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Associations between meeting exercise guidelines, physical fitness, and health in people with spinal cord injury

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ABSTRACT

Purpose: (1) To estimate the proportion of Dutch wheelchair users with spinal cord injury (SCI) who meet different SCI exercise guidelines; (2) to evaluate which demographic and lesion characteristics are associated with meeting these guidelines; (3) whether meeting these guidelines is associated with physical fitness and health.

Materials and methods: Based on the PASIPD questionnaire items, participants were allocated to meeting two SCI aerobic exercise guidelines, which differ in exercise load. Differences in personal, lesion, fitness, and health characteristics between groups were tested with a one-way ANOVA. Multiple regression analyses were performed to evaluate if meeting guidelines was associated with better fitness and health. Statistical significance was accepted at $p < 0.05$.

Results: Of the 358 included participants, 63.1% met at least one aerobic exercise guideline. Being female, older age, having tetraplegia, and lower educational level were associated with a lower likelihood to meet the aerobic exercise guidelines. Meeting aerobic exercise guidelines showed a positive association with all respiratory and exercise capacity parameters. Limited associations were found between meeting exercise guidelines and health.

Conclusions: Meeting exercise guidelines was associated with better respiratory functions and exercise capacity with additional fitness and some body composition benefits in higher exercise activity levels.

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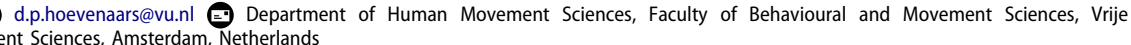
- Meeting SCI exercise guidelines are associated with better respiratory functions and exercise capacity with additional fitness and body composition benefits when higher exercising at higher activity levels, emphasizing the value and importance of regular exercise in individuals with SCI.


Introduction

Being physically active has many potential benefits, such as reduced risks of cardiovascular disease and other noncommunicable diseases, increased mental health, and weight control [1]. However, despite these well-known benefits of physical activity (PA), 31% of the able-bodied adults globally and 43% in Western countries are physically inactive [2]. These numbers are even higher in people with spinal cord injury (SCI), who are 60% less physically active compared to able-bodied individuals [3]. PA promotion is therefore needed and of great importance, especially in people with SCI.

To facilitate PA promotion, the World Health Organization (WHO) developed evidence-based PA guidelines based on studies

on the dose-response relationship between frequency, duration, and intensity of physical activity and health outcomes [4,5]. Although the WHO states “the recommendation can be applied to adults with disabilities,” it is also mentioned that “they may need to be adjusted for each individual based on their exercise capacity and specific health risks or limitations” [4]. Despite the effort to place more emphasis on people with chronic disabilities in the new 2020 WHO PA guidelines, limited evidence was presented on specific chronic conditions and disabilities [5]. Therefore, the two recently developed and published exercise guidelines specifically for people with SCI to promote PA are relevant [6,7]. Both guidelines were specifically designed towards exercise, a subcategory of PA, which is considered as “physical

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Table 1. Overview of different SCI exercise guidelines.

Exercise guidelines	Aerobic exercise					Strength exercise	
	Weekly time spent in minutes in intensity					Frequency per week	
	Moderate	Or	Vigorous	Or	Combination of moderate/vigorous	And	3 sets of each major muscle group
Martin Ginis fitness	40		40		40		2
Martin Ginis cardiometabolic	90		90		90		2
Tweedy	150		60		150/60		2

activity that is planned, structured, repetitive, and purposive in the sense that improvement or maintenance of one or more components of physical fitness is an objective" [8]. Therefore, the focus of the remaining of this paper will be on exercise specifically.

The recent exercise guidelines for people with SCI [6,7] are to a certain extent similar but seem to differ in recommended weekly aerobic exercise, as shown in Table 1. Martin Ginis et al. [6] developed SCI-specific exercise guidelines for improving fitness with additional guidelines with more strenuous recommendations for improving cardiometabolic health. The guidelines developed by Tweedy et al. [7] are based on the assumption that the recommendations for the general population also apply to people with SCI, as SCI-specific exercise evidence is consistent with those from the general population. Therefore, the Tweedy et al. [7] guidelines resulted in a higher physical weekly load regarding frequency and time than the guidelines of Martin Ginis et al. [6]. According to Tweedy et al. [7], this higher load is "required in order for people with SCI to achieve good cardiometabolic health, physical fitness, and functioning."

These differences in load between the exercise guidelines likely influence the proportion of the SCI community meeting them. Rauch et al. [9] documented that sex, age, time since injury (TSI), severity of SCI, and type of locomotion are associated with meeting WHO exercise guidelines, and Rocchi et al. [10] documented that type of locomotion and autonomous motivation are associated with meeting the guidelines of Martin Ginis. It remains unknown, however, if and how meeting different exercise guidelines and therefore weekly load, translates to additional fitness and health benefits [11]. With increasing exercise levels, and therefore, increasing fitness levels, a curvilinear reduction in mortality has been well documented in able-bodied [12]. As a consequence, it could be assumed that physical fitness and health are more likely to be better in people who meet the more strenuous guidelines of Tweedy et al. [7], compared to people who only meet the fitness or cardiometabolic guidelines of Martin Ginis et al. [6] or people not meeting any exercise guidelines at all.

Therefore, the aims of this study were: (1) to estimate the proportion of Dutch wheelchair users with chronic SCI (≥ 5 years after injury) meeting two different exercise guidelines; (2) to evaluate which demographic and lesion characteristics are associated with meeting these guidelines; and (3) whether meeting these guidelines is associated with better physical fitness and health.

Methods

Study design

A cross-sectional analysis was performed on merged data from two Dutch research programs, i.e., "Restoration of mobility in the rehabilitation of persons with SCI" (Umbrella project) [13] and "Active Lifestyle Rehabilitation Interventions in aging Spinal Cord injury" (ALLRISC) [14]. Participants were recruited from eight Dutch rehabilitation centers with a specialized SCI unit. All

participants provided informed consent after being informed about the study. Approval was given by the local medical ethics committee of rehabilitation center Hoensbroek and the medical ethics committee of the University Medical Centre Utrecht for the Umbrella project and by the medical ethics committee of the University Medical Centre Utrecht for the ALLRISC project.

Participants

Individuals were eligible to participate in the Umbrella project if they had a recent SCI, classified as A-D on the American Spinal Injury Association (ASIA) impairment scale [15]; were aged between 18 and 65 years; and were wheelchair dependent for community use. Exclusion criteria to participate were: having an SCI due to malignancies; progressive disease; known cardiovascular disease or psychiatric problems; and insufficient command of the Dutch language. The data of the Umbrella project collected 5 years after the discharge of inpatient rehabilitation were analyzed for this study [16].

Individuals were eligible to participate in the cross-sectional ALLRISC project if they had an SCI, age at injury between 18 and 35 years with at least a time since injury (TSI) of 10 years at inclusion; and were wheelchair dependent for longer distances (>500 m). Insufficient command of the Dutch language was an exclusion criterion to participate in this project [14].

Data collection

The two datasets were prepared and merged on all available parameters relating to personal demographics, lesion characteristics, Physical Activity Scale for Individuals with Physical Disabilities (PASIPD) items, fitness, and health-related outcomes. All participants who did not complete items 4–6 from the PASIPD, needed to determine whether exercise guidelines were met or not, were excluded from the analysis.

Physical activity

Three items (items 4–6) from the PASIPD [17], administered in both projects, were used to determine whether participants met the different SCI-specific exercise guidelines. These items determined the weekly amount of time spent in moderate (item 4) and strenuous (item 5) exercise intensity and on muscle strength exercises (item 6). For each item, the frequency (0, 1–2, 3–4, or 5–7 times a week) and duration (<1 , 1–2, 2–4, >4 h) were reported. This could then be calculated into an average daily time spent (hours/day) on the aerobic exercise of moderate intensity, vigorous intensity, and strength exercise, based on the algorithm the PASIPD provided [17], and converted into weekly average time spent on each activity. PASIPD outcomes were checked on outliers, by comparing the results to answers of other exercise-related available questions (e.g., hours per week spent on sports participation). When the PASIPD outcomes were not in line with the

other exercise-related statements, the participant was excluded from the dataset due to unreliable PASIPD outcomes.

Based on the remaining PASIPD outcomes it was determined whether participants met any aerobic part of any SCI-specific exercise guidelines, with exercise frequency not taken into account. Participants whose weekly time spent on moderate exercise exceeded 150 min or on vigorous exercise exceeded 60 min, were categorized as meeting the exercise guidelines of Tweedy et al. [7] (TW guidelines). A combination of time spent on moderate and vigorous exercise intensity was also allowed to meet the TW guidelines. Time spent on vigorous exercise multiplied by 2.5 was summed with time spent on moderate intensity and should have exceeded the recommended 150 min. Participants whose weekly time spent on moderate and/or vigorous exercise exceeded 90 min were categorized as meeting the cardiometabolic exercise guidelines of Martin Ginis et al. [6] (MG cardiometabolic guidelines). Participants whose weekly time spent on moderate and/or vigorous exercise exceeded 40 min were categorized as meeting the fitness exercise guidelines of Martin Ginis et al. [6] (MG fitness guidelines). If participants did not reach the recommended weekly 40 min, they were categorized as not meeting any guidelines.

Item 6 was used to determine whether individuals were involved in strength exercises at least once a week, as the questionnaire only allows to differentiate frequency into either never, 1–2 times, 3–4 times, or 5–7 times a week. Based on these outcomes, participants were categorized into either: (1) not involved in any strength exercise, or (2) involved in strength exercise at least once a week, which was also done in the study of Rauch et al. [9].

Groups meeting guidelines or not

To test how meeting different exercise guidelines influences fitness and health, participants were allocated to one of the following four groups: (1) not meeting any exercise guidelines; (2) meeting the MG fitness guidelines; (3) meeting the MG cardiometabolic guidelines; or (4) meeting the TW guidelines. Allocation to the different guideline groups was done as described in Table 1. Participants meeting multiple exercise guidelines were only allocated to the most strenuous exercise guidelines in the order as described above with the TW guideline being the most strenuous.

Demographics

Personal and social demographics (sex, age, height, educational level) were collected. Educational level was categorized into three categories according to the Dutch central agency for statistics [18]: (1) lower educational level (primary school, lower educational level), (2) middle educational level (high school, vocational education), and (3) higher educational level (applied-university or higher).

SCI characteristics

SCI characteristics (TSI, etiology, lesion level, motor, and sensory completeness) were collected and assessed according to the International Standards for Neurological Classification of Spinal Cord Injury [15]. Neurological lesion level below T1 was considered as paraplegia and lesions at or above T1 as tetraplegia. The etiology of the SCI was dichotomized into either traumatic or non-traumatic.

Fitness

Respiratory function

Respiratory function was tested and measured according to a standardized protocol [19] with the following outcomes: forced vital capacity (FVC), forced expiratory volume in 1 s (FEV1), forced inspiratory volume in 1 s (FIV1), forced expiratory flow (PEF) and forced inspiratory flow (PIF). All measurements were repeated until at least three measurements of each test within a range of $\pm 5\%$ were recorded. The highest measured outcome value of each test was used for analysis.

Exercise capacity

To test exercise capacity, a graded wheelchair exercise test was performed with the outcome measures peak oxygen uptake (VO_{2peak}) expressed in L/min and L/kg/min and peak power output (PO_{peak}) expressed in Watt (W) and W/kg. Participants were excluded from this test if they had (1) cardiovascular contraindications as stated by the American College of Sports Medicine guidelines [20] or (2) severe musculoskeletal complaints in the upper extremities. The equipment and protocol used for this test have been described in detail elsewhere [16,21]. VO_{2peak} was determined by using the highest recorded values of the average oxygen consumption during 30-s periods. PO_{peak} was the power output measured during the highest treadmill inclination that was maintained by the participant for at least 30 s.

Health

Body mass (kg) and height (m) were measured and used to calculate the body mass index (BMI) (body mass/height²). In the ALLRISC project only, waist circumference (WC, in cm) was measured three times using a tape measure, with the average value being used for analysis.

Systolic (SBP) and diastolic blood pressure (DBP) were measured in mmHg in a seated position by a physician with an automatic (ALLRISC project) or manual sphygmomanometer (Umbrella project). Hypertension was defined as SBP of ≥ 140 mmHg and/or DBP of ≥ 90 mmHg [22]. Mean arterial pressure (MAP) was calculated by the following formula: $DBP + 1/3*(SBP - DBP)$.

Lipid profile was determined from blood samples taken in the morning in a fasting state. Concentrations (mmol/L) of total cholesterol (TC), high-density lipoprotein (HDL), low-density lipoprotein (LDL), and triglycerides (TG) were determined, and TC/HDL calculated. Standardized laboratory protocols were used to obtain the concentrations.

Statistics

IBM SPSS software (Version 27, IBM Corporation, Armonk, NY, USA) was used for analyses. The total study population and the categorized groups based on meeting different SCI-specific exercise guidelines were described. Differences in personal, lesion, fitness, and health characteristics between selected groups were tested with a one-way ANOVA. If the assumptions were violated, the non-parametrical equivalent test was used. All categorical data were tested with the Kruskal-Wallis test. Dichotomous data were tested with the Chi-Square test. In the case of significance of the one-way ANOVA test, a *post-hoc* Bonferroni test was performed among all groups with the significance level set at $p < 0.05$. In the case of significance of the non-parametrical alternative, a corresponding *post-hoc* test was performed among all three groups, with a significance level set on $p < 0.017$ to adjust for alpha inflation (0.05/3–0.017).

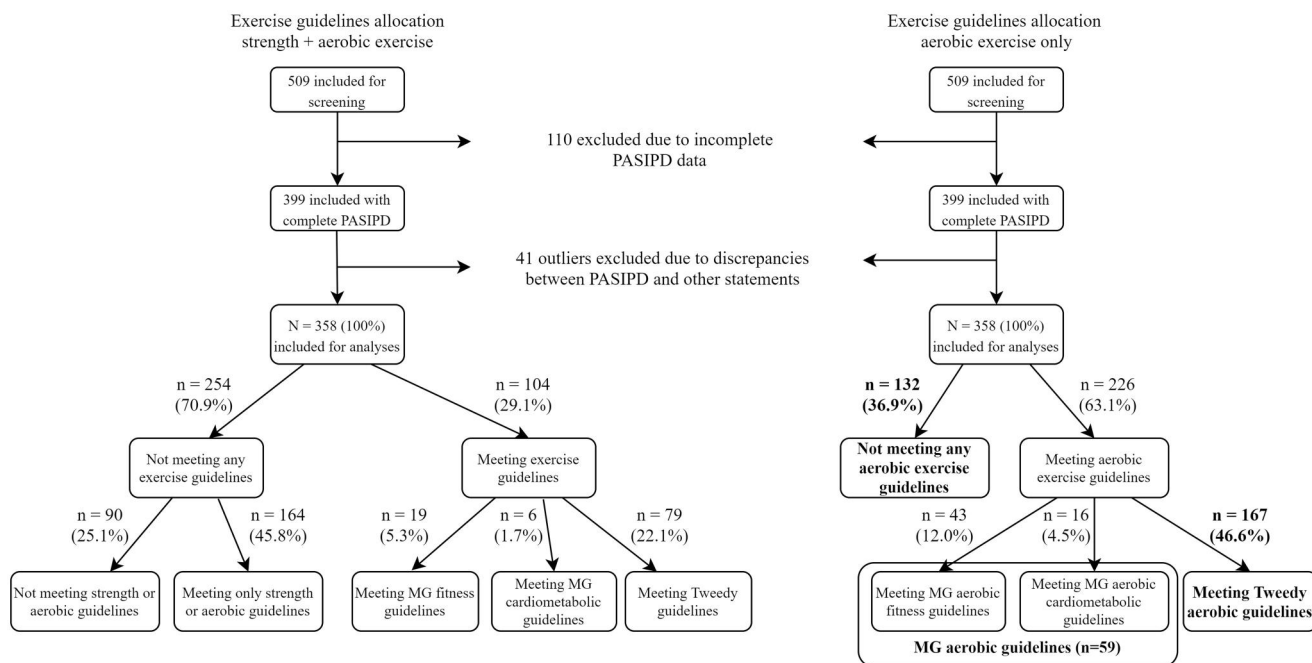


Figure 1. Flowchart of in- and exclusion of data and of group allocation of different SCI exercise guidelines. Bolded groups were used for group comparisons and multiple regression analysis.

Multiple regression analysis was performed to evaluate if meeting SCI-specific aerobic exercise guidelines affects fitness and health. Multiple regressions were performed twice on each fitness and health outcome variable. Once with the MG guidelines group and once with the inactive group as the reference category to allow for multiple comparisons. In the case of dichotomous outcomes, logistic regressions were performed. Outcomes were adjusted for the potential confounders age, sex, TSI, lesion level, lesion completeness, etiology of SCI, and educational level. Statistical significance was considered if one of the two group variables showed $p < 0.05$ compared to the reference category and confidence intervals are presented in [Supplementary Appendix 1](#).

Results

A total of 358 participants were included for analysis after excluding 151 participants. The in-/exclusion of participants, and exercise guidelines allocation process, including when strength exercise was taken into account, is depicted in [Figure 1](#). The MG cardiometabolic group ($n = 16$) was merged with the MG fitness group ($n = 43$) during the group comparisons and regression analyses to ensure decent groups size and is from here onwards referred to as the MG guidelines ($n = 59$). Personal, lesion, fitness, and health characteristics, including the number of participants available for each variable and guidelines allocation, are shown in [Table 2](#). Outcomes for each group separately and group comparisons after allocation based on meeting SCI aerobic exercise guidelines are presented in [Table 3](#).

Several variables showed significant differences between the groups. Being female, older in age, having tetraplegia, and having a lower educational level was associated with a lower likelihood to meet any exercise guidelines ([Table 3](#)). All fitness variables showed more positive outcomes in individuals meeting exercise guidelines compared to inactive individuals, of which multiple variables showed a significant difference. However, no significant differences between groups were found for health-related variables

Table 2. Demographic, lesion, fitness, and health characteristics of all participants ($N = 358$).

Demographic characteristics	<i>n</i>	Frequency (%)/ Mean (SD)
Sex (male)	358	262 (73.2%)
Age (years)	358	47.4 (10.8)
Height (m)	336	1.79 (0.10)
Body mass (kg)	339	82.1 (17.2)
Educational level	337	
Lower educational level		76 (22.6%)
Middle educational level		113 (33.5%)
Higher educational level		148 (43.9%)
Lesion characteristics		
TSI (years)	357	18.5 (11.2)
Etiology of SCI (traumatic)	358	310 (86.6%)
Lesion level (paraplegia)	358	189 (52.8%)
Lesion completeness (motor complete)	358	278 (77.7%)
Guideline allocation		
Meeting aerobic exercise guidelines	358	
Not meeting any exercise guidelines		132 (36.9%)
Meeting MG fitness guidelines		43 (12.0%)
Meeting MG cardiometabolic guidelines		16 (4.5%)
Meeting TW guidelines		167 (46.6%)
Performs strength exercise at least once a week	358	146 (40.8%)
Fitness characteristics		
FVC (L)	329	3.91 (1.27)
FEV1 (L)	330	3.16 (0.98)
FIV1 (L)	319	3.38 (1.13)
PEF (L/s)	330	6.41 (2.22)
PIF (L/s)	326	5.06 (1.79)
VO _{2peak} (L/min)	201	1.34 (0.53)
VO _{2peak} (ml/kg/min)	201	16.82 (6.64)
POpeak (W)	185	50.6 (25.3)
POpeak (W/kg)	184	0.64 (0.31)
Health characteristics		
BMI (kg/m ²)	333	25.6 (5.0)
Waist circumference (cm)	218	98.1 (15.0)
SBP (mmHg)	327	124 (24)
DBP (mmHg)	327	76 (14)
MAP (mmHg)	327	92 (17)
Hypertension (yes)	327	100 (30.6%)
Total cholesterol (mmol/L)	278	4.85 (0.99)
HDL (mmol/L)	278	1.20 (0.37)
Cholesterol/HDL ratio	278	4.34 (1.40)
LDL (mmol/L)	272	3.03 (0.86)
TG (mmol/L)	276	1.59 (1.14)

Table 3. Differences in demographic and lesion characteristics, fitness, and health outcomes between groups meeting different aerobic exercise guidelines.

	Not meeting aerobic exercise guidelines (n = 132)		Meeting MG aerobic guidelines (n = 59)		Meeting TW aerobic guidelines (n = 167)		p-Value
	n	n or mean (SD)	n	n or mean (SD)	n	n or mean (SD)	
Demographic characteristics							
Sex (f/m)	131	42/89 ^b	59	22/37	167	30/136 ^b	0.016 ^a
Age (years)	132	50.0 (11.0) ^b	59	47.3 (11.4)	167	45.4 (10.1) ^b	0.001
Height (m)	123	1.77 (0.11) ^b	54	1.80 (0.10)	159	1.81 (0.09) ^b	0.005
Body mass (kg)	125	82.7 (17.6)	55	80.4 (16.7)	159	82.2 (17.2)	0.713
Education level (low/middle/high)	122	33/44/45 ^b	56	19/17/20 ^c	159	24/52/83 ^{b,c}	0.003 ^a
Lesion characteristics							
TSI (years)	131	20.0 (12.1)	59	17.5 (10.6)	167	17.4 (10.5)	0.209 ^a
Etiology (traumatic/non-traumatic)	132	107/25 ^b	59	51/8	167	152/15 ^b	0.043 ^a
Lesion level (PP/TP)	131	56/75 ^b	59	30/29	167	103/64 ^b	0.015 ^a
Lesion completeness (motor complete/incomplete)	132	102/30	59	43/16	167	133/34	0.559 ^a
Fitness characteristics							
FVC (L)	120	3.37 (1.31) ^{b,d}	53	4.17 (1.13) ^d	156	4.24 (1.14) ^b	<0.001
FEV1 (L)	120	2.76 (1.03) ^{b,d}	51	3.30 (0.87) ^d	157	3.41 (0.87) ^b	<0.001
FIV1 (L)	116	2.93 (1.07) ^{b,d}	53	3.50 (1.03) ^d	152	3.68 (1.10) ^b	<0.001
PEF (L/s)	120	5.58 (2.35) ^{b,d}	52	6.67 (1.88) ^d	157	6.97 (2.03) ^b	<0.001 ^a
PIF (L/s)	118	4.49 (1.63) ^b	52	4.80 (1.34) ^c	156	5.59 (1.88) ^{b,c}	<0.001
VO ₂ peak (L/min)	42	1.17 (0.45) ^b	40	1.20 (0.40) ^c	119	1.44 (0.57) ^{b,c}	0.003
VO ₂ peak (ml/kg/min)	42	14.1 (4.4) ^b	40	15.6 (5.8)	119	18.2 (7.2) ^b	0.001
POpeak (W)	38	40.8 (21.8) ^b	31	42.9 (19.2) ^c	116	56.0 (26.3) ^{b,c}	0.001
POpeak (W/kg)	38	0.50 (0.24) ^b	31	0.56 (0.26)	115	0.70 (0.32) ^b	0.001
Health characteristics							
BMI (kg/m ²)	123	26.4 (5.8)	53	24.8 (4.4)	157	25.1 (4.5)	0.097 ^a
Waist circumference (cm)	78	102.1 (17.6) ^b	36	97.7 (13.2)	104	95.3 (12.9) ^b	0.011
SBP (mmHg)	116	122 (24)	55	123 (27)	156	126 (22)	0.329
DBP (mmHg)	116	76 (15)	55	75 (16)	156	77 (14)	0.710
MAP (mmHg)	116	91 (17)	55	91 (18)	156	93 (16)	0.566
Hypertension (yes/no)	116	32/84	55	18/37	156	50/106	0.681
Total cholesterol (mmol/L)	106	4.83 (1.13)	42	5.09 (0.89)	130	4.78 (0.89)	0.209
HDL (mmol/L)	106	1.19 (0.41)	42	1.27 (0.33)	130	1.18 (0.35)	0.277 ^a
Cholesterol/HDL ratio	106	4.37 (1.42)	42	4.23 (1.12)	130	4.36 (1.46)	0.964 ^a
LDL (mmol/L)	105	3.06 (0.96)	42	3.20 (0.81)	125	2.94 (0.77)	0.214
TG (mmol/L)	104	1.53 (1.01)	42	1.51 (0.74)	130	1.66 (1.34)	0.772 ^a
Strength training							
Performs strength exercises at least once a week (yes/no)	132	42/90 ^b	53	25/28	167	79/88 ^b	0.025 ^a

^aIndicates the use of a non-parametric alternative. *Post-hoc* non-parametrical test significance accepted at $p < 0.017$.

^bSignificant difference between inactive and TW.

^cSignificant difference between MG and TW.

^dSignificant difference between Inactive and MG.

except for waist circumference. TW guidelines group showed a significantly smaller waist circumference compared to the inactive group (Table 3).

Physical fitness

Respiratory function

In all multiple regressions, outcomes were adjusted for demographic and lesion characteristics. All respiratory parameters were significantly higher ($p \leq 0.005$; Table 4) in individuals meeting the MG guidelines compared to the inactive group, except for the PIF. The TW guidelines group showed significantly better scores ($p < 0.001$) on all respiratory parameters compared to the inactive group (Table 4). No significant differences in respiratory parameters were found between the MG and TW guidelines groups, except for PIF, which was higher in the TW guidelines group ($p = 0.009$; Table 4b, Supplementary Appendix 1).

Exercise capacity

The TW guidelines group showed a significantly higher relative VO₂peak ($p = <0.001$, Table 4) and absolute VO₂peak ($p = 0.001$, Table 5a, Supplementary Appendix 1) compared to the inactive group. Both the MG ($p = 0.047$) and the TW guidelines group ($p = <0.001$) scored significantly better on relative POpeak compared

to the inactive group (Table 4). The TW guidelines group scored significantly higher (<0.001) on absolute POpeak compared to the inactive group (Table 5a, Supplementary Appendix 1). Additionally, the TW guidelines group scored significantly better on both absolute VO₂peak ($p = 0.022$) and POpeak ($p = 0.026$) compared to the MG guidelines group (Table 5b, Supplementary Appendix 1).

Health

A significantly lower BMI was found ($p = 0.039$) in the MG guidelines group compared to the inactive group (Table 4). A significantly lower WC was found ($p = 0.007$) in the TW guidelines group compared to the inactive group (Table 4). The TW guidelines group showed significantly higher SBP ($p = 0.005$, Table 6a, Supplementary Appendix 1) and MAP ($p = 0.026$, Table 4) compared to the inactive group. No significant differences in the prevalence of hypertension or in lipid profile outcomes were found among groups.

Discussion

The purpose of this study was to estimate the proportion of Dutch wheelchair users with SCI meeting different SCI exercise

Table 4. Multiple regression analysis on fitness and health outcomes with inactive as reference.

Variables included in the model	FVC		FEV1		FIV1		PEF		PIF	
	B (SE)	p	B (SE)	p	B (SE)	p	B (SE)	p	B (SE)	p
Constant	3.90 (.35)	<0.001	3.44 (.27)	<0.001	3.18 (.32)	<0.001	5.14 (.65)	<0.001	4.84 (.53)	<0.001
MG guidelines vs. inactive	.74 (.19)	<0.001	.46 (.14)	0.001	.51 (.17)	0.003	.98 (.35)	0.005	.15 (.28)	0.603
TW guidelines vs. inactive	.67 (.14)	<0.001	.45 (.11)	<0.001	.59 (.13)	<0.001	1.12 (.27)	<0.001	.87 (.22)	<0.001
Potential confounders										
Sex	.48 (.10)	<0.001	.33 (.08)	<0.001	.38 (.09)	<0.001	.61 (.19)	0.001	.42 (.15)	0.006
Age	-.02 (.01)	0.002	-.02 (.01)	<0.001	-.01 (.01)	0.045	-.02 (.01)	0.082	-.03 (.01)	0.028
Lower educational level vs. middle	.20 (.17)	0.263	.14 (.13)	0.299	.08 (.16)	0.607	.45 (.32)	0.163	.09 (.27)	0.746
Higher educational level vs. middle	.10 (.15)	0.504	.10 (.11)	0.395	.04 (.14)	0.785	.45 (.27)	0.099	.08 (.22)	0.735
TSI	-.003 (.01)	0.688	-.002 (.01)	0.691	-.003 (.01)	0.601	.01 (.01)	0.309	.01 (.01)	0.360
Etiology SCI	-.07 (.20)	0.716	-.22 (.16)	0.163	-.11 (.18)	0.565	-.39 (.38)	0.305	-.29 (.31)	0.352
Lesion level	.38 (.09)	<0.001	.29 (.07)	<0.001	.35 (.08)	<0.001	.71 (.17)	<0.001	.53 (.14)	<0.001
Lesion completeness	.57 (.16)	<0.001	.46 (.12)	<0.001	.46 (.15)	0.002	.75 (.29)	0.012	.20 (.24)	0.426
	Relative VO ₂ peak		Relative POpeak		WC		BMI		MAP	
	B (SE)	p	B (SE)	p	B (SE)	p	B (SE)	p	B (SE)	p
Constant	16.26 (2.71)	<0.001	.58 (.12)	<0.001	88.02 (7.87)	<0.001	21.39 (1.62)	<0.001	65.20 (5.21)	<0.001
MG guidelines vs. inactive	2.46 (1.45)	0.091	.14 (.07)	0.047	-3.41 (3.07)	0.268	-1.79 (.86)	0.039	1.90 (2.67)	0.476
TW guidelines vs. inactive	4.49 (1.20)	<0.001	.25 (.06)	<0.001	-6.36 (2.34)	0.007	-.92 (.66)	0.162	4.65 (2.08)	0.026
Potential confounders										
Sex	1.03 (.63)	0.105	.04 (.03)	0.158	9.87 (2.51)	<0.001	.42 (.37)	0.255	.16 (2.10)	0.941
Age	-.13 (.06)	0.033	-.01 (.003)	0.010	.09 (.23)	0.688	.10 (.03)	0.003	.37 (.11)	0.001
Lower educational level vs. middle	1.61 (1.40)	0.250	.03 (.06)	0.623	-2.30 (3.14)	0.465	.15 (.80)	0.851	.83 (2.48)	0.738
Higher educational level vs. middle	.56 (1.10)	0.611	.06 (.05)	0.230	-1.47 (2.65)	0.580	.47 (.68)	0.492	1.28 (2.13)	0.548
TSI	.004 (.06)	0.940	.002 (.003)	0.345	.13 (.22)	0.554	-.03 (.03)	0.345	.13 (.10)	0.198
Etiology SCI	-.21 (1.64)	0.900	.12 (.08)	0.132	4.72 (3.75)	0.209	-.37 (.94)	0.695	2.77 (2.89)	0.338
Lesion level	2.61 (.60)	<0.001	.12 (.03)	<0.001	-.56 (1.31)	0.669	.15 (.42)	0.717	5.54 (1.30)	<0.001
Lesion completeness	-.34 (1.25)	0.788	-.11 (.06)	0.069	.003 (2.81)	0.999	.35 (.73)	0.637	1.01 (2.27)	0.656

The inactive group was used as reference variable in this table. Sex was coded as female = 0 and male = 1; lesion level as tetraplegia = 0 and paraplegia = 1; lesion completeness as motor complete = 0 and incomplete = 1; etiology as traumatic = 0 and non-traumatic = 1 and middle educational level was used as reference variable.

guidelines, which demographic and lesion characteristics are associated with meeting these guidelines, and whether meeting these guidelines is associated with better physical fitness and health. Results showed that only 29% of Dutch wheelchair users with SCI meet SCI-specific exercise recommendations if strength exercise is taken into account. When strength training is not taken into account, 63% meet either the MG or TW guidelines for aerobic exercise. When adjusted for demographic and lesion characteristics, a strong association was found between aerobic exercise activity levels and beneficial outcomes on physical fitness, with more strenuous guidelines showing better outcomes on exercise capacity. Additional benefits were found regarding body composition in more strenuous aerobic exercise activity levels, and therefore possibly health. These results clearly show the importance of regular exercise and that the SCI-specific exercise guidelines partly achieve what they were designed for.

As expected, older age, being female, having tetraplegia, and low educational level seem to negatively influence exercise behavior, and therefore physical fitness and health outcomes. In this study, only 29% of the participants met the least strenuous SCI-specific exercise guidelines (MG), and 22% of the TW guidelines, when strength exercise was taken into account. This result shows that combining aerobic and strength exercise is a challenge for most Dutch wheelchair users with SCI. Higher proportions were found in Switzerland in previous research of Rauch et al. [9], who applied allocation to guidelines using a similar methodology. Rauch et al. found that 49% of persons with SCI fulfilled the WHO guidelines, including strength exercise, which are comparable guidelines to the TW guidelines. However, the WHO does not differentiate between moderate and vigorous activity levels like the TW guidelines. In contrast, a Canadian study showed much lower percentages, i.e., with only 12% meeting the MG exercise guidelines compared to 29% in this study [10]. When only aerobic exercise was taken into account, 63% of our

participants met the MG guidelines, compared to 36% of the participants in a study of Rocchi et al. [10] who applied the Leisure Time Physical Activity Questionnaire for People with Spinal Cord Injury (LTPAQ-SCI). The use of a different questionnaire might have caused differences in allocating participants to meeting exercise guidelines or not, as the LTPAQ-SCI asks the exact number of days spent in different intensity levels while the PASIPD categorizes this question into: never, 1–2, 3–4, or 5–7 days. Therefore, it is more likely to overestimate the time spent in specific exercise intensities when using the PASIPD. Only 22% of our participants met the TW guidelines, which is much lower compared to the 44% of the general Dutch population who meets the comparable WHO guidelines [23]. This emphasizes once more the necessity to facilitate and support exercise in individuals with SCI.

Results of the regression analyses showed beneficial associations between meeting exercise guidelines and respiratory function, as both the MG and TW guidelines group scored significantly better on almost all respiratory function tests compared to the inactive group, even after correction for lesion level and completeness, and age. Respiratory dysfunction can have a severe impact on daily life in individuals with SCI. Increased residual lung volumes, along with a reduced ability to cough, can cause increased accumulation of secretion, increasing the risk of pulmonary infections and other complications [24]. No significant differences were found between the MG and TW guidelines group, suggesting respiratory function improvement already occurs at relatively low exercise activity levels.

Significantly higher outcomes in relative POpeak were found in the MG and TW guidelines groups compared to the inactive group. This is a valuable finding as most individuals with SCI depend on a manual wheelchair and those with a higher POpeak tend to experience a lower amount of strain in activities of daily living, are more likely to return to work, and experience a higher quality of life [25–27]. The TW guidelines group scored also

significantly better on PO_{peak} and relative VO_{2peak} compared to the inactive group. There may have been a positive selection bias as a higher proportion of individuals with tetraplegia was found in the inactive group (56.8%) compared to the MG (49.2%) and TW (39.0%) guidelines groups. This probably explains the relatively low number of inactive individuals who performed a peak exercise test (31.8%), compared to the MG group (67.8%) and TW group (71.3%). Thus, the actual differences in physical fitness between the inactive group and the MG and TW guidelines groups might be even larger. However, even after controlling for lesion level, a clear pattern was found showing increased benefits in physical fitness with increased exercise activity levels.

One of the main reasons exercise guidelines were developed, was to provide evidence-based recommendations to support behavior that leads to fitness and health benefits and reduce health risks and mortality [5]. Obesity, high blood pressure, and high cholesterol are among the most critical risk factors [28]. Despite the known positive relationship between exercise and these factors, results in the present paper are limited. The TW guidelines group showed a significantly lower WC compared to the inactive group suggesting additional health benefits as the guidelines were designed for. Surprisingly, participants who met the MG guidelines showed a significantly lower BMI compared to the inactive group while participants who met the TW guidelines did not. This could be explained by the fact that BMI does not take body composition, and therefore, muscle mass into account. Significantly higher SBP and MAP were found in the TW guidelines group compared to the inactive group, however, this did not translate into significantly different hypertension ratios compared to other groups. No significant differences were found in lipid profile outcomes, which could be attributed to their complex regulation which is controlled by many factors, of which some cannot be influenced by exercise, or can be influenced by medication use, which was not taken into account in the analyses.

Strengths and limitations

Merging two relatively large SCI datasets made it possible to perform analysis with a relatively large group of 358 participants. However, this study also has some limitations. The PASIPD was used to determine whether exercise guidelines were met, which is a self-administered outcome and a questionnaire not specifically designed to quantify exercise time and exercise intensity precisely. Therefore, the outcomes obtained from the participants might not fully reflect their actual situation. Previous research has shown that the PASIPD tends to overestimate time spent on physical activity, which might have caused biased group allocation [29]. Additionally, answer options of the PASIPD for exercise frequency were in the ranges 0, 1–2, 3–4, or 5–7 times a week, as a result, exercising once a week could not be distinguished from exercising twice a week based on this item. Therefore, the classification of meeting or not meeting the aerobic exercise guidelines was based on total weekly time spent on exercise, leaving frequency (aerobic exercise at least twice a week) out of the process of allocation. The involvement of strength exercise could only be determined as at least once a week, like in the study of Rauch et al. [9]. Therefore, the actual number of participants meeting any of the exercise guidelines including strength exercise could be even lower. Moreover, differentiation in moderate or vigorous intensity level was done subjectively by the participants based on the given PASIPD questions, which included examples of moderate or vigorous exercise activities. Due to the severity and level of their lesion the exercise capacity of individuals with tetraplegia

can be severely reduced, putting them under relatively more strain in activities of similar intensity compared to individuals with paraplegia, making exercise intensity differentiation difficult and possibly unreliable.

Conclusion

With only 29% a small proportion of the Dutch wheelchair users with SCI seem to meet an SCI exercise guidelines. The exercise guidelines seem to at least partially achieve what they are designed for. Meeting the MG guidelines was associated with improved respiratory function and exercise capacity, which is achieved with relatively low exercise levels. Increased exercise levels, like in the TW guidelines, were associated with additional fitness and body composition benefits.

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Ethical approval

Ethical approval was given by the local medical ethics committee of rehabilitation center Hoensbroek and the Medical Ethics Committee of the University Medical Centre Utrecht. We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during the course of this research.

Author contributions

DH, JH, SdG, and TJ conceived and designed the research. LvdW and SdG organized and managed the data collection of both projects. KP was involved in the organization and data collection of the Umbrella project. DH cleaned and merged the datasets. DH analyzed the data with the supervision of JH, SdG, and TJ. DH wrote the paper and all authors read the paper, provided feedback, and approved the manuscript.

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