As expected, this control variable was highly significant, showing on average a 14.5 W lower PO_{max} for subjects who were not able to perform the test at t1 compared with those who were able to do so.

Estimation of WPC During Rehabilitation

Data from the GEE model (**Table 3**) just described can be used for estimating WPC and its development for subgroups with specific lesion and personal characteristics. The estimated values for different subgroups—based on the application of the model in **Table 3**—are given in **Table 4**.

Figures 2 to **4** show examples of the estimated WPC values during rehabilitation for subgroups with different lesion and personal characteristics. **Figure 2** illustrates the effect of lesion level and gender on the development of PO_{max} during rehabilitation for 20- and 50-year-old persons with complete SCI who were able to perform the test at t1. The difference between persons with paraplegia and tetraplegia is constant (21.9 W), but the increase in PO_{max} is larger in men than in women. **Figure 3** illustrates the effect of age in men and women with complete paraplegia: the rate of PO_{max} improvement decreases with older age. **Figure 4** shows the effect of lesion level

Table 4.
Estimated values for wheelchair propulsion capacity (maximal power output during wheelchair ergometry, expressed in watts) during rehabilitation for subgroups with different lesion and personal characteristics. Values shown are valid for persons who were able to perform a maximal exercise test at start of active rehabilitation (t1).

Age (yr)	Women			Men		
	t1	t2	t3	t1	t2	t3
Tetraplegia Complete						
20	15.0	23.9	28.7	22.2	34.6	42.5
35	11.2	18.4	21.2	18.4	29.1	35.0
50	7.4	12.9	13.7	14.6	23.6	27.5
65	3.6	7.4	6.2	10.8	18.1	20.1
Paraplegia Complete						
20	36.9	45.8	50.5	44.1	56.4	64.4
35	33.1	40.3	43.1	40.3	50.9	56.9
50	29.2	34.8	35.6	36.5	45.4	49.4
65	25.4	29.3	28.1	32.7	40.0	41.9
Tetraplegia Incomplete						
20	20.4	29.3	34.1	27.6	40.0	47.9
35	16.6	23.8	26.6	23.8	34.5	40.4
50	12.8	18.3	19.1	20.0	29.0	32.9
65	9.0	12.8	11.6	16.2	23.5	25.5
Paraplegia Incomplete						
20	42.3	51.2	55.9	49.5	61.8	69.8
35	38.5	45.7	48.5	45.7	56.3	62.3
50	34.6	40.2	41.0	41.9	50.8	54.8
65	30.8	34.7	33.5	38.1	45.4	47.3

t1 = start of active rehabilitation
t2 = 3 months after start of active rehabilitation
t3 = end of clinical rehabilitation
Note: For persons who are not able to perform the test at t1, but who are able to do so later in rehabilitation period, values for t2 and t3 should be subtracted by 14.5 W.

50-year-old women. The differences between persons with paraplegia and tetraplegia, as well as the difference between persons with motor-complete and incomplete lesions, remain constant during rehabilitation (no interaction effects). **Figures 2** to **4** only show estimated values for persons who were able to perform the test at t1. To estimate the PO_{max} at t2 and t3 for persons who were not able to perform the test at t1, one should subtract the estimated values at t2 and t3 s by 14.5 W (**Table 3**).

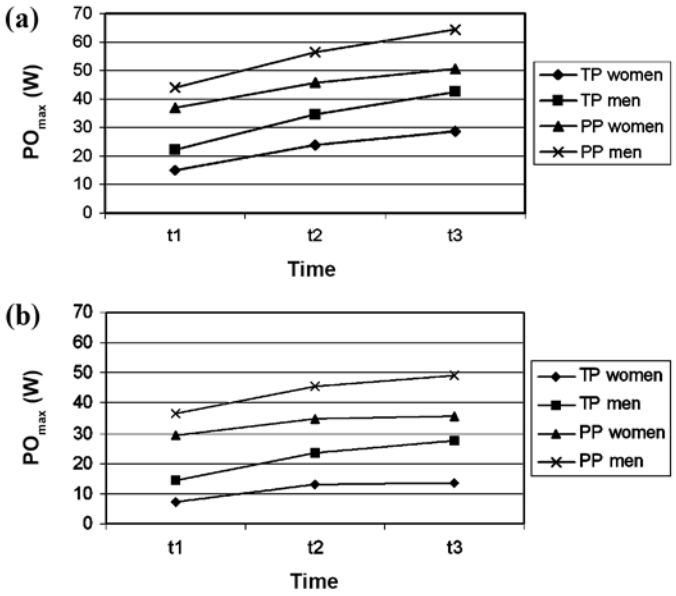

Figure 2.
Effect of lesion level and gender. Estimation of wheelchair propulsion capacity (maximal power output [PO_{max}]) based on generalized estimating equation modeling results of **(a)** 20- and **(b)** 50-year-old persons with complete spinal cord injury who were able to perform maximal exercise test at t1 (start of active rehabilitation) (see body text "Statistics," page 57). Development of PO_{max} for men and women and for persons with paraplegia (PP) and tetraplegia (TP) is shown. t2 = 3 months after start of active rehabilitation and t3 = end of clinical rehabilitation.

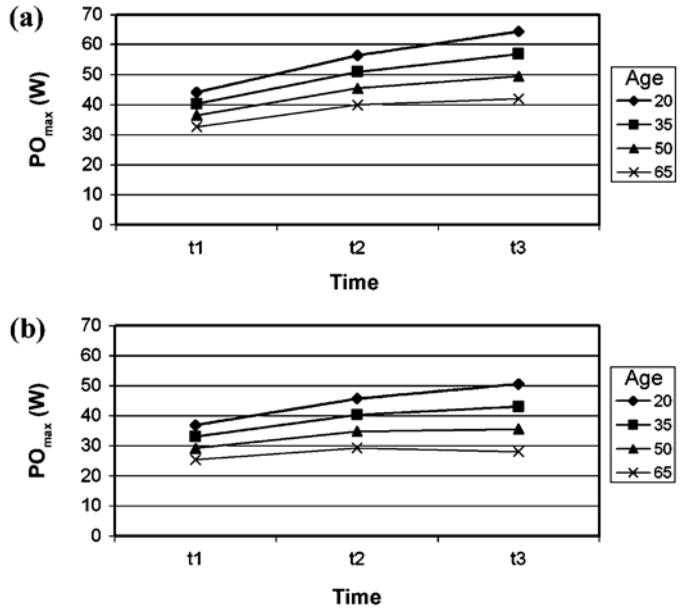

Figure 3.
Effect of age. Estimation of wheelchair propulsion capacity (maximal power output [PO_{max}]) based on generalized estimating equation modeling results for **(a)** men and **(b)** women with complete paraplegia who were able to perform maximal exercise test at t1 (start of active rehabilitation) (see body text "Statistics," page 57). Development of PO_{max} for men and women at 20, 35, 50, and 65 years of age is shown. t2 = 3 months after start of active rehabilitation and t3 = end of clinical rehabilitation.

DISCUSSION

This study determined the course of WPC during rehabilitation of persons with SCI and its relationship with personal and lesion characteristics. The overall improvement in WPC was 45 percent during the whole rehabilitation period. The longitudinal analysis showed that lesion characteristics, gender, and age overall were significantly related to WPC and that the rate of improvement was significantly lower in older and female persons.

Longitudinal Development of WPC

The overall improvement in WPC during the whole rehabilitation period of 45 percent was comparable with results of a former Dutch study [20] that reported a significant increase in PO_{max} of 39 percent in a small group (n = 18) of persons with SCI during rehabilitation, and was somewhat larger than increments reported in a study with a large group of subjects (n = 94), performed in the United States [21] (20%–22%). In the latter study, they found further improvements up to 45 percent at 8 weeks postdischarge, which is comparable with the present findings. Eight weeks postdischarge in the United States may be comparable with time of discharge in the Netherlands because of the shorter length of rehabilitation in the United States. Despite the differences in length of rehabilitation, both results show the potential for improvements of WPC during rehabilitation. However, in those studies, as well as in the current study, determining which part of the improvements results from rehabilitation interventions or is the consequence of natural recovery is not possible. In the current study, all participants followed a regular rehabilitation program (usual care), including endurance and strength training and wheelchair skill interventions. The largest improvements were found in the first 3 months of the active rehabilitation, but this varied however between subgroups (**Figures 2–4**). Also unclear is the extent to which further improvements in WPC can be expected after discharge from rehabilitation. A previous study on WPC 1 year after discharge reported a further improvement of 14 percent compared with time of discharge [20]. Further follow-up research is required to

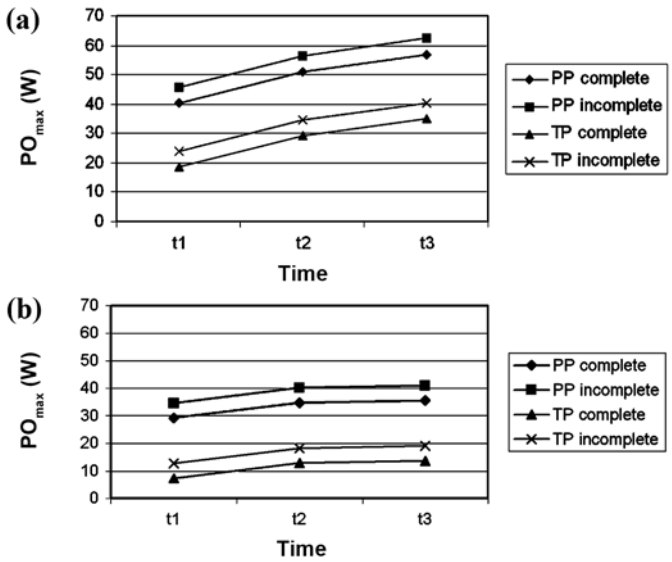

Figure 4.
Effect of lesion level and motor completeness of the lesion. Estimation of wheelchair propulsion capacity (maximal power output [PO_{max}]) based on generated estimating equation modeling results for **(a)** 35-year-old men and **(b)** 50-year-old women who were able to perform the maximal exercise test at t1 (start of rehabilitation) (see body text, "Statistics," page 57). Development of PO_{max} for persons with paraplegia (PP) and tetraplegia (TP), and with complete and incomplete lesions is shown. t2 = 3 months after start of active rehabilitation and t3 = end of clinical rehabilitation.

examine postdischarge developments and their determinants in larger subject groups.

WPC is assumed to be a relevant outcome of physical rehabilitation because of its relationship with wheelchair ADL [2,20]. As stated earlier, WPC is, in contrast to other fitness parameters such as $\dot{V}O_{2peak}$, a functional measure that indicates the actual wheelchair propulsion ability of a person in daily life. However, improvements in physical capacity during SCI rehabilitation have commonly been evaluated by the measurement of $\dot{V}O_{2peak}$ and arm-crank ergometry [9–11]. Although strong positive relationships have been found between PO_{max} and $\dot{V}O_{2peak}$, changes in $\dot{V}O_{2peak}$ are not necessarily accompanied by improvements in PO [13,21]. In addition, PO_{max} of arm-crank ergometry does not provide valid information regarding a person's actual wheelchair propulsion ability. Therefore, distinguishing these measures as different indicators (fitness versus WPC) of rehabilitation outcome seems valuable.

Other studies measured functional improvements during rehabilitation with standardized wheelchair skills tests [23–24]. Considerable improvements in wheelchair skills during rehabilitation were reported. This functional way of testing differs from the currently measured WPC, because other skills, such as ascending curbs and transferring, are also included. However, the advantages of measuring WPC are that the measurement procedure is highly standardized and the outcome can be measured as a continuous measure without ceiling (or floor) effects.

Longitudinal Relationship of WPC with Lesion and Personal Characteristics

Although a highly significant overall mean improvement in WPC was found, a large variation exists within this heterogeneous population. Therefore, identifying the most important factors that affect the level of WPC and the rate of improvement is quite important.

Lesion level and completeness of the lesion are, as expected, important indicators of the level of WPC. This finding agrees with other studies of chronic SCI and of athletes [14–17] and persons with acute SCI [12,21]. The smaller active muscle mass in persons with higher lesion levels reduces the capacity to perform exercise and propel the wheelchair. The mean difference between persons with paraplegia and tetraplegia was as large as 21.9 W, while the mean difference between persons with complete and incomplete lesions was much smaller (5.4 W). The latter finding was as expected, since lower-limb (or trunk) function in persons with motor-incomplete lesions contributes only to a limited extent to arm exercise capacity. However, the rate of improvement in WPC was not significantly different between persons with tetraplegia and paraplegia or between persons with complete and incomplete lesions. Morrison et al. found similar findings [21]. These findings indicate that persons with tetraplegia show larger relative improvements compared with persons with paraplegia.

The multivariate analysis showed that the overall level and the rate of improvement of WPC are higher in male and younger subjects. Differences in PO_{max} between men and women have earlier been reported in chronic SCI [15–16], showing higher values for male persons with SCI. However, the difference in rate of improvement between men and women contrasted with previous findings of Greenwald et al. [25], who reported no effect of gender on changes in functional status during rehabilitation, measured with the Functional Independence Measure (FIM). Differences in measurement instrument are likely to explain these contrasting findings. The current analysis also shows that

age affects the course of WPC; younger subjects' WPC rate of improvement is higher (**Figure 3**). The higher improvement rates for men and younger persons were not unexpected, given the higher level of WPC in these groups. However, important to note is that differences between age groups and men and women are considerable and they further increase during rehabilitation. Results suggest that wheelchair training should receive special attention in persons with specific characteristics (i.e., older and female persons) so as to reach optimal improvements in wheelchair capacity and avoid a loss of independence. Older women with tetraplegia, for example, have the lowest WPC and may be at risk to lose mobility and independence in ADL.

Estimation of WPC During Rehabilitation

One can use the current data to estimate the level of WPC during different stages of rehabilitation. However, although a relatively large group of subjects with SCI was investigated, the group is still very heterogeneous. Therefore, keep in mind that values for WPC can be estimated with the use of the presented equations, but these values should not yet be used as normative values. Extension of the number of subjects in the subgroups is required to describe normative values.

Janssen et al. reported values for WPC in 50 men with tetraplegia and 96 men with paraplegia [15]. They described much higher values than the data in the current study. Their findings may be explained by the higher training status of the group of Janssen et al. (the group included 32 wheelchair athletes) and a longer time since injury. In the current study, the estimated values for men with paraplegia at t3 were all in the lower end of the "fair" category (20–40 percentiles) of Janssen et al. [15], with the values for men aged 50 and over being categorized as "poor" (<20 percentile). In contrast, values for persons with tetraplegia (median for all male subjects with tetraplegia at t3: 28 W, interquartile range: 16 W–32W) were comparable with the normative values reported by Janssen et al. [15].

The present findings emphasize that clinicians and researchers should consider age and gender when assessing WPC during rehabilitation. However, most studies pooled data of subjects of different age groups [12,21,26]. The studies found that the number of women is often too small to analyze separately and draw conclusions regarding the WPC of women with SCI [12,21,26]. Although the number of female subjects and subjects with tetraplegia is also small in the current study, the multivariate analysis showed that irrespective of lesion level, gender is an important determinant of the overall level and rate of improvement in WPC during rehabilitation. However, the small number of female subjects limits the generalizability of the estimated values toward other populations. The estimated values can be used as guidelines for expected values and improvements of WPC during rehabilitation, but one should take care when applying the estimated values to women with tetraplegia. As stated before, extension of the database in the future may reveal reliable normative values for these subgroups.

In our study, we also included patients who were not able to perform a maximal exercise test at t1, but who were able to do so at t2 and/or t3. We included these subjects in the analysis to avoid losing those persons with low abilities who do become manual wheelchair users later on in rehabilitation. Since these persons were not missing at random at t1, we corrected for not being able to perform the test at t1. Consequently, when estimating values for WPC, one should consider this factor.

CONCLUSIONS

This study shows the potential for improvements of wheelchair capacity during rehabilitation and identifies factors that affect the level (lesion level, completeness of the lesion, age, gender) and rate of improvement (age, gender) of WPC during rehabilitation. Clinicians should consider these findings when applying WPC training in SCI rehabilitation. In addition, the present data can be used as a start for a descriptive database of normative values of WPC during rehabilitation for subgroups of patients with different lesion and personal characteristics.

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