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Janssen, T.W.J.; Dallmeijer, A.J.; van der Woude, L.H.V.; Veeger, H.E.J.

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Normative values and determinants of physical capacity in individuals with spinal cord injury

Thomas W.J. Janssen, PhD; Annet J. Dallmeijer, PhD; DirkJan (HEJ) Veeger, PhD; Luc H.V. van der Woude, PhD
Vrije Universiteit, Institute for Fundamental and Clinical Human Movement Sciences; Faculty of Human Movement Sciences; Rehabilitation Center Amsterdam and Centrum voor Orthopedietechniek; Amsterdam, The Netherlands

Abstract—We reanalyzed data from five studies with similar or identical methodology performed by our laboratory to define normative values and determinants of physical capacity in individuals with tetraplegia and paraplegia. Each study consisted of a graded wheelchair exercise test to determine peak oxygen uptake and maximal power output and could additionally include a wheelchair sprint test to determine short-term (anaerobic) power output and/or an isometric strength test. The combined subject population included 166 individuals (20 women), varying considerably for age, body mass, lesion level, time since injury, and activity level. Ranges in physical capacity parameters were extensive and normative values for individuals with tetraplegia and paraplegia were established. These physical capacity norms could be used for evaluation of fitness status and training or therapeutic interventions. Multiple regression procedures indicated that 48–80% of the variance in physical capacity could be explained by lesion level and completeness, activity level, gender, age, body mass, and time since injury. Although physical capacity is largely determined by factors that cannot be altered, such as lesion level, age, and gender, changeable factors such as activity level and body mass play an additional role.

Address all correspondence and requests for reprints to Thomas W.J. Janssen, PhD, FACSM; Vrije Universiteit, Faculty of Human Movement Sciences, Van der Boechorststraat 9, 1081 BT Amsterdam, The Netherlands; Tel: +31-204448586; Fax: +31-204448529; email: t.janssen@fbw.vu.nl.

Key words: *aerobic power, exercise tolerance, normative values, paraplegia, physical capacity, spinal cord injury, strength, tetraplegia.*

INTRODUCTION

Spinal cord injury (SCI) is a devastating injury resulting in the loss of somatic and autonomic nervous system function. The higher the level and the more complete the SCI, the more widespread will be the loss of function. The more paralyzed the muscles, the lower the physical capacity of the individual and the ability to perform voluntary exercise at sufficiently high metabolic rates to stimulate the cardiopulmonary system and achieve adequate aerobic fitness levels. Therefore, the level of the lesion is in general an important determinant of the individual's physical capacity and many studies have indeed shown that those with high-level injuries have lower physical capacity levels than those with low-level injuries (1,2). However, lesion level is not the only factor influencing physical capacity. Many other variables, either SCI-related or not, may play a role. As in the able-bodied population, physical capacity appears to decline with age (3). Also, studies on wheelchair users with SCI indicated that those who maintain a more active lifestyle by regularly participating in exercise and sports programs can increase their muscle strength, aerobic fitness, and physical performance to levels well above those of their sedentary cohorts (1,4–6).

Obviously, physical capacity in individuals with SCI is lower than in the able-bodied population, and normative values are hence not transferable. A few studies, therefore, have been performed to establish normative data for individuals with SCI. Kofsky et al. (7) evaluated aerobic power and upper-body strength in a large group of 229 active as well as inactive individuals with paraplegia (PP). The normative classes, however, were predicted based on submaximal exercise responses, and individuals with tetraplegia (TP) were not included. Also, the exercise mode was arm cranking, and although this skill-free stressor is an appropriate method to determine aerobic power, it does not provide valid information on how individuals can perform in a wheelchair. Using wheelchair ergometry in a small group of 30 individuals with tetraplegia and paraplegia, Rhodes et al. (8) provided norms for aerobic power for this population, but all individuals were grouped together, automatically placing those with tetraplegia in the lower normative classes. Moreover, no information was provided on the maximal power output individuals were able to achieve. Recently, Hutzler et al. (9) provided a classification for short-term power output. However, the testing mode was arm cranking, and only small groups of subjects were evaluated. In addition, no individuals with tetraplegia were included, normative values were based on data not only from individuals with paraplegia but also from individuals with post-polio, and the majority (80 percent) of subjects were competitive athletes.

Hence, it is clear that normative wheelchair-specific physical capacity data for the general population with SCI, including those with tetraplegia and paraplegia, inactive as well as physically active, are very scarce. The first purpose of this study, therefore, was to define normative values for the physical capacity parameters of peak oxygen uptake, maximal endurance power output, short-term (anaerobic) power output, and isometric strength in individuals with tetraplegia and paraplegia with the use of cross-sectional data from a large combined data set obtained from wheelchair exercise tests.

As stated above, physical capacity of individuals with SCI has been shown to be related to several factors such as lesion level, age, and activity level. However, in most cases, determinants have been evaluated individually, which makes identification of important determinants difficult. The second purpose of this study, therefore, was to identify important determinants of physical capacity in this population.

METHODS

Design

For this article, data from five different studies performed by our laboratory were combined and reanalyzed. The methodology of these studies was mostly similar or even identical. Each study consisted of at least a graded wheelchair exercise test (GXT) to determine peak oxygen uptake ($\dot{V}O_{2peak}$) and maximal power output (PO_{max}) and could additionally include a wheelchair sprint test to determine short-term (anaerobic) power output (P_{30}) and/or a test to determine isometric strength (F_{iso}). All tests, except for the endurance tests in studies B and E, were performed on a computer-controlled stationary wheelchair ergometer (10).

Subjects

Subjects from Study A were 32 (of the original 67 with various disabilities) wheelchair athletes with SCI who competed in the World Championships and Games for the Disabled held in Assen, The Netherlands, 1990 (11,12). In study B, 44 men with long-standing SCI participated (13). Hours of weekly sport participation ranged from 0 to 9 with an average of 2.6. Study C included 25 individuals with long-standing tetraplegia (14). Activity level varied between 0 and 6 hours of weekly sports training, while 10 of them participated in quad rugby training for 2 hours per week. Subjects from Study D were 32 individuals with SCI who were tested at or approximately 1 year after discharge from the rehabilitation institution (15,16). Study E included 33 wheelchair athletes with SCI from the French Paralympics team (17). Testing was performed during the IV pre-Olympic training sessions in September 1988. All subjects from these studies used a hand-rim wheelchair as a primary means of locomotion. Each subject participated in only one of the five studies. As can be seen in **Table 1**, the combined subject population included 166 individuals, including 20 women, who varied greatly for age, body mass, lesion level, time since injury (TSI) (years), and activity level. After being informed of the purpose, procedures, and potential risks of the study in question, all subjects signed an informed consent statement.

Table 1.
Subject characteristics (mean ± SD) for combined subject group. For this table, subjects were grouped according to ISMWSF classification. If N < 3, no SD was calculated.

Group	Gender	N	Age (yr)	Body Mass (kg)	Sport ($hr \cdot wk^{-1}$)	TSI (yr)
I	M	50	34.5 ± 12.1	74.5 ± 16.6	3.6 ± 5.3	7.3 ± 9.1
	F	9	31.1 ± 11.3	54.7 ± 9.7	6.4 ± 7.0	3.9 ± 3.2
II	M	21	36.0 ± 7.8	78.2 ± 15.4	7.0 ± 6.4	11.0 ± 9.3
	F	2	47.0	71.0	0	1.7
III	M	32	33.7 ± 10.1	73.2 ± 12.8	5.8 ± 5.8	10.9 ± 8.6
	F	2	43.5	69.0	10.5	7.2
IV	M	43	33.1 ± 11.9	71.8 ± 16.7	5.7 ± 6.7	8.2 ± 7.6
	F	7	38.1 ± 10.1	56.5 ± 6.7	8.3 ± 7.6	13.5 ± 10.3
All	M	146	34.1 ± 11.0	74.0 ± 15.7	5.0 ± 6.0	8.7 ± 8.7
	F	20	36.4 ± 12.3	58.5 ± 12.2	6.9 ± 7.6	6.0 ± 6.5
	M	—	$p = 0.798$	$p = 0.476$	$p = 0.184$	$p = 0.272$
	F	—	*	*	*	*

* No analysis of variance (ANOVA) performed.
TSI = time since injury. Sport = hours of weekly active sport participation.
ISMWSF = International Stoke Mandeville Wheelchair Sports Federation.

Graded Exercise Test

To determine $\dot{V}O_{2peak}$ and PO_{max}, each subject performed a GXT. For studies A, C, and D, this test was performed on the wheelchair ergometer and consisted of 1-min exercise bouts at a constant velocity of 0.56, 0.83, or 1.11 $m \cdot s^{-1}$ (depending on their estimated PO_{max}) and progressive resistance levels. Starting at 10 to 20 percent of the estimated PO_{max} (using isometric strength values and the regression equation from Janssen et al. (18)), resistance was increased each minute in equal steps of 10 percent of the estimated PO_{max}. The test was ended when the subject could no longer maintain the required velocity because of exhaustion. During each exercise bout, torque and linear velocity were measured over 15 s at a frequency of 50 Hz, from which power output (PO) was determined. The highest mean PO (sum of left and right arm) during the test was taken as PO_{max}.

In study B, subjects performed the GXT in their own daily-use wheelchair on a motor-driven treadmill (Enraf Nonius, model 3446, width 1.25 m, length 3.0 m) following a discontinuous protocol. The protocol consisted of 3-min exercise periods at a constant velocity of 0.83, 1.11, or 1.39 $m \cdot s^{-1}$ (for low-, mid-, and high-level performance groups, respectively), separated by 2-min relative rest intervals, during which workload was reduced. The initial PO was calculated from the drag force of the wheelchair-user combination (determined in a drag test according to Woude et al. (19)) and the belt velocity. Every subsequent exercise bout PO was increased with 0.05, 0.10, or 0.15 W/kg (for the three groups, respectively) total mass (subject + wheelchair) by imposing an additional resisting force upon the back of the wheelchair through a pulley system. A test was terminated when the subject could no longer maintain his position on the belt. PO_{max} was the maximal PO the subjects could maintain for more than 30 s.

Study E also used a motor-driven treadmill (Woodway, width 0.9 m, and length 1.5 m). Subjects used their daily-use wheelchair or their competition (basketball) wheelchair. A continuous progressive protocol was applied with 2-min exercise periods. Workload was augmented by increases in velocity (2 $km \cdot hr^{-1}$) and/or in inclination angle (1 percent). Velocity was increased up to a velocity at which correct stroke technique could be maintained after which inclination was increased.

Isometric Strength Test

In studies B to D, upper-body strength was determined in an isometric strength test performed on the wheelchair ergometer. The test consisted of three 5-s maximal force exertions with the hands at top dead center of the blocked rims, while torque was sampled at 50 Hz. The effective force, which is the applied force tangent to the rim, was calculated by dividing the measured effective torque (mean of left and right side) by the rim radius. Maximal isometric strength (F_{iso}) was defined as the effective force averaged over the middle 3 s of the three trials. No isometric strength measurements were performed in studies A and E.

Sprint Test

A sprint test to determine short-term (anaerobic) power output was performed in studies A, B, and D and consisted of a 30-s all-out effort on the wheelchair ergometer. To prevent coordination problems, subjects were required to choose a resistance level that kept peak velocity below 3 $m \cdot s^{-1}$. Since subjects varied considerably in age, lesion level, and activity level, different resistance levels had to be applied. During the all-out effort, the resistance level was normalized relative to the individual's body mass and the mass of a (virtual) wheelchair (20 kg). Verbal encouragement was given throughout the test. Mean power output (sum of left and right side) during the 30-s test period (P_{30}) was determined from the product of angular velocity and effective torque, both recorded at a sampling rate of 65 Hz.

Physiological Measurements

During the GXT, oxygen uptake ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), respiratory exchange ratio (RER), and pulmonary ventilation ($\dot{V}_e$) were measured by open-circuit spirometry (Oxycon Ox4, studies A to D; Ergostar FG90, study E) with 30-s sampling periods. Prior to each test, calibration was performed with reference gases.

Data Analyses

The subject group was divided into four groups based on the International Stoke Mandeville Wheelchair Sports Federation (ISMWSF) classification system (20): I (ISMWSF 1a–c: lesion C4–C8, N = 59), II (2: T1–T5, N = 23), III (3: T6–T10, N = 34), and IV (4–6: below T10, N = 50). A one-way analysis of variance (ANOVA) and a Tukey post-hoc test were performed (21) to establish differences in subject characteristics and physical capacity parameters among groups. This analysis was performed for the whole group of men, but not for the women, because of the insufficient number of women in the subject population.

Norm values were calculated for five quintiles of physical capacity parameters based on percentiles: Poor (below 20th percentile), Fair (20th to 40th percentile), Average (40th to 60th percentile), Good (60th to 80th percentile), and Excellent (above 80th percentile).

Two-tailed Pearson correlation coefficients were calculated (21) to establish relationships among the different subject characteristics and physical capacity variables. Only men were included in these analyses, since gender can markedly influence these correlations and the number of women (n = 20) was insufficient to perform a valid separate analysis. In case of missing values, cases were excluded pairwise.

Stepwise multiple regression procedures were performed (21) to estimate the most important determinants of physical capacity parameters. Since completeness of lesion and hours of sport participation were not determined in all studies, inclusion of these parameters could lead to a markedly smaller number of subjects included. Therefore, two regression analyses were performed. The first included the independent variables age, gender (female = 0, male = 1), lesion level (each level was assigned an arbitrary number from 1 to 22, C4 being 1, and L5 being 22), TSI (years), body mass, body mass index (BMI) (body mass in kilograms divided by height in meters squared), and activity level. For activity level, subjects were assigned a ranking based on the hours of sport participation (if known) and/or the knowledge they were elite athletes:

1. Sedentary (0 $h \cdot week^{-1}$),
2. Moderately active (1 to 3 $h \cdot week^{-1}$),
3. Active (3 to 6 $h \cdot week^{-1}$), or
4. Very active/athlete (>6 $h \cdot week^{-1}$).

The second set of regression analyses used the same independent variables, except that activity level was replaced by the actual hours of sport participation and completeness of lesion (yes = 1, no = 0) was included. Probability of F was used for entry ($p < 0.05$) and removal ($p > 0.1$). In case of missing values, cases were excluded listwise. Overall level of significance was set at $p < 0.05$.

RESULTS

Normative Values of Physical Capacity

For the whole group, there were no significant differences for age, body mass, TSI, and weekly hours of sport activity, among the four lesion groups (**Table 1**). Physical capacity parameters showed a vast range of values, indicated by the large standard deviations shown in **Table 2**. Ranges for PO_{max} (W) values per group were 3 to 74 (I), 13 to 120 (II), 27 to 31 (III), and 40 to 115 (IV). For $\dot{V}O_{2peak}$ ($L \cdot min^{-1}$) ranges were 0.26 to 1.86 (I), 0.86 to 2.61 (II), 0.66 to 2.82 (III), and 0.89 to 3.87 (IV). P_{30} (W) ranged from 5 to 90 (I), 22 to 148 (II), 40 to 167 (III), and 43 to 162 (IV). For F_{iso} (N) ranges were 21 to 304 (I), 117 to 471 (II), 101 to 367 (III), and 127 to 396 (IV). One way ANOVA revealed that all parameters for $\dot{V}O_{2peak}$, PO_{max}, P_{30}, and F_{iso} were significantly lower in men with TP than in each group with PP (**Table 2**). Although there was a trend toward higher physical capacity values with lower lesion levels, no significant differences were found among the paraplegic groups, with the exception of a significantly lower relative $\dot{V}O_{2peak}$ in high-level PP compared to those with low-level PP (<T10). Based on these results, the three paraplegic groups were combined into one and physical capacity five-point normative values were calculated for the two remaining groups. **Table 3** shows norms for men with TP or PP, including those with incomplete lesions.

Determinants of Physical Capacity

Because of missing data, the number of men included in the correlation analyses ranged from 110 to 146. Absolute (r = 0.72) and relative (r = 0.68) PO_{max} and absolute (r = 0.67) and relative (r = 0.65) $\dot{V}O_{2peak}$ were strongest correlated with lesion level (**Table 4**). The amount of weekly sport participation was directly and significantly related with physical capacity parameters and inversely related with age, body mass, and BMI. Age was directly related with body mass and BMI and inversely related with physical capacity parameters. Physical capacity parameters were strongly interrelated (r = 0.80 to 0.93). **Table 5** displays the results from the first regression analysis to define the most important determinants of physical capacity. The independent variables were able to explain 68 to 70 percent of the total variance in $\dot{V}O_{2peak}$ and PO_{max}, 67 percent of the variance in P_{30}, and 50 percent of the variance in F_{iso}. For all parameters, lesion level was the most important determinant explaining 37 to 47 percent of the variance. Each level lower was associated with a higher $\dot{V}O_{2peak}$ (0.06 $L \cdot min^{-1}$) and a higher PO_{max} (3 W). Activity level explained an additional 12 percent of the variance. After adjusting for lesion level, each activity level higher was associated with a 0.2-$L \cdot min^{-1}$ higher $\dot{V}O_{2peak}$, a higher PO_{max} (9 W), and a higher P_{30} (11 W). Body mass was directly related to physical capacity levels, explaining an additional 3 to 6 percent of the variance, and age was inversely related to physical capacity levels, explaining 2 to 5 percent of the variance. The equations showed that

Table 2.
Physical capacity parameters (mean ± SD) for the four lesion level groups and for whole group. Only data from male subjects, including those with incomplete lesions, are shown.

Physical Capacity Parameter	Lesion Level Group					p value	Groups Different
	I	II	III	IV	All		
PO_{max} (W)	25.0 ± 15.9	66.4 ± 23.2	74.9 ± 28.7	79.9 ± 20.3	57.5 ± 32.4	0.000	I–II,III,IV
PO_{max} ($W \cdot kg^{-1}$)	0.34 ± 0.25	0.91 ± 0.41	1.05 ± 0.48	1.16 ± 0.41	0.81 ± 0.52	0.000	I–II,III,IV
$\dot{V}O_{2peak}$ ($L \cdot min^{-1}$)	0.90 ± 0.41	1.68 ± 0.45	1.75 ± 0.56	1.98 ± 0.57	1.52 ± 0.67	0.000	I–II,III,IV
$\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	12.6 ± 6.6	22.8 ± 8.9	24.7 ± 9.1	29.2 ± 10.1	21.6 ± 10.7	0.000	I–II,III,IV; II–IV
P_{30} (W)	39.4 ± 25.7	93.5 ± 31.6	95.5 ± 34.5	112.2 ± 29.7	85.3 ± 41.7	0.000	I–II,III,IV
P_{30} ($W \cdot kg^{-1}$)	0.52 ± 0.32	1.23 ± 0.47	1.35 ± 0.54	1.62 ± 0.54	1.19 ± 0.64	0.000	I–II,III,IV
F_{iso} (N)	124.4 ± 73.2	224.4 ± 99.6	213.9 ± 66.7	254.3 ± 73.9	185.0 ± 93.6	0.000	I–II,III,IV
F_{iso} ($N \cdot kg^{-1}$)	1.62 ± 0.88	2.74 ± 1.10	2.81 ± 0.87	3.35 ± 0.99	2.40 ± 1.18	0.000	I–II,III,IV

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Table 3.
Physical capacity norms for men with tetraplegia and paraplegia, including those with incomplete lesions. Classification based on percentiles: Poor (<20%), Fair (20–40%), Average (40–60%), Good (60–80%), and Excellent (>80%).

Variable		Poor	Fair	Average	Good	Excellent
$\dot{V}O_{2peak}$ ($L \cdot min^{-1}$)	TP	<0.51	0.52–0.79	0.80–0.96	0.97–1.19	>1.19
	PP	<1.33	1.34–1.72	1.73–2.00	2.01–2.31	>2.31
$\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	TP	<7.60	7.61–10.00	10.01–13.39	13.40–16.94	>16.94
	PP	<16.50	16.51–22.70	22.71–29.20	29.21–34.35	>34.35
PO_{max} (W)	TP	<11.60	11.6–20.0	20.1–26.8	26.8–37.5	>37.50
	PP	<52.70	52.8–70.4	70.5–82.1	82.2–97.8	>97.80
PO_{max} ($W \cdot kg^{-1}$)	TP	<0.14	0.15–0.26	0.27–0.34	0.35–0.44	>0.44
	PP	<0.69	0.70–0.92	0.93–1.13	1.14–1.42	>1.42
P_{30} (W)	TP	<18.70	18.8–25.4	25.5–39.1	39.2–68.4	>68.40
	PP	<75.00	75.0–92.9	93.0–114.1	114.2–133.4	>133.40
P_{30} ($W \cdot kg^{-1}$)	TP	<0.25	0.25–0.33	0.34–0.54	0.55–0.93	>0.93
	PP	<1.05	1.05–1.22	1.23–1.58	1.59–1.85	>1.85
F_{iso} (N)	TP	<60.30	60.3–105.6	105.7–119.4	119.5–185.0	>185.00
	PP	<158.50	158.5–206.9	207.0–258.5	258.6–290.1	>290.10
F_{iso} ($N \cdot kg^{-1}$)	TP	<0.87	0.87–1.27	1.28–1.65	1.66–2.48	>2.48
	PP	<2.14	2.14–2.61	2.62–3.41	3.42–3.84	>3.84

men had on average higher $\dot{V}O_{2peak}$ (0.52 $L \cdot min^{-1}$), PO_{max} (18 W), and P_{30} (21 W) values.

Table 6 shows the results of the second set of regression analyses. Because of missing data, especially from studies A and E, up to 92 subjects could be used for these analyses. The independent variables were able to explain 48 to 80 percent of the variance in the physical capacity parameters. The results show that completeness of the lesion had no significant effect on P_{30} and F_{iso}, but those with complete lesions have on average a 0.2-$L \cdot min^{-1}$ lower $\dot{V}O_{2peak}$ and a lower PO_{max} (8 W). Time since injury was directly related to $\dot{V}O_{2peak}$ and PO_{max}.

DISCUSSION

Normative Values

The first purpose of this study was to define normative values for physical capacity parameters in individuals with tetraplegia and paraplegia (**Table 3**). Since this study included data from a wide variety of subjects, including those with tetraplegia and paraplegia, sedentary individuals as well as athletes, the physical capacity norms as presented in **Table 3** may be used for the general population with SCI. However, approximately 40 percent of the subjects were athletes. Also, individuals unable to manually propel a wheelchair, older than 70 and younger than 18, or with serious comorbidities had been excluded from participation in the five studies. In addition, people who volunteer to participate in these studies are generally more healthy, fit, and physically active. Hence, the norm values probably overestimate physical capacity of the whole population, and many individuals with SCI may fall in the lower categories.

The norm values were based on all individuals, including those with incomplete lesions, which may appear to bias the results. However, the percentage of individuals with incomplete lesions appears to have grown considerably over the years as a result of improved medical care and excluding them from the analysis would most certainly reduce the generalizability of the results. From **Table 6**, however, it can be seen that those with incomplete lesions have in general a 0.21-$L \cdot min^{-1}$ higher $\dot{V}O_{2peak}$ than those with complete lesions.

Table 4.
Pearson correlation coefficients for personal characteristics and parameters of physical capacity. Number of subjects for each correlation varies as a result of missing data.

Variable	Age	Body Mass	BMI	Sport	Lesion Level	TSI	PO_{max} (W)	PO_{max} ($W \cdot kg^{-1}$)	$\dot{V}O_{2peak}$ ($L \cdot min^{-1}$)	$\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	F_{iso} (N)	F_{iso} (N)	P_{30} (W)
Body mass	0.32*	—	—	—	—	—	—	—	—	—	—	—	—
BMI	0.39*	0.90*	—	—	—	—	—	—	—	—	—	—	—
Sport ($hr \cdot week^{-1}$)	–0.22†	–0.36*	–0.33*	—	—	—	—	—	—	—	—	—	—
Lesion level	–0.03	–0.09	0.08	0.18	—	—	—	—	—	—	—	—	—
Time since injury	0.22†	0.07	0.14	0.15	0.09	—	—	—	—	—	—	—	—
PO_{max} (W)	–0.23†	–0.05	0.01	0.51*	0.72*	0.15	—	—	—	—	—	—	—
PO_{max} ($W \cdot kg^{-1}$)	–0.31*	–0.34*	–0.23†	0.60*	0.68*	0.16	0.93*	—	—	—	—	—	—
$\dot{V}O_{2peak}$ ($L \cdot min^{-1}$)	–0.20†	–0.03	0.02	0.46*	0.67*	0.19†	0.88*	0.80*	—	—	—	—	—
$\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	–0.30*	–0.41*	–0.31*	0.58*	0.65*	0.17	0.82*	0.90*	0.90*	—	—	—	—
F_{iso} (N)	–0.07	0.27*	0.26†	0.27*	0.62*	–0.14	0.72*	0.62*	0.66*	00.51*	—	—	—
F_{iso} ($N \cdot kg^{-1}$)	–0.21†	–0.11	–0.09	0.31*	0.64*	–0.22†	0.70*	0.74*	0.62*	00.67*	0.70*	—	—
P_{30} (W)	0.28*	0.17	0.05	0.29*	0.68*	0.04	0.86*	0.74*	0.79*	00.66*	0.77*	0.71*	—
P_{30} ($W \cdot kg^{-1}$)	0.38*	–0.36*	–0.27*	0.45*	0.68*	0.05	0.84*	0.89*	0.79*	00.85*	0.68*	0.80*	0.89*

* $p < 0.01$; † $p < 0.05$

The norm table cannot be used easily for values obtained with other modes of upper-body exercise, such as arm-crank ergometry. However, it could be used to some extent for $\dot{V}O_{2peak}$ levels, since $\dot{V}O_{2peak}$ is to a certain degree independent from the mode of upper-body exercise. Several studies have shown that $\dot{V}O_{2peak}$ levels are similar in wheelchair exercise and arm-cranking exercise (22,23). In contrast, PO_{max} is generally considerably higher in arm-crank ergometry than in wheelchair exercise, and the norm data are consequently only applicable to wheelchair performance.

Few studies have attempted to establish normative physical capacity data for wheelchair users with SCI. Rhodes et al. (8) provided norms for $\dot{V}O_{2peak}$ for this population, but individuals with tetraplegia and paraplegia were grouped together, automatically placing those with tetraplegia in the lower normative classes. This is not necessarily an invalid method, since those with tetraplegia have significantly lower physical capacity levels and, compared to those with paraplegia, these levels could be best described by the words "Poor" or "Fair." In our study, we decided to not group TP and PP together, making comparison within each subgroup possible. One has to realize, however, that an "Excellent" level for an individual with tetraplegia would be "Poor" for an individual with paraplegia.

Unfortunately, the study by Rhodes et al. did not provide information on the maximal power output individuals were able to achieve in a wheelchair (8). They provided norms, though, for a 12-min wheel distance, but this distance not only reflects maximal power output but also endurance capacity. Information on wheelchair power output, either maximal or short-term power output, is important for knowing what individuals can actually do in their wheelchair. To our knowledge, no studies have provided norms for maximal power output. Recently, Hutzler et al. (9) provided a classification for short-term power output, but the testing mode was arm cranking (leading to much higher PO_{max} values) and only small groups of subjects were evaluated. In addition, no individuals with tetraplegia were included, normative values were based on data not only from individuals with paraplegia but also from individuals with post-polio, and the majority (80 percent) of subjects were competitive

Table 5.
Results of stepwise multiple regression analyses to predict physical capacity parameters. Age, gender (female = 0, male = 1), lesion level (C4 = 1; L5 = 22), body mass, and activity level (1 = sedentary, 2 = moderately active, 3 = active, 4 = very active/athlete) were used as independent variables. Regression coefficients and intercepts are means ± SD.

Dependent Variable	Subjects Included	Regression Coefficient + Intercept	Independent Variable	*p* value	Cumulative R^2
$\dot{V}O_{2peak}$ ($L \cdot min^{-1}$)	162	$5.5 \times 10^{-2} \pm 0.01$	Lesion level	0.000	0.40
		0.218 ± 0.03	Activity level	0.000	0.52
		0.528 ± 0.10	Gender	0.000	0.63
		$9.6 \times 10^{-3} \pm 0.02$	Body mass	0.000	0.66
		$-1.0 \times 10^{-2} \pm 0.03$	Age	0.001	0.68
		–0.52 ± 0.20	(intercept)	0.011	—
PO_{max} (W)	156	2.91 ± 0.24	Lesion level	0.000	0.47
		9.28 ± 1.27	Activity level	0.000	0.59
		17.95 ± 4.84	Gender	0.000	0.65
		–0.59 ± 0.14	Age	0.000	0.67
		0.38 ± 0.11	Body mass	0.000	0.70
		–23.04 ± 9.44	(intercept)	0.016	—
P_{30} (W)	108	4.17 ± 0.39	Lesion level	0.000	0.43
		11.33 ± 2.13	Activity level	0.000	0.52
		20.53 ± 7.83	Gender	0.010	0.59
		0.73 ± 0.18	Body mass	0.000	0.62
		–0.84 ± 0.22	Age	0.000	0.67
		–35.24 ± 16.45	(intercept)	0.034	—
F_{iso} (N)	101	8.02 ± 1.07	Lesion level	0.000	0.37
		1.73 ± 0.43	Body mass	0.000	0.43
		15.83 ± 7.32	Activity level	0.033	0.47
		–1.16 ± 0.55	Age	0.036	0.50
		–13.36 ± 38.66	(intercept)	0.724	—

athletes. Our norms are also not comparable to theirs, since they used peak power output (5-s value) and we evaluated mean short-term power output (30-s value).

Determinants

The second purpose of this study was to identify important determinants of physical capacity in this population. As expected, lesion level was an important determinant of physical capacity with those with high and complete lesions having lower physical capacity levels. Also, physical capacity declined with increasing age, an expected result similar to the able-bodied population and already described for wheelchair users (3). With all other variables kept constant, every decade resulted in a 0.17-$L \cdot min^{-1}$ lower $\dot{V}O_{2peak}$, similar to other results reported among wheelchair users (3), and somewhat lower than reported among the able-bodied population (24). In contrast to age, time since injury was positively related to physical capacity (**Tables 4** and **6**). It has been suggested that important improvements in physical capacity and functional ability can be expected after the acute phase of injury up to 4 years after injury (25,26), suggesting that the upper body keeps adapting to the new situation while taking over the mobility functions of the lower body after the initial rehabilitation period. In addition, many individuals take up sports activities after a while. A study by Dallmeijer et al. (15) showed that sport activity was an important determinant of changes in PO_{max} after rehabilitation.

Not surprisingly, body mass was directly related to absolute parameters of physical capacity (see **Tables 5** and **6**), indicating that larger individuals have a higher physical capacity. However, body mass was inversely related to relative $\dot{V}O_{2peak}$ with every kilogram increase related to a decrease in $\dot{V}O_{2peak}$ of 0.07 $mL \cdot kg^{-1} \cdot min^{-1}$, a result probably reflecting the amount of (nonexercising) adipose tissue.

Table 6.
Results of stepwise multiple regression analyses to predict physical capacity parameters with time since injury and completeness of lesion (yes = 1, no = 0) added to independent list of **Table 4**: Age, gender (female = 0, male = 1), lesion level (C4 = 1; L5 = 22). In addition, hours of sport participation was used as independent variable instead of activity level. Regression coefficients and intercepts are means ± SD.

Dependent Variable	Subjects Included	Regression Coefficient + Intercept	Independent Variable	*p* value	Cumulative R^2
$\dot{V}O_{2peak}$ ($L \cdot min^{-1}$)	91	$5.6 \times 10^{-2} \pm 0.01$	Lesion level	0.000	0.46
		$5.5 \times 10^{-2} \pm 0.01$	Hours sport	0.000	0.55
		0.25 ± 0.13	Gender	0.055	0.61
		$-1.7 \times 10^{-2} \pm 0.00$	Age	0.000	0.65
		$9.6 \times 10^{-3} \pm 0.00$	Body mass	0.000	0.72
		$1.3 \times 10^{-2} \pm 0.00$	TSI	0.002	0.74
		–0.21 ± 0.07	Completeness	0.003	0.77
		0.27 ± 0.19	(intercept)	0.156	—
PO_{max} (W)	92	3.32 ± 0.24	Lesion level	0.000	0.57
		3.62 ± 0.58	Hours sport	0.000	0.69
		–0.80 ± 0.13	Age	0.000	0.73
		0.38 ± 0.10	Body mass	0.000	0.77
		0.51 ± 0.19	TSI	0.010	0.79
		–8.16 ± 3.18	Completeness	0.012	0.80
		8.97 ± 8.17	(intercept)	0.285	—
P_{30} (W)	67	4.07 ± 0.50	Lesion level	0.000	0.39
		4.73 ± 1.06	Hours sport	0.000	0.53
		–1.20 ± 0.24	Age	0.000	0.60
		0.88 ± 0.20	Body mass	0.000	0.69
		–3.43 ± 17.19	(intercept)	0.842	—
F_{iso} (N)	92	7.62 ± 1.01	Lesion level	0.000	0.35
		1.17 ± 0.44	Body mass	0.000	0.42
		5.69 ± 2.68	Hours sport	0.037	0.46
		–1.21 ± 0.58	Age	0.039	0.48
		6.67 ± 36.00	(intercept)	0.853	—

A practical application of the results of the regression analyses might be the possibility of predicting physical capacity. Many of the laboratory methods to assess physical capacity levels are not suitable for persons with SCI or are too elaborate and expensive. Since a large part (up to 80 percent) of the variance can be explained by parameters that can easily be obtained without testing, the regression equations can be helpful for the practitioner in estimating physical capacity parameters. However, a significant part of the variance still remains unexplained, especially for the isometric-strength variable, indicating that these equations must be used with care and that measurements of physical capacity remain necessary when accurate values are required.

Physical capacity has been shown to be inversely related with physical strain during activities of daily living (13,14,16,27,28), indicating that a low physical capacity can lead to high strain levels and concomitant fatigue or even an impossibility to perform certain activities. Hence, physical capacity should be as high as possible to remain (or become) independent. Although the results of the regression analyses indicate that an important part of the level of physical capacity is determined by factors that cannot be changed (such as lesion level, age, and gender), they also suggest that sports participation can positively affect physical capacity. Even though these results are based on cross-sectional data, and hence no causal relationships can be determined, exercise training has been shown to indeed improve physical capacity of this population.

In summary, this study provided physical capacity norms for the general population of manual wheelchair users with SCI. The normative values could be used to evaluate one's fitness status in comparison to disabled counterparts as well as to evaluate training or therapeutic interventions. The calculated regression equations shed more light on the determinants of physical capacity in this population. Although physical capacity appears to be determined largely by factors that cannot be altered, such as lesion level, age, and gender, changeable factors such as sports participation and body mass play an additional role.

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