Low-intensity wheelchair training in inactive people with long-term spinal cord injury

Jan van der Scheer

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ALLRISC is embedded in the Spinal Cord Injury investigatiOn Network Netherlands (www.scionn.nl) and conducted in collaboration with the Dwarsleasie Organisatie Nederland (DON) and the Nederlands-Vlaams Dwarslaesie Genootschap.

A randomized controlled trial was conducted at rehabilitation centers UMCG location Beatrixoord (Haren, the Netherlands) and Heliomare (Wijk aan Zee, the Netherlands). Pilot studies were conducted at the Center for Human Movement Sciences, University of Groningen, University Medical Center Groningen (the Netherlands) and the Faculty of Human Movement Sciences, VU University Amsterdam (the Netherlands).

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Contents

List of abbreviations

(25-75th)= interquartile range
ACSM = American College of Sports Medicine
ADL = activities of daily living
AIS = American Spinal Injury Association Impairment Scale
ALLRISC = Active LifeStyle Rehabiliation Intervention in aging person with Spinal Cord injury
ASIA = American Spinal Injury Association
BMI = body mass index
bpm = beats per minute
Fiso = highest mean consecutive 3s-force interval over 3 successful trials in an isometric wheelchair-push test
HR = heart rate
HRmax = maximal heart rate
HRpeak = peak heart rate in a peak wheelchair exercise test
HRR = heart rate reserve
LPD = local perceived discomfort
M.D. = medical doctor
Mdn = median
ME = gross mechanical efficiency
meanVelocity-15 m = 15 m divided by stopwatch time
MEsub1 = mean mechanical efficiency over last 30 s of the first block in a submaximal wheelchair exercise test
MEsub2 = mean mechanical efficiency over last 30 s of the second block in submaximal wheelchair exercise test
MET = metabolic equivalent
N.A. = not applicable
N.E. = not entered
O.T. = occupational therapist
P.T. = physical therapist
P30-WAnT = mean unilateral PO over Wingate-based 30s-sprint
P5-15m = highest mean unilateral PO over successive 5-s intervals of a 15-m overground wheelchair sprint
P5-WAnT = highest mean unilateral PO over the 6 successive 5-s intervals of a Wingate-based 30-s sprint
PA = physical activity
Para = paraplegia
PASIPD = Physical Activity Scale for Individuals with Physical Disabilities

PO = power output

POpeak = highest power output maintained for at least 30 s in a peak wheelchair exercise test

Ppeak-15m = peak momentary unilateral PO of a 15-m overground wheelchair sprint

Pstart-15m = mean unilateral PO over the first 3 push cycles of a 15-m overground wheelchair sprint

RC = rehabilitation center

RCT = randomized controlled trial

RERpeak = highest mean 30-s respiratory exchange ratio in a peak wheelchair exercise test

RERsub1 = highest mean 30-s respiratory exchange ratio of the first block in a submaximal wheelchair exercise test

RERsub2 = highest mean 30-s respiratory exchange ration of the second block in a submaximal wheelchair exercise test

RPE = rate of perceived exertion

SCI = spinal cord injury

SD = standard deviation

T1 = baseline measurements

T2 = measurements eight weeks after baseline

T3 = measurements 16 weeks after baseline

T4 = measurements 42 weeks after baseline

Tetra = tetraplegia

Time-15 m = time over a 15-m overground wheelchair sprint

TSI = time since injury

VO2peak = highest 30-s mean oxygen uptake in peak wheelchair exercise test

VO2sub1 = mean oxygen uptake over last 30 s of first block in submaximal wheelchair exercise test

VO2sub2 = mean oxygen uptake over last 30 s of second block in submaximal wheelchair exercise test

WAnT = Wingate Anaerobic Test

Chapter 1

General introduction

BACKGROUND

One of the major public health issues of the 21st century could be physical inactivity.[1-3] Low physical activity and fitness levels can lead to reduced daily and cognitive functioning, while physical inactivity is also associated to increased risk of cardiovascular diseases, depression and several forms of cancer.[3-6] These complications are more likely in people with disabilities, as their impairments often limit physical activity and fitness levels.[7-9]

Among the lowest physical activity and fitness levels have been found in people with spinal cord injury (SCI).[9,10] These low levels have been attributed to direct and indirect consequences of the damaged spinal cord, including impairments in the autonomic nervous system as well as loss of motor and sensory control below the level of lesion, often leading to dependence on the small upper-body muscle mass for physical activity and a manual wheelchair for mobility.[11-16] As a result, people with SCI are predisposed to developing inactivity-related complications as well as other secondary health complications such as urinary tract infections, pressure ulcers and upper-body musculoskeletal pain.[8,15,17-19] For example, a secondary consequence of the loss of bladder control is urinary tract infections,[20] while upper-body musculoskeletal pain is thought to result from manual wheelchair use.[21,22] Secondary health complications of people with SCI have been related to reduced participation in society, lower quality of life as well as to financial burdens of unemployment and hospitalization.[23,24]

It has been assumed that aging people with SCI and those with long-term SCI are likely to enter a vicious cycle of physical inactivity, low fitness and secondary health complications (figure 1).[19,25-27] Physical activity and fitness levels often decline in aging people,[28,29] while increased risk of secondary health complications has been associated with progressing age and time since injury (TSI).[30-33]

Negative effects of such a vicious cycle might be prevented or reduced through the use of a lifespan-covering aftercare system.[27,34] A recommendation for aftercare of people with disabilities is to use interventions to improve physical activity and fitness levels, while simultaneously reducing risk of secondary health complications.[26,35] These interventions could consist of self-management programs, as based on evidence in other populations and preliminary studies in people with SCI.[36-38] They could also consist of exercise training, which has been found effective in improving physical fitness of people with SCI and reducing secondary health complications such as upper-body pain.[39-41]

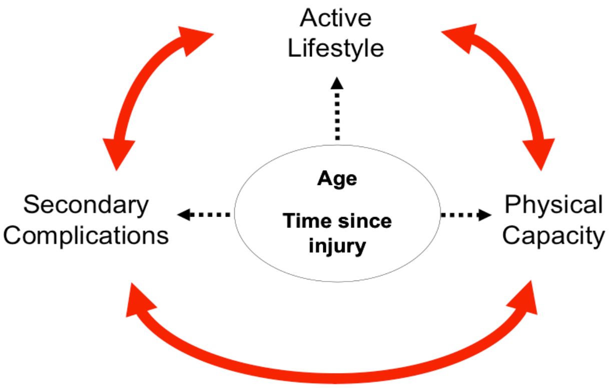

Figure 1. Associations assumed among an active lifestyle, physical fitness, secondary health complications, age and time since injury, as described for people with spinal cord injury by Van der Woude et al.[27] Figure adapted.[27]

A structured aftercare system for people with long-term SCI is not yet operational in the Netherlands, while further study has been recommended on relationships among physical inactivity, low fitness and secondary health complications as well as interventions to improve these factors in people with long-term SCI.[18,33,42] Therefore, the Dutch multicenter research program 'Active LifestyLe Rehabilitation Interventions in aging Spinal Cord injury' (ALLRISC) was developed.[27]

Research program ALLRISC

Research program ALLRISC, the framework of this thesis, had two main objectives: 1) to develop evidence-based components and guidelines for SCI rehabilitation aftercare in the Netherlands; and 2) to improve understanding of requirements of regular aftercare aimed at long-term preservation of an active lifestyle and fitness, prevention of secondary health complications as well as increasing activities, participation, health and quality of life in persons aging with long-term SCI.[27] As such, ALLRISC is a continuation of a previous multicenter research program, which consisted of a longitudinal cohort study on physical capacity and strain of people with SCI during and up to five years after inpatient rehabilitation.[43] Both research programs are embedded in the Dutch SCI clinical rehabilitation network.[44] ALLRISC is funded by FondsNutsOHRA under responsibility of ZonMw.[45] Program-wide outcomes of ALLRISC were formulated using the International Classification of Functioning (ICF) model of the World Health Organization applied to people with SCI (figure 2).[27,46,47]

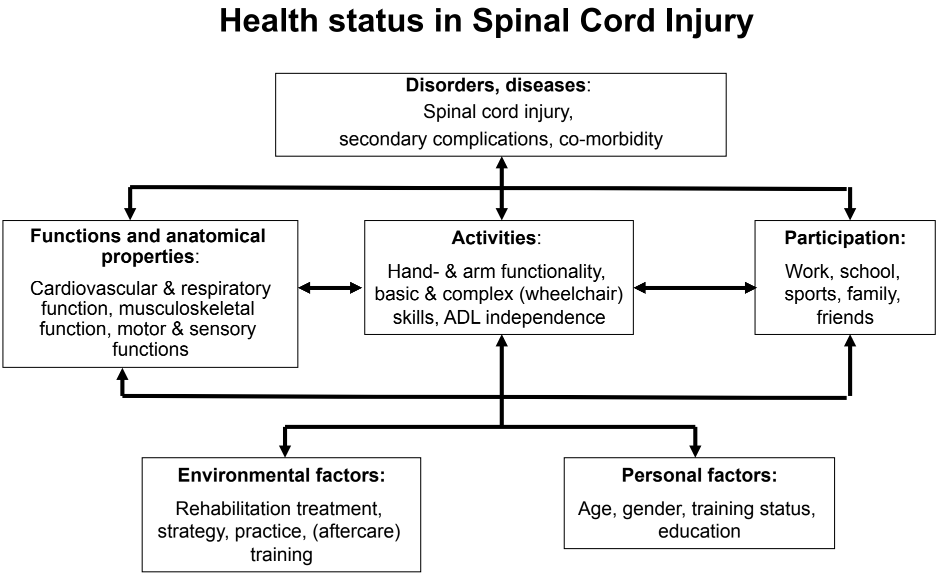

Figure 2 The International Classification of Functioning (ICF) model of the World Health Organization applied to people with spinal cord injury.[46,47] This model was used in formulating program-wide outcomes of research program ALLRISC.[27] Figure reprinted.[47]

ALLRISC consists of four Ph.D. projects that started in 2010: one cross-sectional cohort study and three randomized controlled trials (RCTs) in which self-management or exercise interventions were employed.[33,36,48,49] The objective of the cross-sectional cohort study was to describe physical fitness, functioning and the prevalence of secondary health complications in people with long-term SCI, in addition to studying the impact of these conditions on the program-wide outcomes of ALLRISC.[33] The study consisted of an aftercare check-up in eight SCI-specialized rehabilitation centers in the Netherlands. Participants with the lowest physical activity levels were also invited for one of the three RCTs. Objective of the first RCT was to evaluate a self-management intervention aimed at stimulating active lifestyle and teaching self-management skills in inactive people with long-term SCI.[36] Objective of the other two RCTs was to evaluate different forms and doses of exercise in inactive people with long-term SCI.[48,49] The exercise interventions were aimed at improving physical fitness, and through that, increasing an active lifestyle and reducing risk of secondary health complications related to upper-body overuse and lower-body disuse.[48,49] One of these interventions consisted of low-intensity wheelchair training and was the focus of this thesis.

LOW-INTENSITY WHEELCHAIR TRAINING

Wheelchair training has been found effective in improving wheelchair-specific fitness of people with SCI when performed at moderate and vigorous intensities (tables 1 and 2).[39] In inactive or deconditioned populations, however, it is suggested that such exercise intensities may lead to low adherence, dropout and musculoskeletal injury. [6,50] Furthermore, it has been found that higher wheelchair exercise intensities lead to increased upper-body joint loads,[51] which could contribute to upper-body pain of people with SCI.[21,22] As a safer and more feasible alternative for inactive or deconditioned populations, it has been recommended to use low-intensity exercise (table 1).[6] Low-intensity training using the lower body has already been found effective in improving fitness of inactive or deconditioned people such as older adults and cancer survivors (25-40% heart rate reserve [HRR], 9-40 weeks, 3-5 times per week, 14-45 min per session).[52-54]

Table 1. Definitions of exercise intensities used in this thesis, as based on guidelines of the American College of Sports Medicine and a study on exercise in people with tetraplegia.[6,55]

Exercise intensity	% HRR	RPE on 1-10 scale[56]
Low	30-40	1-3
Moderate	41-60	4-6
Vigorous	61-90	7-10

Abbreviations: HRR = heart rate reserve; RPE = rate of perceived exertion.

Table 2. Definitions and brief explanations of terms used in this thesis.

Term	Definition and brief explanation
Wheelchair training	Exercise program consisting of manual wheelchair propulsion, for example using an ergometer or treadmill (figure 3).
Wheelchair-specific fitness	Physical fitness measured during manual wheelchair propulsion tests, as assessed based on anaerobic work capacity, isometric strength, submaximal fitness and peak aerobic work capacity.[47]
Wheelchair skill performance	Variety of manual wheelchair skills necessary to deal with physical barriers encountered in daily life.[57,58] It can be assessed using a test battery such as the Wheelchair Circuit, which includes tests such as crossing a doorstep, propulsion on a slope, a circuit-of-eight and a 15 m-sprint.[59]
Propulsion technique	Force and timing parameters based on contact between hand and handrim, for example push frequency, peak force and contact angle.[60,61]

Figure 3. Wheelchair propulsion using a motor-driven treadmill.

However, low-intensity wheelchair training has not yet been systematically evaluated in inactive or deconditioned people with long-term SCI. Preliminary studies are available on low-intensity wheelchair training in able-bodied groups, novice to wheelchair propulsion (appendix).[62-64] After exercising for seven weeks, three times a week for 30 or 70 min per session, improvements were found in wheelchair-specific fitness, for example about 30% in wheelchair-specific anaerobic work capacity, about 15-30% in submaximal fitness and about 30-50% in peak aerobic work capacity (appendix).[62-64] It is also not known whether low-intensity wheelchair training in people with SCI leads to improved physical activity levels and wheelchair skill performance (defined in table 2). Physical activity and wheelchair skill performance could improve as a result of increased wheelchair-specific fitness, as suggested by findings in studies on the associations among these factors.[65,66] Also not known are the effects of low-intensity wheelchair training on propulsion technique (table 2) in people with SCI. Changing propulsion technique has been proposed as a way to reduce joint damage that might occur during manual wheelchair propulsion in daily life.[60] Favorable changes in propulsion technique, such as reduced push frequency, have been found in long-term wheelchair users performing relatively high-intensity training as well as able-bodied novices performing low-intensity wheelchair training.[64,67]

A multicenter RCT was conducted in a group of physically inactive manual wheelchair users with long-term SCI (table 3).[49] An exercise group followed a 16-week training consisting of wheelchair treadmill propulsion at 30-40% heart rate reserve or its equivalent in rate of perceived exertion, twice a week, 30 min per session. The control group was not offered any intervention. Measurements were performed in both groups at baseline as well as after eight and 16 weeks, while a follow-up measurement was performed 42 weeks after baseline (figure 4). Outcomes were based on project-specific and program-wide outcomes of ALLRISC (figure 2), which included outcomes of wheelchair-specific fitness, wheelchair skill performance, physical activity levels and propulsion technique.[27,49] Measurements and exercise took place in two SCI-specialized rehabilitation centers (Heliomare, Wijk aan Zee and University Medical Center Groningen, location Beatrixoord, Haren, the Netherlands).

Table 3. Selection criteria in the randomized controlled trial. [49]

Inclusion criteria
Long-term SCI (time since injury > 10 years)
Aged 28-65 years
Dependent on a manual wheelchair (regular use in daily life)
Physically inactive as defined by a PASIPD score < 75th percentile of a Dutch SCI cohort[68,69]
Exclusion criteria
Cardiovascular contra-indications for testing according to ACSM guidelines[70]
Resting diastolic blood pressure above 90 mm Hg
Resting systolic blood pressure above 180 mm Hg
Severe musculoskeletal complaints of the upper extremities, neck or back that contraindicate wheelchair propulsion
Insufficient mastery of Dutch language
Pregnancy
Progressive disease
Psychiatric problems
Plans to change lifestyle, for example engaging in a diet or another physical activity program

Abbreviations: SCI = spinal cord injury; PASIPD = Physical Activity Scale for Individuals with Physical Disabilities; ACSM = American College of Sports Medicine.

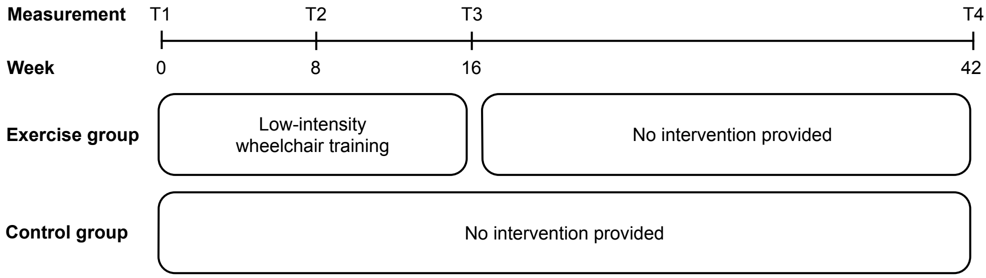

Figure 4. Experimental design of the randomized controlled trial.[49]

AIM AND OUTLINE OF THIS THESIS

The aim of this thesis was to study the effects of low-intensity wheelchair training on wheelchair-specific fitness, wheelchair skill performance, physical activity levels and propulsion technique in physically inactive people with long-term SCI.

Chapter 2 presents a cross-sectional study on wheelchair-specific peak aerobic work capacity in a cohort with long-term SCI. Aim of this study was to investigate the impact of physical activity and TSI on wheelchair-specific fitness in people with a SCI longer than 10 years. For this purpose, associations were determined among wheelchair-specific peak aerobic work capacity, TSI and physical activity as well as potential confounders in personal and lesion characteristics. Furthermore, differences were studied between participants able or not able to perform a peak wheelchair exercise test, providing insight into potential selection bias and the extent in which results could be generalized to the population with long-term SCI.

Chapter 3 is a detailed description of the design and methodology in the multicenter RCT on low-intensity wheelchair training. Working mechanisms underlying this type of training are also discussed in this chapter.

Since the multicenter RCT took place in rehabilitation centers, feasible tests were needed to study effects on wheelchair-specific fitness. For this purpose, a new test was developed: a 15 m-overground sprint test in a wheelchair equipped with a measurement wheel to determine power output. Whether this test could be used to assess wheelchair-specific anaerobic work capacity was evaluated in **chapter 4**.

Aim of the cross-sectional study in **chapter 5** was to provide insight into several wheelchair-specific fitness components in physically inactive people with long-term SCI. For this purpose, baseline personal and lesion characteristics were described of the group that participated in the RCT, in addition to providing a description of wheelchair-specific anaerobic work capacity, isometric strength and peak aerobic work capacity. These fitness components were assessed with tests feasible for use in rehabilitation centers. Associations among these fitness components were also investigated, since strong associations would imply that several tests may not be necessary for assessment of different wheelchair-specific fitness components.

Chapter 6 is an evaluation of the effects of the training in the RCT on wheelchair-specific fitness, wheelchair skill performance and physical activity levels in the inactive group with long-term SCI. **Chapter 7** focuses on effects of the training on propulsion technique.

Last, in **chapter 8**, main findings are combined and discussed with the aim of providing suggestions for future research and clinical implications.

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Chapter 2

Wheelchair-specific fitness of persons with a long-term spinal cord injury:

Cross-sectional study on effects of time since injury and physical activity level

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ABSTRACT

Aim: To study the impact of time since injury (TSI) and physical activity (PA) on fitness of persons with spinal cord injury (SCI) for at least 10 years.

Methods: Cross-sectional study. Persons with SCI (N=213) in three TSI strata: 10-19, 20-29 and ≥30 years after SCI and divided in an active and inactive group. Fitness (peak power output [POpeak] and peak oxygen uptake [VO2peak]) was assessed during a graded wheelchair exercise test.

Results: Of the participants, 35% (N=75) were not able to perform the exercise test. They were significantly older (p=0.04), had a longer TSI (p=0.03), and had more often tetraplegia (p=0.01) than participants in the exercise test. In tetraplegia, no significant differences in fitness were found among TSI strata while the active group had a better fitness than the inactive group. A significant interaction between TSI and PA was found for the relationship with POpeak in tetraplegia. The group with paraplegia for ≥30yrs showed a significantly lower fitness compared to those with TSI<30yrs. Furthermore, after controlling for confounders, it was shown that TSI had a negative effect on fitness, while PA was not significantly associated with fitness in people with paraplegia.

Conclusions: Active people with tetraplegia showed higher fitness levels and less decline in POpeak with an increase in TSI compared to inactive people. In paraplegia, fitness was significantly lower in those with a TSI ≥30yrs. Results indicated that those with a long TSI need attention to remain fit and that PA seems an important element in that respect.

INTRODUCTION

Since the majority of people with a spinal cord injury (SCI) is wheelchair dependent,[1] a good wheelchair-specific fitness is important for people with a SCI. Fitness in SCI has found to be positively related to health,[2] participation[3] and quality of life.[4] Previous research showed that wheelchair-specific fitness, expressed as peak power output (POpeak) and peak oxygen uptake (VO2peak) measured during a graded wheelchair exercise test, increased significantly during and in the first year after inpatient SCI rehabilitation.[5] In the following four years a stabilisation was observed.[6]

Not much is known about wheelchair-specific fitness of people with long-term SCI (>10 years). With increasing age and time since injury (TSI), secondary health problems such as infections, spasticity, high blood pressure, and chronic pain may occur more frequently.[7,8] These health problems might subsequently lead to a reduction of fitness,[9] and, therefore, deconditioning in this group might go faster compared to the aging general population.

Janssen *et al.*[10] studied the change in wheelchair-specific fitness over a 3-yr period in 37 men with long-standing SCI (mean TSI: 14.7±8.6 years). The VO2peak remained the same while the POpeak significantly increased. TSI and the hours of weekly active sport participation were the most important predictors of changes in wheelchair-specific fitness. Shiba *et al.*[11] found no change in VO2peak over 20 years in seven athletes with paraplegia (TSI at the start ranged from 2-23 years), which might be explained by continuation with wheelchair sport activities over those 20 years. As far as known, besides these longitudinal studies, no study has yet investigated the effect of having a long-term SCI (>10 years) on wheelchair-specific fitness. Since people with a tetraplegia and paraplegia have a different level (of change) of fitness, it is important to study these groups separately.[5] Furthermore, the effect of physical activity (PA) on wheelchair-specific fitness has not been evaluated in people with a long-term SCI.

It might be possible that part of the population with a long-term SCI is not able to perform an exercise test due to risk factors such as cardiovascular of musculoskeletal problems. To determine whether participants of an exercise test are a positive selection of the total population with a long-term SCI, it is important to study differences among the participants and non-participants. Therefore, the aims of this study were to investigate: 1) differences in personal and lesion characteristics, PA and upper-extremity pain among participants and non-participants of a graded peak wheelchair exercise test; and 2) the impact of time since injury (three strata of TSI: 10-19, 20-29 and ≥30 years) and PA on wheelchair-specific fitness of persons with long-term SCI, i.e. paraplegia and tetraplegia.

METHODS

Participants

This cross-sectional study among persons with long-term SCI in the Netherlands was part of the research program ‘Active LifestyLe Rehabilitation Interventions in aging

Spinal Cord injury (ALLRISC).[12,13] Strata of TSI were 10-19, 20-29 and ≥30 years or more after SCI. Inclusion criteria were: traumatic or non-traumatic SCI; age at injury between 18-35 years; TSI at least 10 years; current age between 28-65 years; wheelchair dependent (hand-rim propelled or electric wheelchair) at least for longer distances (>500 m). Overall exclusion criterion was: insufficient mastery of the Dutch language to respond to an oral interview or to understand the test instructions.

Design

The design of this study is described in detail elsewhere.[13] Random samples were drawn from eight Dutch rehabilitation centres with a specialized SCI-unit. Participants were invited on a voluntary basis for a one-day visit to the rehabilitation centre, including an aftercare check-up by a SCI rehabilitation physician, physical tests by a trained research assistant, and completing a self-report questionnaire. The study protocol has been approved by the Medical Ethics Committee of the University Medical Centre Utrecht. Participants signed an informed consent form before testing.

Graded peak wheelchair exercise test

Wheelchair-specific fitness was determined during a graded peak wheelchair exercise test on a motor-driven treadmill in the participant's own wheelchair. Prior to testing the wheelchair was inspected for malfunctioning and tire pressure. Participants were asked to void their bladder and not to smoke or drink coffee or alcohol in the 2 hours before the test. During a familiarization warm-up a suitable treadmill velocity (0.55, 0.83 or 1.11 $m \cdot s^{-1}$) was chosen for the exercise test. After two submaximal exercise tests and two minutes of rest the actual graded peak exercise test began with a 0.36° increase in treadmill inclination per minute. The test ended when the participant was completely exhausted or could no longer maintain the treadmill speed.

Oxygen uptake and heart rate (HR) were continuously measured during the test by an Oxycon Delta (CareFusion, San Diego, USA), which was calibrated with standard volume and gases before the test, and a Polar HR monitor (Polar Electro Oy, Kempele, Finland), respectively. The VO2peak ($L \cdot min^{-1}$), peak respiratory exchange ratio (RERpeak) and HRpeak (bpm) were defined as the highest values recorded during 30 seconds. The POpeak (W) was determined from the product of treadmill belt velocity and drag force measured during a separate wheelchair drag test. The technique for the drag test was developed by the technical department of the Faculty of Human Movement Sciences, VU University, Amsterdam, the Netherlands.[14] POpeak was defined as the power output at the highest inclination that the participant could maintain for at least 30 seconds.

Personal and lesion characteristics

Participant information regarding age, gender, body mass, height, waist circumference, and lesion characteristics was collected. Lesion level and completeness were determined by a rehabilitation physician using the International Standards for Neurological Classification of Spinal Cord Injury.[15] Tetraplegia was defined as a lesion at or above the T1 segment, and paraplegia as a lesion lower than T1. A lesion was defined motor complete when participants had grades A or B on the American Spinal Injury Association (ASIA) impairment scale. The body mass index (BMI) was calculated as: body mass (kg) divided by height (m^2). Supine waist circumference was measured at the level of the umbilicus using a tape measure.

Questionnaires

Information on level of PA was collected using the Dutch version of the Physical Activity Scale for Individuals with Physical Disabilities (PASIPD),[16] which requests the number of days a week, hours a day, and intensity of participation in leisure (6 items), household (5 items), and occupational (1 item) activities over the past 7 days. The total PASIPD score is expressed in metabolic equivalent (METs in $hr \cdot day^{-1}$, maximum score is 182.3 MET $hr \cdot day^{-1}$). People were qualified as 'inactive' if the score on the PASIPD was lower than the 75th percentile in a Dutch cohort study (PASIPD<30 MET $hr \cdot day^{-1}$),[17] which was the inclusion criteria in the three randomized-controlled trials within the ALLRISC research program.[12]

Participants were asked in a separate standardized questionnaire if they experienced pain on the joints or muscles of the wrist, elbow and shoulder of both arms.[18] An overall upper-extremity pain score was obtained by multiplying the pain score of each joint by the seriousness and frequency of complaints. The scores of the three joints of both upper extremities were summed to obtain an upper-extremity pain score (range: 0-90).[18]

Statistics

Independent *t*-tests and chi-squared tests were used to analyse differences between participants and non-participants of the graded peak wheelchair exercise test.

Differences in test outcomes among the three TSI strata, for the total group and those with tetraplegia and paraplegia separately, were tested with an Oneway ANOVA and Bonferroni post-hoc tests. An independent *t*-test was performed to study differences in outcomes between active and inactive persons.

The effects of TSI (years) or PA (PASIPD total score) on wheelchair-specific fitness, corrected for possible confounding factors (lesion and personal characteristics), were studied with linear regression analyses for the total group and those with a paraplegia and tetraplegia separately. The dependent variable was POpeak or VO2peak, the independent variable was TSI or PA. Possible confounders were added to the models one by one. When the beta of TSI or PA changed more than 10%, the added variable was a confounder and it was added to the final model.

Lastly, both TSI, PA and the interaction between them were entered in a regression model to study whether the effect of TSI on fitness varies as a function of PA. The significance was set at $p<0.05$ for all tests.

RESULTS

Participants vs. non-participants

Of the 213 participants, 35% was not able to perform the exercise test (figure 1). The reasons for not participating in the peak exercise test were mainly using a power wheelchair (40%) and cardiovascular contra-indications (27%) (figure 1).

Non-participants of the exercise test (*N*=75), compared to participants (those who were able and allowed to perform the exercise test), were significantly older (*p*=0.01), had a higher BMI (*p*=0.01) and waist circumference (*p*=0.001), had a longer TSI (*p*=0.008), had more often a tetraplegia (p<0.001), had a higher upper-extremity pain score (*p*=0.02), and were less active (*p*=0.001) (table 1).

Seventeen participants who were medically approved to participate in the peak exercise test dropped out due to equipment problems, not being able to perform the test at the selected speed, high systolic blood pressure or musculoskeletal pain at the neck and shoulder during the preceding submaximal exercise tests.

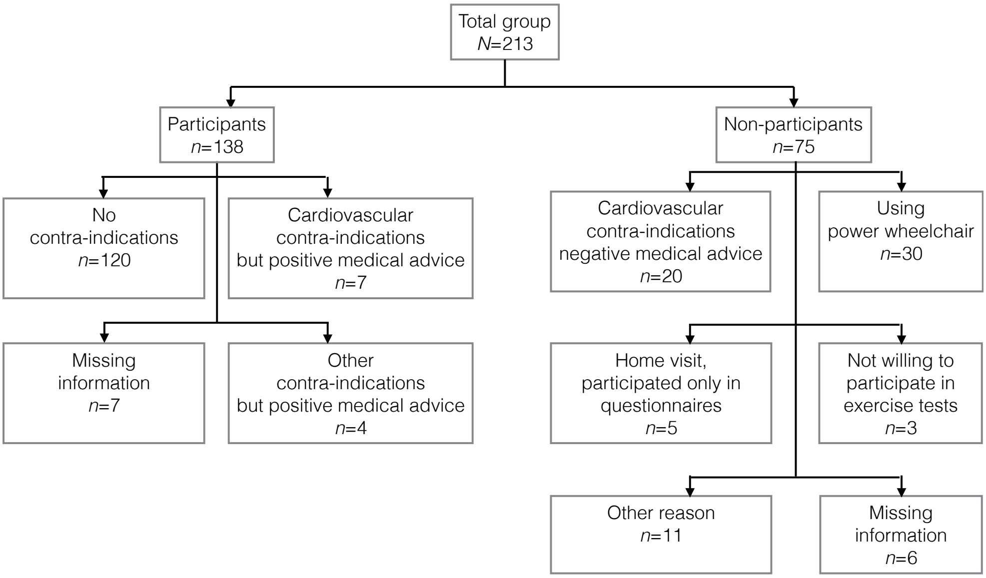

Figure 1. Flow chart regarding participation and non-participation in the peak exercise test, including reasons for non-participation among which contra-indications.

Table 1. Personal and lesion characteristics, expressed as mean (standard deviation [SD]) or percentage, of the participants and non-participants of the peak exercise test.

Outcome	Participants		Non-participants		
	N	Mean (SD) or %	*N*	Mean (SD) or %	*p*
Sex (% men)	138	68%	75	72%	0.34
Age (years)	138	47.9 (8.5)	75	51.0 (8.9)	0.01
Body mass index (kg·m^2)	138	24.9 (4.6)	75	26.7 (5.0)	0.01
Waist circumference (cm)	129	95.2 (14.3)	66	102.8 (15.8)	0.001
Time since injury (years)	138	23.7 (8.3)	70	27.1 (9.5)	0.008
Lesion level (% tetraplegia)	137	50%	74	75%	<0.001
Lesion completeness (% compl.)	138	78%	74	85%	0.13
Upper-extremity pain (sum score)	137	7.4 (10.0)	75	11.6 (16.2)	0.02
Shoulder pain (sum score)	138	3.9 (6.1)	75	5.6 (7.9)	0.10
PASIPD (MET h·day^{-1})	132	22.3 (22.1)	65	12.0 (15.9)	0.001

p based on comparison between participants and non-participants.
Abbreviations: PASIPD = Physical Activity Scale for Individuals with Physical Disabilities[16]; MET = metabolic equivalent of task.

Effect of time since injury and physical activity

In the total group and in those with tetraplegia, no significant differences were found among the three TSI strata in POpeak or VO2peak (Table 2). This is in contrast with the group with paraplegia, which showed a significant difference in POpeak (p=0.04), VO2peak (p=0.01) and HRpeak (p=0.04) among TSI strata (Table 2). The group with a TSI ≥ 30 yrs had a lower VO2peak (72%) and POpeak (66%) compared to those with a TSI between 10-19yrs and POpeak was also lower (70%) compared to the 20-29yrs TSI group.

After controlling for confounders, no significant associations were found between fitness and TSI for the total group (although nearly significant for VO2peak: p=0.06) or for those with tetraplegia (table 3). In the group with paraplegia, TSI was significantly associated with POpeak (p=0.001) and VO2peak (p=0.05) (table 3); those with the longest TSI had the lowest POpeak and VO2peak.

A significantly higher POpeak was found for active persons compared to inactive persons for the total group (p=0.02) as well as for those with tetraplegia (p=0.01) (table 4). A nearly significant difference (p=0.05) in VO2peak was found in people with a tetraplegia, with active people showing a higher VO2peak compared to inactive people (table 4).

After controlling for confounders, no significant association was found among PA and fitness in the total group and those with paraplegia (table 5). In contrast, a significant positive association was found between PA and POpeak in people with a tetraplegia (p=0.02). Also a significant interaction term (TSI·PA) was found in the relationship with POpeak in the total group (p=0.03) as well as in the group with tetraplegia (p=0.02). Those with a low PA level showed a decline in POpeak with an increase in TSI in contrast to those with a high PA level.

Table 2. Mean and standard deviation of the outcome measures of the graded peak exercise test among the time since injury cohorts for the total group and groups with a tetraplegia and paraplegia separately.

		POpeak (W)			**VO2peak (L·min^{-1})**			**HRpeak (bpm)**			**RERpeak**		
	TSI cohort	Mean (SD)	*N*	*p*	Mean (SD)	*N*	*p*	Mean (SD)	*N*	*p*	Mean (SD)	*N*	*p*
Total	10-19 y	54.2 (28.0)	48	0.24	1.40 (0.62)	48	0.19	148 (32)	48	0.50	1.13 (0.14)	48	0.17
	20-29 y	53.9 (26.9)	43		1.38 (0.48)	42		150 (27)	44		1.15 (0.20)	47	
	≥ 30 y	45.0 (21.4)	32		1.19 (0.37)	30		142 (30)	30		1.07 (0.17)	31	
Tetra	10-19 y	39.5 (23.3)	26	0.92	1.09 (0.51)	25	0.54	130 (31)	25	0.94	1.12 (0.17)	25	0.28
	20-29 y	39.4 (22.3)	21		1.22 (0.40)	22		133 (30)	19		1.08 (0.20)	23	
	≥ 30 y	42.4 (27.8)	16		1.09 (0.42)	15		134 (37)	15		1.03 (0.13)	16	
Para	10-19 y	71.6 (22.9)	22	0.04	1.75 (0.54)	23	0.01	168 (18)	23	0.04	1.14 (0.12)	23	0.15
	20-29 y	67.8 (23.7)	22		1.54 (0.51)	20		163 (16)	25		1.22 (0.19)	24	
	≥ 30 y	47.5 (13.1)[a]	15		1.26 (0.25)[b]	14		152 (19)[b]	14		1.13 (0.21)	14	

[a] Significantly lower in TSI cohort ≥30 yrs compared to TSI cohorts 10-19 years and 20-29 years.

[b] Significantly lower in TSI cohort ≥30 yrs compared to TSI cohorts 10-19 years.

Abbreviations: TSI = time since injury; POpeak = peak power output; VO2peak = peak oxygen uptake; bpm = beats per minute; SD = standard deviation; Tetra = tetraplegia; Para = paraplegia.

Table 3. Results of the regression analyses with peak power output or peak oxygen uptake as dependent variables, time since injury (years) as independent variable and lesion and personal characteristics as confounders. Results are shown for the total group and for people with a tetraplegia and paraplegia separately.

	Total				**Tetra**				**Para**			
	POpeak (W)		**VO2peak (L·min^{-1})**		**POpeak (W)**		**VO2peak (L·min^{-1})**		**POpeak (W)**		**VO2peak (L·min^{-1})**	
	Beta (SE)	*p*	Beta (SE)	*p*	Beta (SE)	*p*	Beta (SE)	*p*	Beta (SE)	*p*	Beta (SE)	*p*
Constant	50.15 (13.31)		1.60 (0.14)		-3.59 (20.39)		0.75 (0.35)		92.05 (8.29)		2.02 (0.39)	
TSI (y)	-0.37 (0.37)	0.32	-0.01 (0.006)	0.06	-0.13 (0.47)	0.78	-0.01 (0.01)	0.58	-1.22 (0.34)	0.001	-0.026 (0.013)	0.05
Lesion level[a]	21.93 (4.15)	<0.001	-		N.E.		N.E.		N.E.		N.E.	
Lesion completeness[b]	5.23 (5.25)	0.32	-		15.86 (6.56)	0.02	-		-		-	
Age (y)	0.02 (0.36)	0.96	-		0.85 (0.52)	0.11	0.01 (0.01)	0.18	-		0.003 (0.012)	0.81
Sex[c]	-17.26 (4.25)	<0.001	-		-13.81 (6.09)	0.03	-0.31 (0.12)	0.01	-			

- = not a confounder

[a] Tetraplegia = 0; Paraplegia = 1.

[b] Incomplete lesion level = 0; Complete lesion level = 1.

[c] Male = 0; Female = 1.

Abbrevations: SE=Standard Error; N.E.=not entered; other abbreviations: see table 2.

Table 4. Mean and standard deviation of the outcome measures of the graded peak exercise test among active and inactive groups for the total group (total) and groups with a tetraplegia and paraplegia separately.

		POpeak (W)			**VO2peak (L·min^{-1})**			**HRpeak (bpm)**			**RERpeak**		
	Cohort	Mean (SD)	*N*	*p*	Mean (SD)	*N*	*p*	Mean (SD)	*N*	*p*	Mean (SD)	*N*	*p*
Total	Active	48.4 (26.0)	91	0.02	1.29 (0.54)	88	0.08	145 (29)	92	0.11	1.12 (0.19)	94	0.97
	Inactive	62.7 (25.0)	26		1.50 (0.48)	26		156 (33)	24		1.12 (0.16)	26	
Tetra	Active	37.3 (21.0)	52	0.01	1.09 (0.42)	51	0.05	131 (30)	48	0.52	1.07 (0.17)	53	0.41
	Inactive	58.4 (33.4)	9		1.40 (0.57)	9		139 (45)	9		1.12 (0.20)	9	
Para	Active	63.7 (25.1)	38	0.86	1.56 (0.57)	36	0.92	160 (17)	43	0.29	1.19 (0.19)	40	0.20
	Inactive	64.9 (20.0)	17		1.55 (0.43)	17		166 (19)	15		1.12 (0.14)	17	

Abbreviations: see table 2.

Table 5. Results of the regression analyses with peak power output or peak oxygen uptake as dependent variables, physical activity (PASIPD score) as independent variable and lesion and personal characteristics as confounders. Results are shown for the total group and for people with a tetraplegia and paraplegia separately.

	Total				Tetra				Para			
	POpeak (W)		**VO2peak (L·min^{-1})**		**POpeak (W)**		**VO2peak (L·min^{-1})**		**POpeak (W)**		**VO2peak (L·min^{-1})**	
	Beta (SE)	*p*	Beta (SE)	*p*	Beta (SE)	*p*	Beta (SE)	*p*	Beta (SE)	*p*	Beta (SE)	*p*
Constant	53.0 (7.3)		1.28 (0.08)		36.1 (5.3)		0.81 (0.34)		125.9 (16.6)		2.27 (0.47)	
PASIPD[a]	0.11 (0.09)	0.23	0.001 (0.002)	0.65	0.41 (0.18)	0.02	0.004 (0.003)	0.30	-0.17 (0.10)	0.08	-0.003 (0.003)	0.26
Lesion level[b]	21.9 (4.2)	<0.001	0.40 (0.09)	<0.001	-		-		-		-	
Lesion completeness[c]	-		-		N.E.		N.E.		N.E.		N.E.	
Age (y)	-		-		-		0.008 (0.007)	0.30	-0.49 (0.46)	0.29	0.001 (0.01)	0.93
Sex[d]	-17.6 (4.3)	<0.001	-0.43 (0.09)	<0.001	-9.7 (6.2)	0.12	-0.28 (0.12)	0.03	-26.78 (5.04)	<0.001	-	
TSI (y)	-0.35 (0.25)	0.17	-		-		-		-1.06 (0.51)	0.04	-0.03 (0.01)	0.04

- = not a confounder

[a] PASIPD total score.[16]

[b] Tetraplegia = 0; Paraplegia = 1.

[c] Incomplete lesion level = 0; Complete lesion level = 1.

[d] Male = 0; Female = 1.

Abbrevations: Physical Activity Scale for Individuals with Physical Disabilities = PASIPD; other abbreviations: see table 3.

Discussion

In summary, the results showed that the participants of the graded peak exercise test were a positive selection of the total group. Furthermore, TSI did seem to have an effect on wheelchair-specific fitness of people with paraplegia in contrast to those with tetraplegia or the total group. Being physical active seemed to be positively related to wheelchair-specific fitness in persons with tetraplegia but not in those with paraplegia.

That non-participants of a graded peak exercise test are older and have more often a tetraplegia was previously found.[6] Older people might have more contra-indications for exercise testing and not every wheelchair user with a tetraplegia is able to propel a manual wheelchair, which is shown by the high percentage (40%) of the non-participants that use a power wheelchair. In contrast to Van Koppenhagen *et al.*[6], our non-participants had a higher BMI and waist circumference compared to the participants. This might be explained by their higher age and longer TSI. Previous studies showed an increase in BMI during and after inpatient rehabilitation[19,20] and a positive association between age and BMI.[20] The higher upper-extremity pain score of the non-participants might be explained by the higher percentage of people with tetraplegia and longer TSI in this group. Persons with tetraplegia[18] or longer TSI[21] show more upper-extremity musculoskeletal pain. Furthermore, severe musculoskeletal pain can be a contra-indication for exercise testing. The higher percentage of persons with a tetraplegia and longer TSI in this group might also explain the lower PA score in the non-participants, since both factors were found to relate to a lower PASIPD score.[17]

When comparing our total participants group with people with a SCI 5 yrs after discharge of inpatient rehabilitation,[6] the POpeak of the TSI 10-19yrs (54.2W) and 20-29yrs (53.9W) groups is quite similar to a group with on average 6.6 yrs after injury (56.3W). However, the group with a TSI≥30yrs had a lower POpeak (45W). Similar results were found for the VO2peak. Furthermore, the wheelchair-specific fitness of our active group (62.7W; 1.5 $L \cdot min^{-1}$) was significantly higher compared to our inactive group and also somewhat higher than people five years after discharge.[6] When comparing our results with normative values,[22] based on 166 persons with a SCI (TSI~8.7 years, 12% women, 36% tetraplegia, 39% wheelchair athletes, 19% measured 1-year after discharge), our three TSI groups with tetraplegia all showed an excellent POpeak and a good to excellent VO2peak. There was only a slight discrepancy in wheelchair-specific fitness classification among our active (excellent) and inactive (good) people with a tetraplegia. In contrast, those with paraplegia and a TSI between 10-29 years showed a fair to average POpeak and VO2peak while those with a TSI ≥30yrs showed a poor POpeak and VO2peak according to the normative values.

The regression analyses, with correction for confounders, showed similar results. That TSI did not seem to have an effect on the wheelchair-specific fitness of people with tetraplegia might be explained by the high percentage of people with tetraplegia that was not able to perform the exercise test. So when people with tetraplegia are able to perform the test, especially when having a SCI for a long-term, this is probably a positive selection of the total group with tetraplegia. This is also shown by the good to excellent values of VO2peak and POpeak in this group. A previous study showed that the VO2peak in wheelchair athletes can remain stable over a 20-years period when they continue in sports activities.[11] Although the majority of our group with tetraplegia (85%) was classified as inactive based on their PASIPD score, they were more active compared to our non-participants. Furthermore, our regression analysis showed that PA has a positive effect on POpeak in the participants with tetraplegia. Those with a higher PA level also showed reduced decline in POpeak with an increase in TSI compared to their less active counterparts. This positive association among an active lifestyle and fitness was previously shown in persons with SCI.[22,23]

TSI had an effect on the wheelchair-specific fitness in people with paraplegia, i.e. the longer the TSI, the lower their fitness. An explanation for this might be the higher chance of secondary complications when TSI progresses. This might lead to reduced PA and subsequently deconditioning. A review showed that the prevalence of cardiovascular disease indeed seems to increase over time, which appeared related to age and SCI duration.[24] Furthermore, it was found that people with a longer TSI are less active,[17] and that a lower activity level is related to a lower POpeak and VO2peak.[22] However, in the present study no significant relationship was found among PA level and fitness in people with paraplegia.

Implications

From the results it is clear that wheelchair-specific fitness can diminish over time after the injury and that an active lifestyle can moderate this effect. Since wheelchair-specific fitness is related to functioning,[25] participation[3] and quality of life,[4] it is important to pay special attention to the group with a long TSI (≥30yrs) to maintaining their long-term fitness. A systematic review by Hicks *et al*.[26] showed that, although most studies were of low quality, the evidence was consistent that exercise training is effective in improving the wheelchair-specific fitness in SCI. Therefore, people with SCI must be provided with opportunities to maintain a physically active lifestyle.[27] It is a challenge to help people with a disability to become and stay active due to, among others, equipment barriers or economic issues.[28] There is an important role for rehabilitation professionals and fitness trainers in assisting people with a disability into general PA leisure activities and sports[27] over the lifespan to prevent long-term deconditioning in the first place.

Limitations

The present study was cross-sectional, so it is impossible to infer causality in the relation among fitness, TSI or PA. Furthermore, it only included persons that were wheelchair dependent, who are most often persons with more severe lesions. As a result, the outcomes cannot be generalized to the whole population with a SCI.

Another limitation might be the measurement of PA level by a questionnaire. There is a risk of overestimation when using a questionnaire, which is also shown by the weak relationship with objectively measured PA levels.[29] There is a clear need for cheaper wheelchair-specific activity monitoring technology.

CONCLUSION

The participants of the graded peak exercise test were a positive selection of the total research group regarding age, TSI, lesion level, upper-extremity pain and activity level. TSI did not seem to have an effect on the wheelchair-specific fitness of people with tetraplegia, which might be explained by the high percentage of people that was not able to perform the exercise test. In people with tetraplegia, activity level was positively related to POpeak. In people with paraplegia the wheelchair-specific fitness was significantly lower in those with a TSI longer than 30 years, indicating that the group with a long TSI needs extra attention to maintaining their long-term fitness.

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Chapter 3

Design of a randomized-controlled trial on low-intensity aerobic wheelchair exercise for inactive persons with chronic spinal cord injury

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ABSTRACT

Purpose: To investigate effects and working mechanisms of low-intensity aerobic wheelchair exercise on fitness, (upper-body) health and active lifestyle in inactive persons with chronic spinal cord injury (SCI).

Methods: A multicenter randomized-controlled trial (RCT) in 40 inactive manual wheelchair users (aged 28-65y) with chronic paraplegia or tetraplegia (time since injury >10y). Subjects will be randomly assigned to an intervention or a control group. The intervention will consist of 16 weeks (2 times per week, 30 minutes per session) of low-intensity aerobic handrim wheelchair exercise (30-40% HRR) on a treadmill. Repeated measurements will be performed before starting the intervention or entrance of the control group, and after week 8, 16 and 42 following the start. The primary outcome will be wheelchair-specific physical fitness. Secondary outcomes will be upper-body pain and discomfort, shoulder load, propulsion technique, wheelchair skill performance, and physical activity levels.

Conclusions: Results of this first RCT on low-intensity aerobic wheelchair exercise for inactive persons with chronic SCI can improve SCI-specific exercise guidelines and provide an evidence-base for an aftercare program aimed at preserving fitness, health and active lifestyle of persons aging with SCI.

INTRODUCTION

Low physical fitness levels are common in persons with chronic spinal cord injury (SCI), which can limit performance of activities of daily living (ADL).[1] Upper-body complaints (pain and pathology) are also high in this population, e.g. 31-73% for shoulder pain and 49-73% for carpal tunnel syndrome,[2] and seem to increase with time since injury.[3] These upper-body complaints are thought to result from overuse during performance of manual (handrim) wheelchair-related ADL: joints are loaded with a high frequency (e.g. wheelchair propulsion) or strained with a high load (e.g. transfer).[4-6] In addition, lower fitness can lead to a lower ability to perform such ADL, which further increases (risk of) overuse, as indicated by the inverse association between fitness and upper-body complaints of persons with SCI.[7,8] However, to maintain independence, fitness and health, performing wheelchair-related ADL is essential for persons with SCI.[1] As a consequence, a downward spiral of physical inactivity, deconditioning and secondary health complications might develop.[9] This downward spiral can be prevented or reversed with exercise interventions.[9] For example, resistance-training programs for persons with SCI have been found to increase strength and decrease upper-body complaints.[10,11] Other fitness and health benefits, such as improved cardiovascular fitness and work capacity, can be derived from aerobic wheelchair exercise.[10] Advantages of aerobic wheelchair exercise are its accessibility and specificity for daily-life propulsion. A disadvantage is that it could worsen upper-body complaints if exercise intensity is not balanced with a person's capacity; increased risk of overuse at higher intensities is shown by the gradual increment in shoulder load with wheelchair exercise intensity.[12] As such, current SCI guidelines,[13] prescribing moderate to vigorous aerobic intensities to improve work capacity and cardiorespiratory fitness, may not be appropriate for wheelchair exercise of persons with chronic SCI, since these subjects are often physically inactive and deconditioned.[1,14] For this population it was already in 1994 recommended to avoid higher aerobic intensities.[15]

Table 1. Definition of low-intensity exercise according to recent guidelines of the American College of Sports Medicine.[16]

Measure of intensity	Relative intensity
Heart rate reserve (HRR)	< 40% HRR
Maximal heart rate (HRmax)	< 64% HRmax
Peak oxygen uptake (VO2peak)	< 46% VO2peak
Rate of perceived exertion on 6-20 scale	< 12

Based on preliminary studies, low-intensity aerobic wheelchair exercise, as defined in table 1, can be a solution to the negative effects of inactivity and too intensive training: relatively low upper-body joint loading, while still obtaining important fitness improvements.[17-19] After such an exercise program, a 12% increase in wheelchair-specific peak work capacity was found in persons with SCI,[17] while a 34% improvement, without signs of overuse, was observed in fit able-bodied persons.[19] Another benefit of low-intensity exercise might be that it reduces dropout and improves adherence,[16] especially if it is performed 2 times instead of 3 times per week.[20,21] These promising effects need a systematic evaluation in persons with chronic SCI, which can be used to 1) improve the preliminary SCI-specific guidelines for aerobic exercise, and 2) provide an evidence-base for developing effective interventions that should be part of a long-term aftercare rehabilitation program for preserving fitness, health and active lifestyle of persons aging with SCI. Further substantiation of these guidelines and evidence-base can be reached by research on mechanisms that underlie effects of low-intensity aerobic wheelchair exercise on fitness and upper-body health.

Especially in the deconditioned and inactive chronic SCI population, that is at high risk for upper-body complaints, it can be expected that improved fitness leads to a more active lifestyle (i.e. wheelchair skill performance and physical activity levels) and lower risk of overuse (figure 1, arrows 7-9). With higher fitness, relative joint loading during ADL may be lower (e.g. a lower percentage of maximal force is needed to perform transfers or manual wheelchair strokes). Wheelchair skill performance seems to benefit from improved wheelchair-specific fitness, given its strong association with wheelchair-specific peak work capacity, independent of confounders such as age, gender or lesion level,[22] and its relationship with submaximal capacity.[23] Although this could imply that less energy is used for wheelchair-related ADL, thereby decreasing a stimulus for maintaining fitness, it may also enWWWwable a person to be more active.[24] As such, it may increase physical activity levels and thereby prevent or reduce deconditioning, leading to a positive spiral, as indicated by the moderate relationship between wheelchair-specific peak work capacity and physical activity levels.[25]

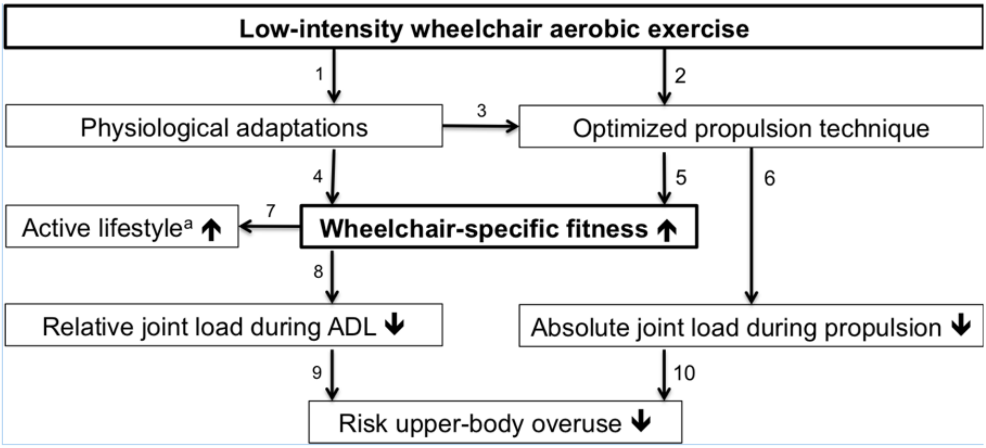

Figure 1. Schematic representation of hypotheses related to fitness and upper-body overuse. Numbers at arrows are used in the text for reference to this figure.
[a]Wheelchair skill performance and physical activity levels
Abbreviation: ADL = activities of daily living.

Physiological adaptations and an optimized propulsion technique (i.e. timing and force application variables such as stroke frequency and rate of force rise applied to the handrim) may be factors underlying improved fitness and upper-body health after low-intensity aerobic wheelchair exercise. Physiological adaptations, e.g. a chronic change in muscle fiber type recruitment,[26] may underlie improvements in all fitness components (figure 1, arrow 1 and 4). Such adaptations may also underlie changes in propulsion technique (figure 1, arrow 3); for example, improved vascular function of upper-body muscles may delay the onset of fatigue during wheelchair propulsion, i.e. the inability to maintain a constant power output, and consequently prevent potentially injurious technique changes observed during fatiguing propulsion.[27] In addition, specific fitness components, such as wheelchair-specific peak work capacity and submaximal capacity, can benefit from improved propulsion technique (figure 1, arrow 5).[22,28] For example, in persons with SCI, optimized stroke frequency has been found to accompany a higher mechanical efficiency.[29] Furthermore, an optimized propulsion technique can lower risk of overuse due to less frequent and lower joint loading during wheelchair propulsion, e.g. a reduced risk of median nerve injury through a lower stroke frequency and rate of force rise applied to the handrim (figure 1, arrow 6 and 10).[2] Another mechanism leading to improved propulsion technique during low-intensity aerobic wheelchair exercise may be the incorporation of extended, non-fatiguing propulsion periods (figure 1, arrow 2). Favourable changes in technique were found during such a 10-minute period, when comparing end to start.[30] This may be a unique stimulus of wheelchair exercise, since extended propulsion periods seem to be lacking in daily-life of manual wheelchair users: most periods of continued propulsion are reported not to exceed 3 minutes.[31]

To answer the question whether low-intensity aerobic exercise has beneficial effects on fitness of inactive persons with chronic SCI without the negative effects of higher intensities, and what mechanisms may underlie these effects, a systematic evaluation is warranted. To this aim, we designed a study to evaluate whether a 16-week low-intensity aerobic wheelchair exercise program, consisting of two 30-minute sessions per week at 30-40% heart rate reserve (HRR), will:

- be effective in improving wheelchair-specific fitness of inactive persons with chronic SCI without (further) development of upper-body overuse symptoms;
- influence active lifestyle (i.e. wheelchair skill performance and physical activity levels);
- lead to an optimized propulsion technique; and
- reduce upper-body complaints through improved fitness and an optimized propulsion technique.

The study is part of research program 'ALLRISC'.[32]

METHODS

Participants

Approval of the study protocol was given by the Medical Ethical Committee of the VU University Medical Center in Amsterdam (the Netherlands) and the two participating rehabilitation centers. Forty inactive persons with a chronic paraplegia or tetraplegia, dependent on a manual wheelchair, will be included in a randomized-controlled trial (RCT). Persons seemingly eligible for inclusion will be located through the archives of the rehabilitation centers and receive an information letter. If written or verbal interest is declared, a paramedic research assistant and a medical specialist for rehabilitation will conduct a screening procedure for inclusion and exclusion criteria (table 2). Given the presence or high risk of upper-body overuse complaints in this population, try-outs of low-intensity wheelchair exercise can additionally be performed. In addition, for all participants during the intervention period, a log will be used to monitor upper-body overuse symptoms (see 'Intervention'). Finally, when a person meets the criteria, further information on the study will be provided; if he/she is then willing to participate, written informed consent should be given.

Table 2. Inclusion and exclusion criteria.

Inclusion criteria
Chronic SCI (TSI > 10y)
Aged 28-65 years
Dependent on a manual (handrim) wheelchair, i.e. regular use in daily life
Physically inactive (PASIPD score<75th percentile of a Dutch SCI cohort25
Exclusion criteria
Cardiovascular contra-indications for testing according to the ACSM guidelines[33]
Resting diastolic blood pressure above 90 mm Hg
Resting systolic blood pressure above 180 mm Hg
Severe musculoskeletal complaints of the upper extremities, neck or back that contraindicate performance of wheelchair propulsion
When expected to lead to dropout within the research period of 42 weeks:
Progressive disease
Psychiatric problem
Plans to change lifestyle, e.g. diet or another physical activity program
Insufficient mastery of Dutch language
Pregnancy

Abbreviations: SCI = spinal cord injury; TSI = time since injury; PASIPD = Physical Activity Scale for Individuals with Physical Disabilities[34]; ACSM = American College of Sports Medicine.

Design

A multicenter RCT will be conducted to evaluate effects and working mechanisms of a 16-week low-intensity aerobic wheelchair exercise program. Participants will be randomly allocated to an intervention group or a non-training control group. The study set-up will not allow for blinding of testers and trainers. Repeated measurements will be performed in both groups, i.e. before starting the intervention or entrance of the control group (T1), and after week 8 (T2), 16 (T3) and 42 (T4) following the start (figure 2).

All exercise tests and training sessions will be conducted within the two rehabilitation centers. To decrease participant burden, an accredited laboratory of the participant's choice will be visited for fasting blood sampling, and self-report questionnaires will be filled out at home using web-based open-source software (LimeSurvey, version 1.90+).

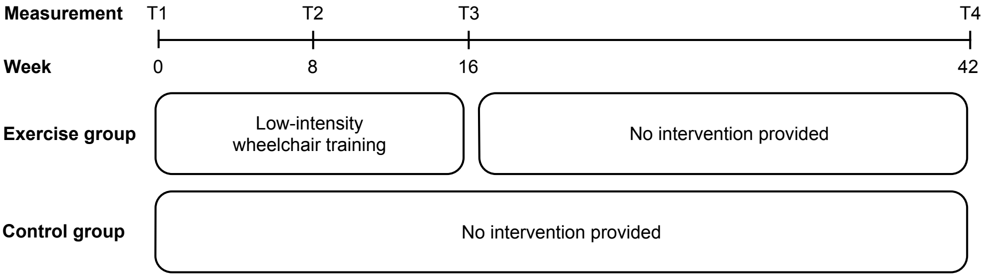

Figure 2. Experimental design of the study.

Randomization

For practical purposes, group sizes and allocation ratios will differ between the 2 rehabilitation centers (table 3). Random allocation to the intervention or control group will occur after baseline measurements, using varying blocked randomization.

Table 3. Group size and allocation ratio of the two rehabilitation centers.

	RC 1	RC 2
Allocation ratio (intervention:control)	3:2	1:2
Block sizes (varying)	5 or 10	3 or 6
N (total group)	25	15
N (intervention group)	15	5
N (control group)	10	10

Abbreviation: RC = rehabilitation center.

Table 4. Training protocols of the low-intensity aerobic wheelchair exercise program.

	Exercise (min)	Exercise + rest (min)	Exercise blocks (N)	Rest between exercise blocks (min)
Week 1				
Protocol 1	18	23	6	1
Protocol 2	18	28	6	2
Protocol 3	18	28	6	2
Week 2				
Protocol 1	24	29	6	1
Protocol 2	24	34	6	2
Protocol 3	24	38	8	2
Week 3-7				
Protocol 1	30	31-35	2-6	1
Protocol 2	30	33-40	4-6	1-1.5
Protocol 3	30	39-48	10	1-1.5
Week 8-16				
Protocol 1	30	30	1	0
Protocol 2	30	33	4	1
Protocol 3	30	39	10	1

Intervention

A 16-week low-intensity aerobic wheelchair exercise program will be employed; participants conduct two 30-minute sessions per week on a motor-driven treadmill (center 1: 1.2x5.47m; center 2: 1.2x5.30m) (ForceLink B.V., Culemborg, the Netherlands) in the manual wheelchair most often used in daily-life propulsion. Power output (PO) will be regulated such that heart rate equals 30-40% HRR.

For this purpose, the individual relationship between PO and heart rate will be determined during a peak wheelchair exercise test performed on T1.[35,36] In some persons with a Th4 lesion or higher, this relationship might be attenuated due to an impaired autonomic nervous system.[37] If so, a rate of perceived exertion (RPE) of 1-3 (11-point scale) will be used instead of 30-40% HRR.[38] Although still ambiguous, RPE can be seen as an indicator of exercise intensity in persons with SCI.[21,39] The RPE of 1-3 has been chosen based on the use of a RPE of 4-7 for moderate- to vigorous-intensity handcycle exercise of persons with tetraplegia.[21]

PO is adjusted based on actual HRR or RPE, so that relative intensity will remain unchanged throughout the 16-week training period. Treadmill velocity will be the primary mean of adjusting PO; it will not exceed 1.1 $m \cdot s^{-1}$ and can be lower depending on the participant's motor abilities. Secondary to velocity, weight can be added to a pulley system to increase PO.[40] Since determination of rolling resistance is needed to calculate PO, a drag test will be performed on T1.[41]

For each participant, 1 out of 3 training protocols will be chosen (table 4). This choice is based on performance of the exercise tests of T1 (table 5), as well paramedic advice. The protocols will be equal in training dose (924 minutes over 32 sessions), and will only differ in number and duration of exercise blocks and rest blocks. Further individualization during the program will be allowed; trained paramedics, who supervise all sessions, will assess this. These protocols should enable all participants, regardless of baseline fitness level, to complete the program. Propulsion technique can be freely chosen, and no feedback will be given, except for the general recommendation of a "long, smooth, low-frequency stroke".

Before each session, wheelchair tire pressure, maintenance and set-up will be checked. If needed, adjustments are made to assure that wheelchair conditions will be standardized over the training period. If adjustments cannot be made, wheelchair changes will be recorded in a log to identify potential confounders.

A log will be used to assess overall intensity of the program and to screen for (upper-body) overuse. In this log, RPE and mean %HRR over the first and last exercise block will be recorded, in addition to local perceived discomfort (LPD) of the upper body. LPD will be assessed with a detailed psychophysiological scale.[42] To correct for baseline LPD, scores will also be recorded before each session. Furthermore, a score will be noted on how the participant feels that day (1-10; 1=worst ever; 10=never been better), as well as a session RPE (11-point scale).[38]

Outcomes

All outcomes and their instrumentation are presented in table 5. The primary outcome will be wheelchair-specific fitness, determined with 4 exercise tests which will be performed in a fixed sequence with rest periods sufficient to prevent confounding fatigue: 1) 15m-sprint, 2) isometric wheelchair push, 3) submaximal exercise test, and 4) peak exercise test. All tests will be performed in the manual wheelchair participants most often used in daily-life propulsion (same as in the intervention). Protocols will be identical for T1-T4, and will include asking participants to refrain from smoking, caffeine or alcohol at least 2h before testing, and to eat a light meal and empty their bladder prior to testing. Wheelchair tire pressure, maintenance state, set-up and sitting position will be checked and, if needed, adjusted to assure that it will be standardized over T1-T4. If adjustments are not possible, this will be noted in order to identify potential confounders.

Secondary outcomes will be upper-body pain and discomfort, shoulder load, propulsion technique, wheelchair skill performance, and physical activity levels. Supplementary outcomes, also presented in table 5, will be used for 1) descriptive purposes, 2) identification of possible confounders, 3) evaluation of underlying mechanisms of effects in primary and secondary outcomes, and 4) to explore effects on other health and life domains. Details on instrumentation of primary and secondary outcomes are provided below.

Table 5. Outcome measures and instrumentation (including main literature references).

Outcome measure	Instrumentation	T1	T2	T3	T4
Primary outcome: wheelchair-specific fitness					
Peak work capacity	Peak wheelchair exercise test[35]	X	X	X	X
Peak aerobic capacity	Peak wheelchair exercise test[35]	X	X	X	X
Submaximal capacity	Submaximal wheelchair exercise test[35]	X	X	X	X
Anaerobic work capacity	15m overground wheelchair sprint[35], with OptiPush set-up	X	X	X	X
Isometric strength	Isometric wheelchair push[43]	X	X	X	X
Secondary outcomes					
Upper-body pain	Wheelchair User's Shoulder Pain Index (WUSPI)[44] Questionnaire on musculoskeletal upper-body pain[8] Adapted version of the Chronic Pain Grade Questionnaire[45]	X	X	X	X
Upper-body discomfort	Local Perceived Discomfort (LPD) scale[42]	X	X	X	X
Shoulder load	Delft Shoulder and Elbow model[46]	X[a]		X[a]	
Propulsion technique	Force and timing parameters derived from output OptiPush wheel[28,47]	X	X	X	X
Wheelchair skill performance	Wheelchair Circuit[35]	X	X	X	X
Physical activity levels	Physical Activity Scale for Individuals With Physical Disabilities (PASIPD)[34] Mechanical wheelchair odometer[48]	X	X	X	X
Supplementary outcomes					
Demographics and environmental (mobility) factors	Self-report questionnaire	X	X[b]	X[b]	X[b]
Lesion level	ASIA assessment	X			
Secondary health complications (last 3 months) and risk factors	Examination by physician	X	X[b]	X[b]	X[b]

Range of motion (active and passive)	Goniometer-measured angles of shoulder, elbow and wrist joints	X	X[b]	X[b]	X[b]
Wheelchair satisfaction and sitting comfort	Dutch version of the Quebec User Evaluation of Satisfaction with assistive Technology (D-QUEST)[49] Self-report questionnaire used in ergonomic practice	X	X	X	X
Metabolic health	Clinical identification of the metabolic syndrome (supine waist circumference, blood pressure, fasting glucose, triglycerides, HDL cholesterol)[50]	X	[c]	X	X
Self-efficacy	SCI Exercise Self-Efficacy Scale (ESES)[51] Self-efficacy in Wheeled Mobility (SEWM) scale[5]2	X	X	X	X
Fatigue	Fatigue Severity Scale (FSS)[53]	X	X	X	X
Mood	Hospital Anxiety and Depression Scale (HADS)[54]	X	X	X	X
Participation	Utrecht Scale for Evaluation of Rehabilitation-Participation (USER-P)[55]	X	X	X	X
Quality of life	5-item World Health Organization Quality of Life Assessment (WHOQoL-5)[56]	X	X	X	X
Independence	Spinal Cord Injury Measure version III (SCIM-III)[57]	X	X	X	X
Pulmonary functioning	Forced spirometry measurements[21]	X	X	X	X

[a] Subgroup of participants with paraplegia and tetraplegia (total: N=8; control: N=2x2; intervention: N=2x2).

[b] Systematic assessment, by researcher and paramedic research assistant, whether there are changes relative to the T1 measurement.

[c] Not performed in order to reduce participant burden.

Peak and submaximal wheelchair exercise test

Peak work capacity, peak aerobic capacity and submaximal capacity will be determined through a protocol consisting of tests on a motor-driven treadmill.[35] Treadmills used will be those described at 'Intervention'. First, after measurement of resting heart rate and oxygen uptake (Oxycon Delta, Jaeger, Hoechberg, Germany) during 5 minutes of quiet sitting, and a 3-minute familiarization procedure with the treadmill, a drag test will be performed to determine rolling resistance of the wheelchair-user combination on 10 treadmill inclination angles (in Newton).[41] This will allow calculation of PO during treadmill propulsion: rolling resistance on a specific inclination angle will be multiplied by treadmill velocity. The drag test will also be performed with wheels replaced by an OptiPush wheel (MAX Mobility, Antioch, USA) and an inertia-compensated dummy wheel. The OptiPush wheel measures 3-dimensional forces and moments applied to the handrim, and will be used for defining propulsion technique (see 'Propulsion technique').

Second, 2 blocks of 3 minutes of submaximal exercise will be performed; inclination will be 0% (block 1) or 0.5-0.6% (block 2), while velocity will be 0.56, 0.83 or 1.11 $m \cdot s^{-1}$ (depending on participant's motor ability during the familiarization procedure). The Optipush set-up, synchronized to measurement of gas exchange (Oxycon Delta, Jaeger, Hoechberg, Germany), will be in place. Over the last 30 seconds of each block, mean values will be determined of PO, oxygen uptake (VO2), heart rate and respiratory exchange ratio (RER). Energy expenditure, calculated with VO2 and RER according to Garby and Astrup,[58] will then be used to derive gross mechanical efficiency (ratio of PO to energy expenditure).

Third, participants will perform a peak wheelchair exercise test at the same velocity as in the submaximal test.[35] The inclination angle will be increased every minute by 0.5-0.6% until participants will no longer be able to maintain treadmill velocity. PO will be calculated over the last block maintained for at least 30s (POpeak), VO2 over the highest 30s-interval (VO2peak), and heart rate over the highest 5-s interval (HFpeak).

15m overground wheelchair sprint

Anaerobic work capacity will be based on PO during a 15m overground wheelchair sprint on a linoleum surface, similar to a protocol of the Wheelchair Circuit.[35] The sprint will be performed with the OptiPush set-up in place, since its output will allow calculation of PO.[47] In pilot experiments with able-bodied subjects, the peak value of PO on this test was found to correlate with mean PO over a 30s Wingate-like wheelchair ergometer sprint ($r=0.84$, $p<0.001$).

Isometric wheelchair push

Isometric strength will be assessed with a modified protocol of a wheelchair-ergometer force test used in other studies.[19,43] It can be seen as an isometric wheelchair push with hands at the top of the rim; performing a fast, maximal isometric contraction maintained for 5 seconds (figure 3). To assure that none of the participants will be able to cross the upper range of the force transducer (1000 N), a lightweight pulley system is used (figure 3), and force will therefore be doubled. Over 3 successful trials, peak force and the highest consecutive 3s-force interval will be determined.

Figure 3. Set-up of the isometric wheelchair push used to assess isometric strength. See chapter 5 for a schematic presentation of the set-up.

Self-report questionnaires on upper-body pain

Three questionnaires will be used. First, the Wheelchair User's Shoulder Pain Index (WUSPI), which has shown its reliability, validity and sensitivity to exercise-induced changes in persons with SCI.[10,11,59] Second, a questionnaire developed for SCI populations on presence, severity and frequency of musculoskeletal pain of 7 upper-body regions in the last 3 months.[8] Third, the Chronic Pain Grade Questionnaire,[45] shown reliable in a SCI population,[60] will be used with a slight adaptation (asking for musculoskeletal pain in the last week instead of pain in the last 6 months).

Local Perceived Discomfort (LPD) scale

Upper-body LPD during wheelchair propulsion will be assessed with a detailed psychophysiological scale,[42] similar to a protocol used to study handcycling in able-bodied subjects.[61] Using a scheme of the upper body, 26 different regions (e.g. left ventral wrist/hand, right dorsal shoulder) will systematically be scored on a 10-point scale (0=no discomfort and 10=extreme discomfort), allowing individual and summed scores.[61] It will be employed before, and immediately after the peak and submaximal exercise tests.

Propulsion technique

Propulsion technique will be defined by timing and force parameters during the submaximal exercise blocks (see 'Peak and submaximal exercise test').[28] No feedback will be given on propulsion technique, which may freely be chosen. Velocity and inclination angle will be identical in T1-T4; as such, given that rolling resistance will not change, PO will remain constant. Technique parameters will be derived from output of the OptiPush wheel, and will include calculation of stroke length, stroke frequency, peak forces and rate of force rise over each stroke,[47] which are seen as indicative for risk of upper-body complaints,[2] as well as work per push and braking torque.[47]

Delft Shoulder and Elbow model

Shoulder load during wheelchair propulsion will be studied with an inverse dynamic musculoskeletal model,[46] similar to a protocol in persons with SCI.[12] In a subgroup of participants with paraplegia and tetraplegia, additional kinematic measurements will be performed during the submaximal exercise blocks to determine mean and peak model-based glenohumeral reaction forces, as well as forces of important shoulder muscles.[12]

Wheelchair Circuit

The Wheelchair Circuit, a reliable and valid test battery consisting of 8 items (e.g. a figure-of-8 shape, uphill propulsion), will be used to assess wheelchair skill performance.[35] Scores will be calculated for 1) ability, 2) performance and 3) cardiovascular strain.

Physical Activity Scale for Individuals With Physical Disabilities (PASIPD)

Self-reported physical activity level will be assessed with the PASIPD.[34] Of note is that the PASIPD will also be used in the inclusion criteria (table 2).

Wheelchair odometer

Next to the PASIPD, physical activity level will be assessed with distance covered with the most commonly used manual wheelchair(s) of the participants. For this purpose, a mechanical wheelchair odometer will be used; it counts the number of revolutions of a wheel with known diameter.[48] For 1 week, over each day, participants will record the number of revolutions, in addition to remarks on distance covered when not handrim propelling the wheelchair (e.g. being pushed, (motorized) handcycle). Datestamps will be used, so that seasonal influence (e.g. rainy season) can be analysed.

Statistical analysis

The sample size was calculated with formulas given by Twisk on the primary outcome measure POpeak,[62] and was based on two intervention studies: low-intensity aerobic wheelchair exercise in able-bodied persons and handcycle exercise in persons with tetraplegia.[19,21] Power was set at 0.8 and alpha at 0.05, resulting in a required group size of 18 to detect a difference of 9W. With an expected dropout of 10-15%, 20 participants per group will be aimed to be recruited.

Multivariate repeated measures analyses will be used to study differences in outcomes within and between the two groups, next to interaction effects (group x time). Both the impact of differences at baseline, and changes in outcomes during and after the intervention will be post-hoc analyzed. The influence of lesion, demographic and environmental characteristics on intervention effects will be investigated and included as covariates if needed. In case of missing data, multilevel regression analyses will be applied.[62] Reasons for dropout will be recorded, and withdrawing subjects will be asked to continue performing the follow-up measurements, allowing analysis according to the intention-to-treat principle. Alpha is set at 0.05.

DISCUSSION

The rationale, design and methodology of the first RCT on effects and working mechanisms of low-intensity aerobic wheelchair exercise for inactive persons with chronic SCI were presented in this paper. The intervention will be aimed at improvement of wheelchair-specific fitness and (upper-body) health, which can lead to a more active lifestyle (i.e. improved wheelchair skill performance and physical activity levels).

Results of this study can improve SCI-specific aerobic exercise guidelines, especially those for persons with low fitness, low activity levels, a high risk of upper-body overuse or a combination of these factors. Furthermore, results can provide an evidence-base for developing effective interventions that should be part of a long-term aftercare rehabilitation program aimed at preserving fitness, active lifestyle and health persons aging with SCI.

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Chapter 4

Can a 15 m-overground wheelchair sprint be used to assess wheelchair-specific anaerobic work capacity?

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ABSTRACT

Objective: To evaluate whether outcomes based on stopwatch time and power output (PO) over a 15 m-overground wheelchair sprint test can be used to assess wheelchair-specific anaerobic work capacity, by studying their relationship with outcomes on a Wingate-based 30s-wheelchair ergometer sprint (WAnT).

Methods: Able-bodied persons (N=19, 10 men, aged 18-26y) performed a 15 m overground sprint test in an instrumented wheelchair and a WAnT. 15 m-outcomes were based on stopwatch time (time and mean velocity over 15 m) and on PO (primary outcome: highest mean unilateral PO over successive 5-s intervals (P5-15m)). WAnT-outcomes were mean unilateral PO over 30s and the highest mean unilateral PO over successive 5-s intervals. Correlation coefficients (Pearson's r) and coefficients of determination (R2) were calculated between 15-m sprint outcomes and WAnT-outcomes.

Results: Time over 15 m (7.2s (±1.0)) was weakly related to WAnT-outcomes (r=-0.61 and -0.60, R^2=0.38 and 0.36, p<0.01), similar to mean velocity over 15 m (2.1 $m{\cdot}s^{-1}$ (±0.3), R^2=0.43 and 0.39, p<0.01). P5-15m (38.1W (±14.0)) showed a moderate relationship to WAnT-outcomes (r=0.77 and 0.75, R^2=0.60 and 0.56, p<0.001).

Conclusions: It seems that outcomes based on stopwatch time over a 15 m-overground sprint cannot be used to assess wheelchair-specific anaerobic work capacity, in contrast to an outcome based on PO (P5-15m). The 15-m sprint with an instrumented wheel can be implemented in rehabilitation practice and research settings when WAnT equipment is not available, although care is needed when interpreting P5-15m as an outcome of anaerobic work capacity given that it seems more skill-dependent than the WAnT.

INTRODUCTION

Manual wheelchair propulsion is important in daily-life mobility and participation of the majority of persons with spinal cord injury (SCI).[1,2] Essential wheelchair propulsion-activities in daily life (ADL) of persons with SCI are often short (<1 min) but intensive,[3,4] e.g. sprinting a short distance, ascending a ramp, and propulsion over uneven surfaces.[1,5] The duration and intensity of these ADL indicate a predominant use of anaerobic metabolism for delivering energy.[6-8] Anaerobic metabolism therefore seems important for mobility of manual wheelchair-dependent persons with SCI; especially in those with low fitness levels whose wheelchair-ADL can evoke high intensities.[3] The capacity of anaerobic energy systems specific for wheelchair propulsion-ADL can be estimated by assessing wheelchair-specific anaerobic work capacity 9, using power output outcomes over a Wingate-like sprint test in a wheelchair ergometer or roller (WAnT; all-out 30s-wheelchair sprint with heavy resistance).[8,10,11] However, such ergometers or rollers are often not available in rehabilitation centers. This hampers assessment of anaerobic work capacity necessary for fitness monitoring during and after SCI rehabilitation,[12,13] and during multicenter intervention studies.[14] Alternative tests for anaerobic work capacity are therefore needed, especially simpler and more feasible alternatives.

Using a stopwatch to record performance time, a short overground wheelchair sprint test in a standardized setting can be such an alternative when assuming that, similar to the WAnT, it requires a high-intensity short-duration muscular effort. A 15 m-overground sprint test has been used in cohort studies as part of a wheelchair skills test to monitor wheelchair skill performance over time in persons with spinal cord injury during and after rehabilitation,[15-17] and as such has been implemented in rehabilitation practice.[18] Stopwatch time over this 15-m sprint test has shown excellent test-retest reliability, discriminative ability between persons with high- and low-level spinal cord lesions,[15] and sensitivity to changes in performance during inpatient rehabilitation of persons with spinal cord injury.[17] The relationship between overground wheelchair sprint performance and WAnT-outcomes has already been shown in wheelchair athletes: distance on a 30s-overground wheelchair sprint test was related to WAnT-outcomes (r=0.9) and was also related to 20m-overground sprint time (r=-0.9),[19] while others found 100m sprint times correlated to WAnT-outcomes (r=-0.7 to -0.9).[8] However, it is still unknown whether stopwatch time over the 15-m sprint relates to WAnT-outcomes in non-athletes, i.e. persons who are generally not highly skilled or trained for overground sprinting, and whether this relationship is influenced by differences in load between the tests. In the WAnT, load is relatively high (comparable to overground propulsion on a 6 degree slope) and adjusted for each participant to optimize PO.[20] In the 15-m sprint test, load will generally be lower and can be dependent on body mass and factors such as surface type and tire pressure.[21,22]

It is not yet known how PO is expressed in a 15 m-overground sprint and whether it can be used to derive an alternative for WAnT-outcomes. Determination of PO during overground propulsion is now possible and feasible in rehabilitation practice due to the recent development of commercially available force and torque-instrumented wheels, which simply replace regular wheelchair wheels.[23,24] These wheels allow determination of PO outcomes over an overground sprint, for example the highest mean PO over successive 5-s intervals as used in the WAnT.[8,10,11] In the WAnT, the highest PO usually occurs during the first 5-10s,[7] which resembles time needed to complete a 15 m-overground sprint.[16,19] The relationship between PO outcomes of the 15-m sprint and WAnT needs further study, especially given the generally lower load in the 15-m sprint that, in contrast to the WAnT, may result in handrim velocities >2-3 $m \cdot s^{-1}$. These high velocities may lead to upper-body coordination problems and ineffective power transfer to the handrim.[20]

Able-bodied persons participated in this initial study on 15-m sprint outcomes as alternatives to WAnT-outcomes, since they are usually equally (in)experienced and form a somewhat more homogeneous and well-accessible group compared to non-athletic wheelchair users.[25] The aim of this study was to evaluate whether outcomes based on stopwatch time and PO over a 15 m-overground wheelchair sprint test can be used to assess wheelchair-specific anaerobic work capacity, by studying the relationship between 15-m sprint and WAnT-outcomes in a group of able-bodied persons.

METHODS

Participants

A convenience sample of able-bodied persons (*N*=19, 10 men; college students; see table 1 for characteristics) voluntarily participated after being informed about the study protocol and signing a written informed consent. The study was approved by the local ethical board of the Faculty of Human Movement Sciences (VU University Amsterdam, the Netherlands).

Table 1. Participant characteristics (*N*=19, 10 men).

Characteristic	Mean ± SD (range)
Age (y)	23 ± 2 (18-26)
Height (m)	176 ± 10 (163-195)
Body mass (kg)	69 ± 12 (50-94)
Wheelchair experience (h)	1 ± 2 (0-9)
Elbow angle[a] (°)	106 ± 6 (95-118)
Fiso[a] (N)	297 ± 92 (142-446)

[a] Measured when hands were on top of the handrim.
Abbreviation: Fiso = wheelchair-specific isometric force.

Equipment

A common daily wheelchair was used for the 15 m-overground sprint (Sopur Starlight 622; Sunrise Medical GmbH, D-69254 Malsch/Heidelberg, Germany; weight: 11.4 kg, wheel camber: 0°, seat width: 0.46m, angle seat-backrest: 90°). The regular rear wheels of the wheelchair were replaced on the left side by a force and torque-instrumented wheel (OptiPush, MAX Mobility, Antioch, USA) and on the right side by an inertia-compensated dummy wheel (each wheel: 5.7 kg, wheel size: 0.61m (24 inch), handrim diameter: 0.52 m, tire pressure: $8 \cdot 10^5$ Pa). The instrumented wheel allows measurement of propulsive torque around the wheel axle and the angle over which the wheel is rotated. Data collection was manually started and stopped 5s before and after the start of the 15-m sprint, and data were wirelessly transferred to a laptop at 200 Hz.

We used a custom-built stationary ergometer[26] for the WAnT that allows measurement of propulsion torque and (resultant) velocity of both wheels, as well as individualization of load based on previously described protocols (e.g.[25]). The ergometer dimensions were adjusted so that it matched as closely as possible the wheelchair used in the overground sprint (ergometer camber +1°; seat width +2 cm). Ergometer data were sampled at 100 Hz. Real-time wheelchair velocities of both wheels (indicated by dimensionless bars) were presented on a computer screen.

Protocol

One 15-m sprint and one WAnT were performed on two separate days. To minimize confounding anthropometric changes, learning effects or insufficient recovery, these test days were performed in a counter-balanced order and were separated by 2-7 days of rest. Participants were asked to refrain from heavy exercise at least 48h before a test day, and to refrain from alcohol, smoking or heavy meals in the 2 hours before the experiment. On both days, participants were familiarized with the equipment, which took 5-10 min and also served as a warming-up. For the 15 m-overground sprint, this included acquaintance with overground propulsion, in addition to experiencing how to safely perform an overground sprint start. For the WAnT, this included familiarization with ergometer propulsion and learning to maintain the same relative velocity between both wheels using the computer screen.

The protocol of the 15-m sprint test was similar as the protocol implemented in rehabilitation centers and as used in previous cohort studies on spinal cord injury,[15-18] including the use of a stopwatch to record time which has shown excellent test-retest reliability.[15] The sprint was performed on a linoleum floor with the instrumented and dummy wheel in place. Two markers were placed on the floor, 15 m apart. The participant sat in the wheelchair, with the front casters turned backward and behind the first marker. At the starting signal (5 s after starting data collection of the instrumented wheel), the participant propelled the wheelchair towards the second marker as fast as possible while receiving verbal encouragement. Time was manually recorded using a stopwatch from the moment the start signal was given until the front casters passed the second marker (time-15 m).

The protocol of the WAnT was similar as the protocol used in earlier studies (e.g.[25]). First, maximal isometric strength was measured with a test in which participants pushed as forcefully as possible for 5s on the top of the handrims; over three trials the highest consecutive 3s-force was determined (Fiso). Using the relationship between Fiso and WAnT-outcomes as reported by Janssen *et al.*[27], initial load of the WAnT was selected. After 8 min of rest, participants were asked to propel the wheels as forcefully as possible for 4-8 strokes, mimicking the start of the WAnT. If propulsion velocity remained <2.0 m·s^{-1}, the selected load was used in the subsequent WAnT. Otherwise, the procedure was repeated to find an optimal load. Following a 2 min rest, the WAnT was then performed: wheels were blocked during a 10s countdown, after which the participant was verbally encouraged to propel as fast as possible for 30s (start velocity of 0 m·s^{-1}, i.e. no rolling start) and to maintain relative wheel velocity over both wheels. If a participant reached a velocity higher than 2 m·s^{-1} or was unable to propel the wheelchair near the end of the 30s, the trial was omitted. Load was then adjusted and another trial was performed after at least 8 min of rest.

Data processing

Time-15 m was used to calculate mean velocity over 15 m (meanVelocity-15 m; 15 m divided by time-15 m). Raw data of the instrumented wheel were filtered (low-pass Butterworth filter of 20 Hz for torque[24] and 6 Hz for angle data[28]) and analyzed using custom-written software.[28] Within the raw data, start and end of the 15-m sprint needed to be defined: start was the sample of the first push detected by the software and end was the sample representing the start angle plus 15 m in radians (figure 1). The product of unilateral torque and angular velocity defined unilateral PO.

Subsequently, the equivalent of one of the WAnT-outcomes[6,8] was determined, i.e. the highest mean unilateral PO over successive 5-s intervals (P5-15m, see figure 1); for P5-15m this was either over one or two 5-s intervals (depending on performance time: resp. <10s or 10-15s). To assess whether a 15 m-PO outcome with a relatively high load and low velocity would stronger relate to WAnT-outcomes, PO over the first three cycles (Pstart-15m) was determined. Peak momentary PO (Ppeak-15m), i.e. the highest single-sample value of the 15 m-interval (figure 1), was determined since it may stronger relate to WAnT-outcomes due to its independency of load found in a study on the WAnT.[20]

The raw velocity and torque data of the left wheel of the ergometer were filtered (20 Hz low-pass Butterworth filter[20]) and unilateral PO was again determined from the product of angular velocity and torque. Then, mean unilateral PO over 30s (P30-WAnT) and the highest mean unilateral PO of the 6 successive 5-s intervals (P5-WAnT) were determined (figure 2).[6,8] Over the intervals of each outcome of the 15-m sprint and WAnT, mean and peak velocities were also established.

Statistics

All data were found to be normally distributed based on the Shapiro-Wilk test and tests for skewness and kurtosis ($p<0.05$). Group mean and standard deviation were determined for each variable, and correlation coefficients (Pearson's r) and coefficients of determination (R^2) were calculated between 15-m outcomes (time-15 m, meanVelocity-15 m, P5-15m, Pstart-15m and Ppeak-15m) and WAnT-outcomes (P30-WAnT and P5-WAnT) with $p<0.05$. Correlation coefficients ≥0.90 were considered as high, 0.70-0.90 as moderate but still acceptable to prove a relationship between variables, and <0.70 as weak.[29] Furthermore, P5-15m and P5-WAnT were compared with a Bland-Altman plot and by calculating the standard error of measurement (SEM) between the two outcomes.

To study velocity differences between the tests that might result from the differences in load, paired-samples t-tests ($p<0.05$) were used to compare mean and peak velocities of the intervals of 1) P5-15m vs. P5-WAnT, 2) P5-15m vs. Pstart-15m, and 3) Pstart-15m vs. P5-WAnT. To study possible confounding effects of interindividual differences in anthropometrics (i.e. body mass, gender or elbow angle) on the relationship between outcomes of the two tests, hierarchical multiple regression analyses were performed on a selection of outcomes, i.e. P30-WAnT as the dependent variable, and either time-15 m or P5-15m as the independent variable (step 1) and combined in step 2 with one of the anthropometric factors. SPSS 19.0 for Mac (SPSS Inc., Chicago, IL) was used for all statistical analyses.

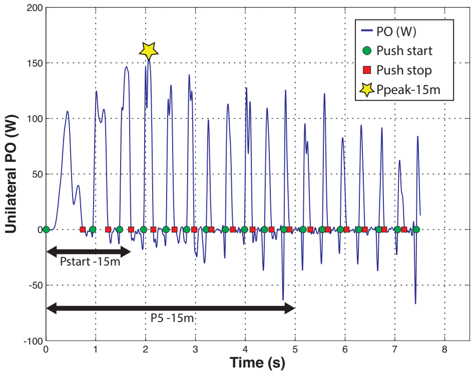

Figure 1. Typical example of a participant's unilateral power output (PO) over the 15-m overground wheelchair sprint and of the PO outcomes, with t=0 representing the sample of the first push detected by the software and the last data point representing the start angle plus 15 m in radians.

Abbreviations: P5-15m = highest mean unilateral PO over successive 5-s intervals of 15-m sprint (not a moving average, i.e. only one interval for this participant); Pstart-15m = mean unilateral PO over first 3 push cycles of 15-m sprint; Ppeak-15m = peak momentary unilateral PO of 15-m sprint.

Characteristics of this example: female; age: 21y; height: 170 cm; body mass: 59.5 kg; wheelchair experience: 0.17h; elbow angle: 110°; Fiso: 263N.

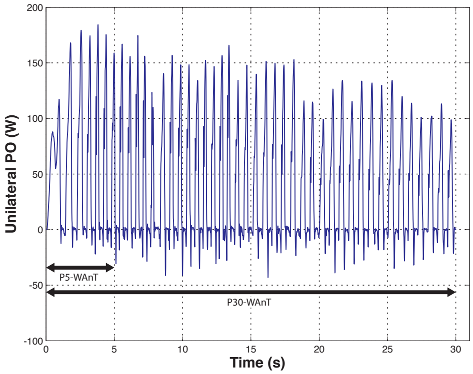

Figure 2. Typical example of a participant's power output (PO) over the Wingate-based 30s-wheelchair ergometer sprint and of the PO outcomes.

Abbreviations: P30-WAnT = mean unilateral PO over Wingate-based 30s-sprint;
P5-WAnT = highest mean unilateral PO over the 6 successive 5-s intervals of Wingate-based 30s-sprint (for this participant, it was the first of the 6 intervals).

Characteristics of this example: see figure 1.

RESULTS

All subjects (N=19) successfully completed the two tests. Time-15 m was on average 7.2s (±1.0), meanVelocity-15 m on average 2.1 m·s^{-1} (±0.3). Table 2 shows PO outcomes of both tests as based on unilateral PO, and typical examples of a participant's unilateral PO during the 15-m sprint and WAnT are respectively depicted in figure 1 and 2.

Table 3 shows Pearson's r and R^2 that were calculated between 15-m sprint outcomes and WAnT-outcomes. The linear model with time-15 m was significantly but weakly related to the WAnT outcomes (P30-WAnT and P5-WAnT resp. r=-0.60 and -0.61, R^2= 0.38 and 0.36, $p<0.01$), similar to the model with meanVelocity-15 m (R^2= 0.43 and 0.39, $p<0.01$). To visualize the relationship between meanVelocity-15 m and one of the WAnT-outcomes (P5-WAnT) over the range of the data, a scatter plot with the regression line of the linear model is shown in figure 3. Stronger relationships were found between 15-m PO outcomes and WAnT-outcomes: correlations were moderate between all outcomes ($r\approx0.8$, $p<0.001$, table 3).

Table 2. PO outcomes of the 15 m-overground wheelchair sprint and the Wingate-based 30s-wheelchair ergometer sprint (WAnT), and mean and peak linear velocity over the intervals of these PO outcomes over all participants (N=19).

PO outcome	Unilateral PO (W)	Mean velocity (m·s^{-1})	Peak velocity (m·s^{-1})
P5-15m	38.1 ±14.0	1.8 ±0.3*	3.1 ±0.4*
Pstart-15m	46.3 ±17.0	1.0 ±0.2*	2.1 ±0.4*
Ppeak-15m	228.0 ±71.6	N.A.	2.4 ±0.4
P30-WANT	44.4 ±17.3	1.2 ±0.3	1.6 ±0.3
P5-WANT	57.0 ±19.0	1.2 ±0.2*	1.5 ±0.3*

Data in mean ±SD.

*Significant difference (p<0.05) when comparing mean velocities and peak velocities of 1) P5-15m vs. P5-WAnT, 2) P5-15m vs. Pstart-15m, and 3) Pstart-15m vs. P5-WAnT.

Abbreviations: see figures 1 and 2.

Table 3. Correlations coefficients (Pearson's r) between outcomes of the 15 m-overground wheelchair sprint and the Wingate-based 30s-wheelchair ergometer sprint (WAnT) over all participants (N=19).

	P30-WAnT		**P5-WAnT**	
	Pearson's r	R^2	Pearson's r	R^2
Time-15 m	-0.61 (-0.83 to -0.22)*	0.38*	-0.60 (-0.82 to -0.20)*	0.36*
MeanVelocity-15 m[a]	0.65 (0.29 to 0.85)*	0.42*	0.63 (0.25 to 0.84)*	0.39*
P5-15m	0.77 (0.49-0.91)**	0.59**	0.75 (0.45-0.89)**	0.56**
Pstart-15m	0.79 (0.52-0.92)**	0.62**	0.78 (0.51-0.91)**	0.61**
Ppeak-15m	0.83 (0.60-0.93)**	0.69**	0.78 (0.50-0.91)**	0.61**

Values between brackets represent 95% confidence intervals of r.

*p<0.01; **p<0.001.

[a] Linear model without intercept

Abbreviations: Time-15 m = time over 15 m sprint; meanVelocity-15 m = time-15 m divided by stopwatch time; other abbreviations: see figures 1 and 2.

Average P5-WAnT was about 20W higher than P5-15m (table 2), which can also be seen in the typical example in figure 4 (top window). However, large between-participant variation in differences between P5-15m and P5-WAnT was also found: SEM of P5-15m and P5-WAnT was relatively large (15.7W), as is also visible in the Bland-Altman plot (figure 5).

During the 30s-WAnT, peak velocity was <2 $m \cdot s^{-1}$ in all participants (table 2). Mean and peak velocities over the interval of P5-15m were generally above >2-3 $m \cdot s^{-1}$, and about 1.5-2 times higher than mean and peak velocities of P5-WAnT ($p<0.05$, table 2). More similar velocities were found in the interval of Pstart-15m compared to P5-WAnT, but these were still significantly higher for mean velocity (2.1 ±0.4 vs. 1.5 ±0.3 $m \cdot s^{-1}$, $p<0.05$, table 2).

Results of the multiple regression analyses (table 4) with time-15 m and either body mass, elbow angle or gender as independent variables showed that only the combination with body mass significantly explained additional variance of P30-WAnT ($\Delta R^2=0.25$, $p<0.01$), although borderline significant results were found for elbow angle ($\Delta R^2=0.12$, $p=0.06$) and gender ($\Delta R^2=0.11$, $p=0.07$). None of these factors reached statistical significance when combined with P5-15m to explain additional variance of P30-WAnT, although elbow angle was borderline significant ($\Delta R^2=0.08$, $p=0.06$).

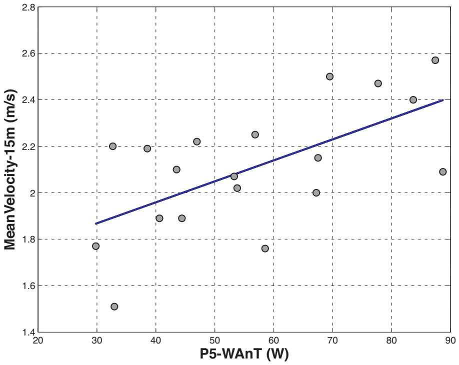

Figure 3. Scatter plot of meanVelocity-15m against P5-WAnT (*N*=19), with the regression line representing the linear model used to study the relationship between the outcomes over a data range than can be expected in practice.[15,16,19]

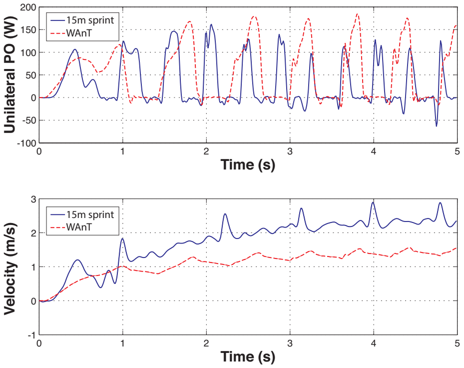

Figure 4. Typical example of a participant's unilateral power output (PO) (top window) and linear velocity (bottom window) over the interval of the highest successive 5-s unilateral mean PO interval of the 15-m overground wheelchair sprint (P5-15m) and over its counterpart (P5-WAnT) of the Wingate-based 30s-wheelchair ergometer sprint (WAnT).

Participant characteristics of typical example: see figure 1.

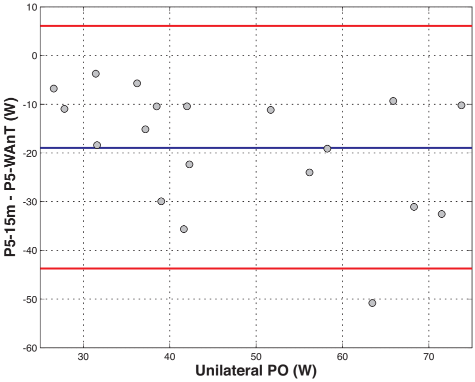

Figure 5. Bland-Altman plot of the highest successive 5-s unilateral mean unilateral PO interval of the 15 m-overground wheelchair sprint (P5-15m) and of its counterpart (P5-WAnT) of the Wingate-based 30s-wheelchair ergometer sprint: the differences between P5-15m and P5-WAnT (y-axis: P5-15m – P5-WAnT) in relation to the mean of the two outcomes (x-axis). Middle line is plotted indicating mean difference between the outcomes, while upper and lower lines indicate limits of agreement (mean difference ± 2 SD).

Table 4. Results of hierarchical multiple regression analysis (N=19) with mean unilateral power output (W) over Wingate-based 30s-sprint (P30-WAnT) as the dependent variable, in step 1 with a 15 m-outcome (either time-15 m or P5-15m) as the independent variable which is combined in step 2 with one anthropometric factor (either body mass, elbow angle or gender).

	Time-15 m (s)				**P5-15m (W)**			
	ß	SE	*p*	R²	*ß*	SE	*p*	R²
Step 1								
Constant	120.36	24.01	<0.001		7.84	7.59	0.316	
15 m-outcome	-10.50	3.29	0.005	0.38	0.96	0.19	<0.001	0.61
Step 2								
Constant	78.96	22.88			-7.01	14.95		
15 m-outcome	-11.53	2.64	0.001		0.88	0.20	<0.001	
Body mass (kg)	0.70	0.21	0.005	0.63	0.26	0.22	0.265	0.63
Step 2								
Constant	212.63	50.93			103.27	47.83		
15 m-outcome	-7.68	3.34	0.035		0.80	0.19	0.001	
Elbow angle[a] (°)	-1.06	0.53	0.061	0.50	-0.84	0.42	0.061	0.69
Step 2								
Constant	104.77	23.63			17.04	11.13		
15 m-outcome	-7.50	3.43	0.044		0.81	0.23	0.002	
Gender (0=men)	-12.96	6.75	0.073	0.49	-6.97	6.24	0.278	0.64

[a] Measured when hands were on top of the handrim.

Abbreviations: *ß* = regression coefficient; SE = standard error; R² = explained variance after step 1 or 2; Time-15 m = time over 15 m sprint; P5-15m = highest mean unilateral PO over successive 5-s intervals of 15 m sprint.

Discussion

This study was aimed at assessing whether outcomes based on stopwatch time and PO over a 15 m-overground wheelchair sprint test can be used to assess wheelchair-specific anaerobic work capacity, by studying their relationship with WAnT-outcomes in a group of able-bodied persons. We found WAnT-outcomes to be weakly related to 15 m-outcomes based on stopwatch time, and moderately related to PO-outcomes of the 15-m sprint (table 3).

The weak relationship found between stopwatch time over the 15 m-overground sprint and WAnT-outcomes can be explained by the differences in load between the tests. The relatively lower load in the 15-m sprint led to velocities >2-3 $m \cdot s^{-1}$ (table 2, figure 4). These velocities are thought to cause upper-body coordination problems impacting effective power transfer to the handrim.[20,25] The skill to propel the wheelchair at these high velocities may have differed between our participants while this variance is not expected in the WAnT as velocities >2-3 $m \cdot s^{-1}$ are prevented through the use of a relatively high and individualized load (table 2, figure 4).[20,25] Effects of high handrim velocities on power transfer to the handrim may especially occur in participants who are not highly skilled wheelchair athletes, which would explain the relatively weak relationship between 15 m-stopwatch time outcomes and WAnT-outcomes in this study (e.g. r=0.61 between time-15 m and P30-WAnT) compared to overground sprint outcomes found in wheelchair athletes (100m-overground sprints: r=-0.7 to -0.9; 30s-sprint: r=0.9).[8,19] Another explanation for the relatively weak relationships in our sample may be that overground sprinting requires motor skill needed for steering and for explosively starting to propel an inherently unstable wheelchair while this is not required in a WAnT-ergometer or roller. In wheelchair athletes, this variance may be smaller due to higher skill and training in overground sprinting. A last explanation for the weak relationships may be effects of between-participant variations in load caused by differences in body mass (distribution), which is directly associated to rolling resistance, and some air friction differences due to body size and sitting posture. In the WAnT, air friction is non-existent and effects of variations in body mass are likely to be small since load is individualized based on propulsion velocity.[20,25] The effect of between-participant differences in body mass is indicated by the regression analyses: time-15 m combined with body mass explained an additional 25% of variance of P30-WAnT compared to time-15 m alone (table 4).

A limitation of the linear model that was used to study the relationship between time-15 m and the PO-outcomes of the WAnT is that it does not reflect an infinite value of P5-WAnT or P30-WAnT at time-15 m=0. However, the aim of this study was not to accurately predict time-15 m based on WAnT-outcomes, but to study their relationships over a range of time-15 m that can be expected in practice, about 4-20s,[15,16,19] in which we assume a linear relationship. Nonetheless, alternative models may be more valid and as such may explain more variance between overground sprint time and WAnT-outcomes. Therefore, we also determined variance explained between WAnT-outcomes and meanVelocity-15 m (similar to the inverse of time-15 m) based on a linear model with intercept, which more closely resembles a valid model at low values (figure 3).

However, explained variance was about the same as the model with time-15 m (table 3), indicating that meanVelocity-15 m also cannot be used as an outcome of anaerobic work capacity. We did not test a model without intercept, i.e. satisfying the condition of meanVelocity-15 m=0 at P5-WAnT=0 and P30-WAnT=0, since it would inevitably explain even less variance. In hand cycling, a relatively simple non-linear relationship between overground velocity and PO, being dependent on rolling resistance and air resistance, has been shown valid 30. Although it may seem that such a relationship also applies to 15 m-velocity and WAnT-PO, it seems unsuitable for our data due to the PO-dependent influence of skill to handle high handrim velocities in the 15-m sprint. This is confirmed by visual inspection of the scatter plot (figure 3), which does not indicate that such a non-linear relationship exists over the range in our study. A valid non-linear model needs further study, but our observations indicate that this would give rise to the same conclusion as based on the linear model tested in this study: stopwatch time over the 15-m sprint cannot be used as an outcome of wheelchair-specific anaerobic work capacity of non-athletes.

It seems P5-15m can be used as an outcome of anaerobic work capacity given its moderate correlation to both WAnT-outcomes (both $r \approx 0.8$, $p < 0.001$, table 3). An explanation for the higher correlation compared to time-15 m is that P5-15m can account for interindividual differences in body mass: rolling resistance of a heavier person is higher which can affect velocity and therefore time-15 m, but in P5-15m this person may compensate for their lower velocity by applying more torque (assuming the heavier person is also stronger). This hypothesis is substantiated by the multiple regression analyses in which P5-15m combined with body mass did not significantly explain additional variation of P30-WAnT compared to P5-15m alone (table 4). P5-15m and P5-WAnT were both determined over the highest of successive 5-s PO intervals, but absolute values of P5-15m were generally lower than P5-WAnT (group average 19W lower, figure 5). However, the range over the group in differences between P5-15m and P5-WAnT was large (-51 to -4W, figure 5) and may be explained by the between-participant variations in skill (to start and steer in the 15 m sprint, and to handle high handrim velocities, as described above) that are not required in the WAnT. Although it may seem that these interindividual variations are smaller in participants with lower PO (clustering of data points in upper left corner of figure 5, and larger absolute variation at higher PO in right part of figure 5), variations seem similar when considering these as relative values.

Pstart-15m (PO over first 3 cycles) was used to study whether a 15 m-PO outcome during an interval with relatively low handrim velocities may stronger relate to WAnT-outcomes than P5-15m. Although in most participants inertia indeed seemed to prevent high handrim velocities during the interval of Pstart-15m ($<$2-3 $m \cdot s^{-1}$),[20,25] correlation coefficients with WAnT-outcomes were similar compared to P5-15m (also $r \approx 0.8$, $p < 0.001$, table 3). This may be explained by Pstart-15m being relatively more influenced by between-participant differences in skill to explosively start to propel the wheelchair. Another alternative 15 m-PO outcome was studied, i.e. single-sample peak PO (Ppeak-15m) since its counterpart in the WAnT had been shown to be independent of load 20, and may therefore also be independent of handrim velocity. However, also Ppeak-15m did not bear a substantially stronger relationship with WAnT-outcomes compared to P5-15m (also $r \approx 0.8$, table 3), which in this case may be explained by the relatively larger influence of outliers on Ppeak-15m that may not reflect actual sprint capacity.[8,20] Given the similar correlation coefficients, we recommend using P5-15m over Pstart-15m and Ppeak-15m since P5-15m is determined identically to the widely accepted P5-WAnT.[6,8]

It is difficult to find a sufficiently sized sample of non-athletic wheelchair users that is homogenous in training status, wheelchair skill level and disability characteristics.[25] Therefore, able-bodied persons participated in this initial study since they are usually a more homogeneous and well-accessible group compared to non-athletic wheelchair users.[25] The range in time-15 m and WAnT-outcomes of our able-bodied sample seem representative for non-athletic wheelchair-dependent persons with low-level spinal cord injury,[8,16,27,31] while lower performance scores can be expected in a sample of persons with high-level lesions due their physical fitness level and reduced upper-body coordination.[15] Still, we expect similar relationships between 15-m sprint and WAnT-outcomes in various non-athletic wheelchair populations, since variance caused by body mass (distribution) and skill for overground sprinting may be similar in these populations not highly skilled or trained for overground propulsion. Heterogeneity in our able-bodied sample in anthropometrics (i.e. body mass, elbow angle and gender) was studied with multiple regression analyses (table 4). Due to the sample size, combining these factors into one model was not possible. Effects of body mass were already explained above. A range of elbow angles was found over the group since seat height was not individualized (table 1). Nonetheless, seat height was identical in both tests and therefore we expected that the effect of elbow angle would affect both tests similarly. However, elbow angle nearly reached significance in explaining additional variance of P30-WAnT by time-15 m and P5-15m (both $p=0.061$, table 4). It may be that individualization at an optimal elbow angle is more important in the 15-m sprint compared to the WAnT due to the necessity to start and steer and to handle high handrim velocities. The borderline significant effect of gender on time-15 m ($p=0.073$, table 4), in contrast to P5-15m, may be associated to differences in body mass and effective muscle mass between males and females seem are only reflected in time and not in PO.

Suggestions for future research are 1) to test the assumption that the relationships between the tests in an able-bodied sample are similar in non-athletic wheelchair-dependent populations, 2) to assess whether relationships of 15 m-outcomes with WAnT-outcomes are stronger in wheelchair athletes, since the influence of between-participant differences in skill may be smaller compared to non-athletes,[8] and 3) to improve understanding of the relationships found between wheelchair-specific isometric force, aerobic power and sprint power,[27] using P5-15m.

We conclude that outcomes based on stopwatch time over a 15 m-overground sprint cannot be used to assess wheelchair-specific anaerobic work capacity, in contrast to an outcome based on PO (P5-15m). The 15-m sprint in an individually optimized wheelchair with an instrumented wheel can be implemented in rehabilitation practice and research settings when WAnT-equipment is not available, although care is needed when interpreting P5-15m as an outcome of sprint power given that it seems more skill-dependent than the WAnT. Although the use of instrumented wheels in rehabilitation practice is growing,[23,32] further technological developments are needed to facilitate implementation, e.g. more ideal for assessment of wheelchair-specific anaerobic work capacity would be to mimic a WAnT with an inexpensive wheelchair roller with sufficient resistance, combined with a low-cost commercially available wheel only tailored towards measurement of PO.

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Chapter 5

Wheelchair-specific fitness of inactive people with a long-term spinal cord injury

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ABSTRACT

Objectives: To describe wheelchair-specific anaerobic work capacity, isometric strength and peak aerobic work capacity of physically inactive people with long-term SCI using outcomes of tests feasible for use in rehabilitation centers, in addition to determining associations among these fitness components.

Design: Cross-sectional study.

Participants: Manual wheelchair users with spinal cord injury for at least 10 years, who were inactive based on a norm score of a physical activity questionnaire (N=29; 22 men; 20 with paraplegia; median age: 53y).

Methods: Participants performed three exercise tests in their own wheelchair to determine: highest 5-s power output over 15-m overground sprinting (P5-15m); highest 3s-isometric push-force (Fiso); and peak power output (POpeak) and peak oxygen uptake (VO2peak) over a peak test.

Results: Median (25-75th) was in P5-15m 16.1W (9.4-20.9); in Fiso 399N (284-610); in POpeak 40.9W (19.1-54.9); and in VO2peak 1.26 $L \cdot min^{-1}$ (0.80-1.67). Pearson's r among outcomes of fitness components were weak (r=0.50-0.67, $p<0.01$), except for P5-15m with POpeak (r=0.79, $p<0.001$).

Conclusions: Relatively low levels appeared in all fitness components, implying the specific need of this group for interventions to improve wheelchair-specific fitness. The weak to moderate associations among components imply that separate tests should be used when monitoring wheelchair-specific fitness in rehabilitation centers.

INTRODUCTION

Maintaining wheelchair-specific fitness is considered important for many people with spinal cord injury (SCI), as most depend on a manual wheelchair in daily life (81% estimated in the Netherlands).[1,2] Wheelchair-specific fitness, defined as physical fitness measured during manual wheelchair propulsion tests, has a positive association with health, participation and quality of life of people with SCI.[3-5] Physically inactive people with long-term SCI are a group that is expected to specifically suffer from low wheelchair-specific fitness.[6] This group not only has an inactive lifestyle that has been associated with lower wheelchair-specific fitness,[7] but also a relatively high incidence of secondary health complications that can lead to reduced wheelchair-specific fitness.[8-10]

However, descriptions of wheelchair-specific fitness of inactive people with long-term SCI are limited.[11-13] A detailed description of wheelchair-specific fitness should include anaerobic work capacity, isometric strength as well peak aerobic work capacity, as these fitness components are assumed to reflect the capacity needed in essential wheelchair activities such as propelling a long distance, propulsion over uneven surfaces and ascending a ramp.[14] Such a description is not yet available for inactive people with long-term SCI using outcomes of tests feasible for use in rehabilitation centers. Feasible tests are a prerequisite for systematic fitness monitoring in rehabilitation centers, which can support maintenance of fitness.[1,15]

Furthermore, it is not clear if and how wheelchair-specific fitness components are associated in inactive people with long-term SCI performing tests feasible for use in rehabilitation centers. If outcomes of different components are strongly associated, it implies that separate tests for each component are not necessary since an outcome of one component could be used to predict another, which may reduce measurement burden.[16-18] Furthermore, such strong associations may also imply that different exercise forms can improve various wheelchair-specific fitness components of inactive people with long-term SCI, for example strength exercise improving peak aerobic work capacity or endurance exercise improving isometric strength.[16,17,19] Strong associations among wheelchair-specific anaerobic work capacity, isometric strength and peak aerobic work capacity have already been found in a group with long-term SCI (r=0.81-0.90), but in this study lab-based wheelchair ergometer tests were used.[16]

The aim of this cross-sectional study was to describe levels of wheelchair-specific anaerobic work capacity, isometric strength and peak aerobic work capacity of a group of physically inactive people with long-term SCI using outcomes of tests that are feasible for use in rehabilitation centers, in addition to determining associations among the group's fitness components. Our hypotheses were to find relatively low fitness levels when compared to previous studies in people with SCI such as those on lab-based tests,[13,20,21] in addition to strong associations among components similar to those found using lab-based tests.[16]

METHODS

Participants, procedures and outcomes in this cross-sectional study were part of baseline measurements in a multi-center randomized controlled trial (RCT) on low-intensity wheelchair exercise.[22]

Participants

Participants were physically inactive people with a long-term SCI who were community-dwelling manual wheelchair users. Long-term SCI was defined by a time since injury > 10 years, while physical inactivity was defined by a score on the Physical Activity Scale for Individuals with Physical Disabilities (PASIPD) < 75th percentile of a Dutch cohort with SCI.[23] Participants were included after their voluntary agreement, written informed consent and eligibility screening.[22] Exclusion criteria comprised: cardiovascular contraindications (for example systolic blood pressure >180 mm Hg and metabolic conditions such as uncontrolled diabetes and thyrotoxicosis); musculoskeletal complaints contraindicating manual wheelchair propulsion; mental contraindications; and insufficient mastery of Dutch language.[22,24] The study was approved by the Medical Ethical Committee of the VU University Medical Center (Amsterdam, the Netherlands) and the two participating rehabilitation centers.

Procedures and outcomes

On a single day in a standardized procedure,[22] participants performed three exercise tests in their own wheelchair: first, a 15-m overground sprint test with an instrumented wheel; second, an isometric-push test; and last, a graded peak exercise test on a treadmill. These tests were used to assess wheelchair-specific anaerobic work capacity, isometric strength and peak aerobic work capacity.

Anaerobic work capacity (15-m test)

Anaerobic work capacity was determined in a 15 m-overground sprint test in participants' own wheelchairs, similar to a protocol in a pilot study on able-bodied people.[25] This protocol was based on a 15 m-sprint test used in previous SCI cohort studies as part of a wheelchair skill test battery.[5,26] The right rear wheel of the participant's wheelchair was replaced with an instrumented wheel that sampled 3-dimensional forces and moments applied to the handrim throughout the test at 200 Hz (OptiPush, MAX Mobility, Antioch, USA). The left wheel was replaced with an inertia-compensated wheel (both wheels weighed about 5.7 kg).

Outcome was the highest mean unilateral power output over successive 5-s intervals of the 15-m test (P5-15m).[25] Concurrent validity of P5-15m was seen as acceptable given its strong association with outcomes on a Wingate-like test on a wheelchair ergometer found in a pilot study (r=0.75-0.77).[25]

Isometric strength (isometric-push test)

Isometric strength was determined using a protocol in which participants performed a maximal isometric contraction for 5 s with hands on top of their handrim, while their wheelchair with regular wheels was attached via a rope and a force transducer to a wall.[22,27] The setup is shown in figure 1. During the test, an investigator held the front casters of the wheelchair on the floor. The participant performed 3-5 trials of the test interspersed with 2 min rest periods between trials.

In data processing, force was doubled as the transducer was connected to only one of the two anchor points (figure 1). The outcome of the isometric wheelchair push-test was the highest mean consecutive 3s-force interval over 3 successful trials (Fiso, a bilateral force outcome), similar to a wheelchair ergometer test.[13]

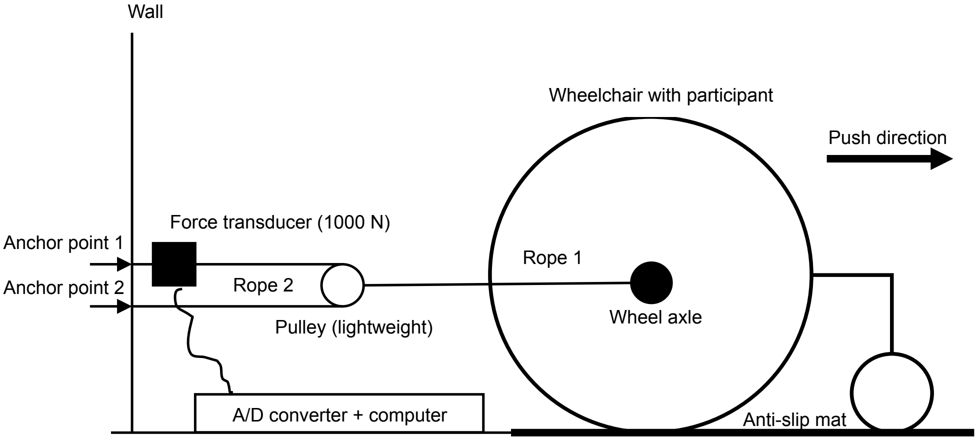

Figure 1. Setup of the isometric wheelchair push-test (see Chapter 3[22] for a photo). The participant's wheelchair was blocked by attaching it – via a system with ropes and a pulley – to a one-dimensional strain gauge transducer. A computer received the signal of the strain gauge transducer so that force could be determined at 100 Hz.

Peak aerobic work capacity (peak exercise test)

Peak aerobic work capacity was determined in a protocol similar to that in previous SCI cohort studies on people with SCI.[26,28] The protocol consisted of: familiarizing the participant with treadmill propulsion including determination of treadmill velocity during the tests, that is <0.56, 0.56, 0.83 or 1.11 $m \cdot s^{-1}$; a drag test to determine a participant's power output at each inclination angle of the treadmill; two blocks of three min of submaximal treadmill propulsion; and an incremental exercise test in which the inclination angle of the treadmill increased every minute by about 0.3 degrees until the participant could no longer maintain treadmill velocity.[26]

Outcomes were mean power output over the last 30s of the test (POpeak) and the highest mean 30s-oxygen uptake over the test (VO2peak). As a reference for peak performance, the highest 30s-respiratory exchange ratio over the test was determined, in addition to assessing rate of perceived exertion immediately after the test (scale of 0-10).[29]

Statistics

Descriptive statistics were determined over the total group as well as subgroups with paraplegia and tetraplegia for all participant characteristics and outcomes. All data of the total group was normally distributed based on tests for skewness and kurtosis ($p<0.10$), in contrast to data of the subgroups with paraplegia and tetraplegia. For descriptive purposes, participant characteristics and outcomes of the subgroups were compared using Fisher's tests and Mann-Whitney U-tests ($p<0.05$).

Over the total group, Pearson's r was calculated among P5-15m, Fiso, POpeak and VO2peak. High correlations were defined as $r\geq0.90$, moderate as $r=0.70\text{-}0.90$ and weak as $r<0.70$ 30. Significance was set at $p<0.05$.

RESULTS

Participants

The majority of the 29 participants was middle-aged and had a complete paraplegia for about 17 years. Average activity scores were as low as 4.7 MET h·week^{-1}, while only two participants were engaged in sports (either 2 h of badminton or 1 h of handcycling). Other demographics and lesion characteristics are described in table 1.

Procedures

Participants used wheelchairs with a rear wheel diameter of 0.61 ($n=21$), 0.64 ($n=4$) or 0.66 m ($n=4$), while all tire pressures were set at $6\cdot10^5$ Pa. All participants used regular handrims, except for two: a participant with a complete T11 lesion used handrims integrated with the wheel rim and one participant with an incomplete C4 lesion needed handrims with rods perpendicular to the handrim.

All participants performed all tests according to protocol, except in the 15-m test ($n=2$) and peak test ($n=1$). The 15-m test could not be performed by a participant with an incomplete T3 lesion due to the instrumented wheels not fitting the wheelchair axle of the participants' wheelchair, while the participant with the incomplete C4 lesion was not able to use the instrumented wheels given the need for handrims with rods. A participant with an incomplete C6 lesion preferred to perform the peak test without the mask used to determine VO2peak. In addition, missing data due to technical problems occurred in POpeak ($n=1$), P5-15m ($n=4$) and Fiso ($n=1$). Table 2 shows resulting sample sizes.

Description of outcomes

In the total group, P5-15m was on average 16.1W (range: 2.0-39.4 W), Fiso on average 399 N (range: 93 to 1113 N), POpeak on average 40.9 W (range: 3.6-92.8 W) and VO2peak on average 1.26 L·min^{-1} (range: 0.39-2.03 L·min^{-1}), as shown in table 2 and figure 2. Variance over the group was high in all outcomes (figure 2). Although the subgroup with paraplegia had significantly higher outcomes than the subgroup with tetraplegia (table 2), overlap between these subgroups was apparent: some participants with tetraplegia had outcomes equal or higher than those with paraplegia (figure 2).

Mean respiratory exchange ratio in the peak test was on average >1.00 for the total group (median [interquartile range]: 1.02 [0.91-1.12]), indicating that on average peak aerobic performance was reached. Rate of perceived exertion on a 0-10 scale was on average 6 in the total group (interquartile range: 5-9).

Table 1. Participants' characteristics.

	Total	**Para**[a]	**Tetra**[b]	**Para vs. Tetra**
	N	*n*	*n*	*p*
Group size	29	20	9	
Men / women	22 / 7	15 / 5	7 / 2	1.00
Complete / incomplete[a]	20 / 9	15 / 5	5 / 4	0.40
AIS A / B / C / D	17 / 3 / 7 / 2	14 / 1 / 4 / 1	3 / 2 / 3 / 1	N.A.
C4-6 / C7-8 / Th1-9 / Th10-L5	5 / 4 / 13 / 7	0 / 0 / 13 / 7	5 / 4 / 0 / 0	N.A.
Married or partner / single	18 / 11	12 / 8	6 / 3	1.00
Cohabiting / not cohabiting	19 / 10	13 / 7	6 / 3	1.00
Employed / not employed	20 / 9	13 / 7	7 / 2	0.68
Low / medium / high education level	14 / 13 / 2	9 / 10 / 1	5 / 3 / 1	N.A.
Help in daily-self care / no help[b]	17 / 12	9 / 11	8 / 1	0.04
Help in household / no help[b]	25 / 4	18 / 2	7 / 2	0.57
	Mdn (25-75th)	**Mdn (25-75th)**	**Mdn (25-75th)**	
Age (y)	57 (45-63)	54 (44-61)	63 (43-65)	0.30
Height (m)	1.80 (1.69-1.86)	1.79 (1.69-1.85)	1.80 (1.65-1.93)	0.80
Body mass (kg)	88 (78-100)	89 (82-102)	82 (74-99)	0.37
BMI (kg/m^2)	28 (25-32)	28 (25-33)	27 (17-38)	0.56
TSI (y)	17 (14-29)	18 (14-28)	14 (13-33)	0.80
Age at onset SCI (y)	30 (23-44)	30 (22-43)	30 (25-49)	0.69
PASIPD (MET h·week-1)[c]	8.0 (4.2-14.6)	9.2 (6.9-15.2)	4.7 (1.6-12.9)	0.15

Statistical comparison based on Fisher's tests and Mann-Whitney *U*-tests ($p<0.05$).

[a] Para defined as lesion <Th1; Complete defined as motor complete lesion.[31]

[b] Help from partner and/or health care professional.

[c] PASIPD < 30 used as the criterion for being physically inactive[22]; missing in $n=2$ (para: $n=1$).

Abbreviations: Para = paraplegia; Tetra = tetraplegia; AIS = American Spinal Injury Association Impairment Scale[31]; BMI = body mass index; TSI = time since injury; SCI = spinal cord injury; MET = metabolic equivalent; PASIPD = Physical Activity Scale for Individuals with Physical Disabilities[23;] Mdn (25-75th) = median (interquartile range); N.A. = Fisher's tests not applicable.

Table 2. Description of wheelchair-specific fitness: outcomes over the total group and subgroups with paraplegia and tetraplegia

	Total		**Para**		**Tetra**		**Para vs. Tetra**
	Mdn (25-75th)	*N*	Mdn (25-75th)	*n*	Mdn (25-75th)	*n*	*p*
P5-15m[a] (W)	16.1 (9.4-20.9)	23	18.3 (14.5-26.4)	17	8.0 (4.8-15.5)	6	0.02
Fiso[b] (N)	399 (284-610)	28	525 (334-677)	19	211 (128-375)	9	<0.001
POpeak (W)	40.9 (19.1-54.9)	28	51.2 (36.3-59.0)	19	18.7 (8.3-33.1)	9	<0.001
VO2peak ($L \cdot min^{-1}$)	1.26 (0.80-1.67)	28	1.52 (1.07-1.75)	20	0.68 (0.54-1.07)	8	0.01

Statistical comparison based on Fisher's tests and Mann-Whitney *U*-tests ($p<0.05$).

[a] Unilateral power output

[b] Bilateral force

Abbreviations: P5-15m = highest mean unilateral power output over successive 5-s intervals of the 15-m test; Fiso = highest mean consecutive 3s-force interval over 3 successful trials of the isometric push-test; POpeak = mean power output over last 30s of the peak test; VO2peak = highest mean 30s-oxygen uptake over peak test; Para = paraplegia; Tetra = tetraplegia; Mdn (25-75th) = median (interquartile range).

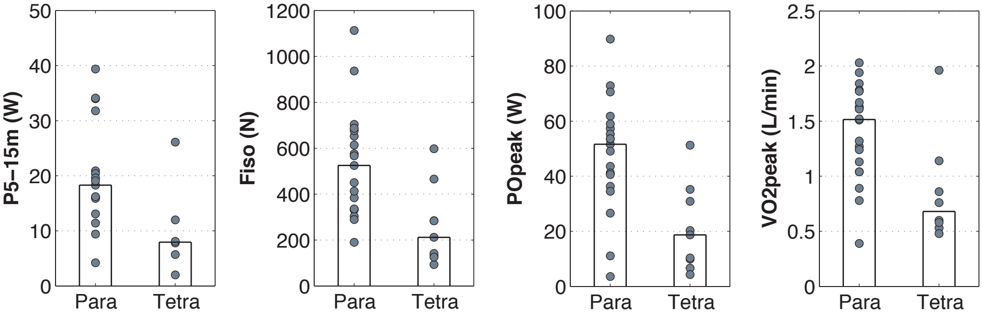

Figure 2. Description of wheelchair-specific fitness: outcomes of individual participants. Dots represent a participant's outcome. Bars represent medians of the subgroups with paraplegia and tetraplegia.

Abbreviations: see table 2.

Associations among fitness components

Correlations among outcomes of fitness components were all significant but weak (r=0.50-0.67, *p*<0.01), except for P5-15m with POpeak (*r*=0.79, *p*<0.001) (table 3, figure 3). A moderate to high correlation was found within outcomes of the peak exercise test (POpeak with VO2peak: *r*=0.89, *p*<0.001).

Table 3. Associations among fitness components: *r* among outcomes in the total group.

	POpeak			**VO2peak**			**P5-15m**		
	r	95% CI of *r*	*N*	*r*	95% CI of *r*	*N*	*r*	95% CI of *r*	*N*
VO2peak	0.89**	0.77-0.95	27	0.67*	0.35-0.85	22			
P5-15m	0.79**	0.55-0.91	22	0.50*	0.15-0.74	27			
Fiso	0.64**	0.35-0.82	28	0.64**	0.35-0.82	28	0.55*	0.17-0.79	22

*p<0.01; **p<0.001

Abbreviations: see table 2; CI = confidence interval.

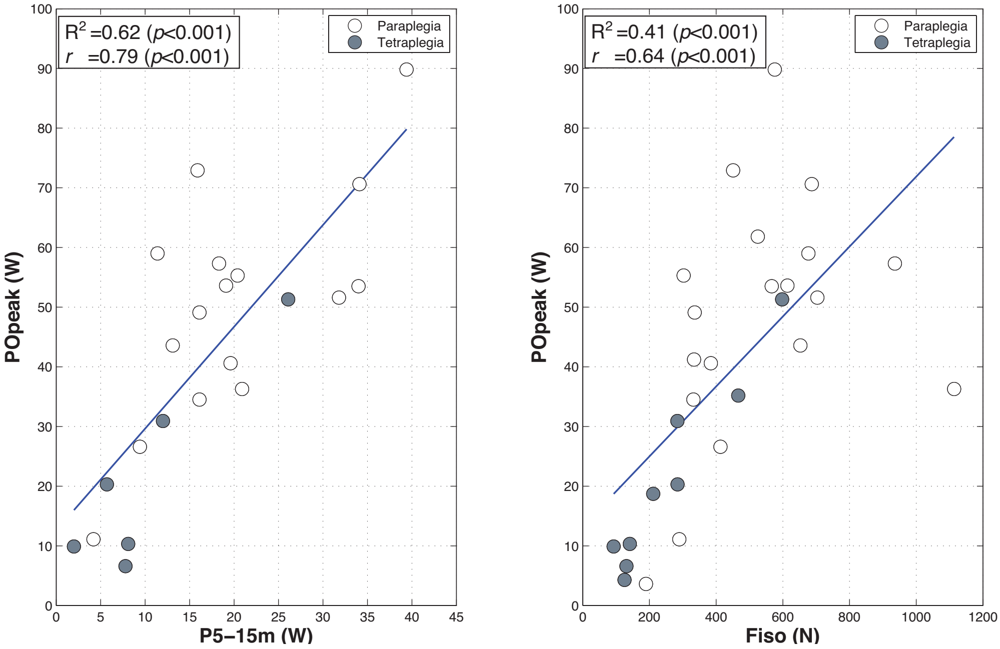

Figure 3. Associations among fitness components: illustration with scatter plots, linear regression lines, correlation coefficients (Pearson's r) and explained variance (R2) for POpeak with P5-15m and Fiso.

Abbreviations: see table 2.

DISCUSSION

The group had relatively low levels in outcomes of wheelchair-specific anaerobic work capacity, isometric strength as well as peak aerobic work capacity when compared to previous studies in people with SCI such as those on lab-based tests.[13,20,21] Variance over the group was high in all outcomes. Weak to moderate associations were found among the group's wheelchair-specific fitness components (r=0.50-0.79).

Description of wheelchair-specific fitness

Anaerobic work capacity in our study was lower than found in studies on more active people with SCI in which a similar 5 s-power output outcome was determined in lab-based Wingate tests of 20 or 30 s.[20,21] In part, this may be due to a lower resistive load in our overground-sprint test compared to the body-mass standardized load in the Wingate test. Regardless of fitness level, power output outcomes seem to be lower in wheelchair sprint tests with less resistive load.[25,32] P5-15m has only been determined in novice able-bodied people (mean: 38.1W),[25] which was much higher than the groups with paraplegia and tetraplegia in our study (about 2 to 4 times, respectively). Lower wheelchair-specific anaerobic work capacity of people with SCI has been associated with higher physical strain during activities of daily living (ADL).[33]

The group also had relatively low wheelchair-specific isometric strength, for example in comparison to a study with normative values based on active as well as inactive people with SCI performing lab-based wheelchair ergometer tests.[13] Average Fiso of the subgroups with paraplegia and tetraplegia would be placed in the lower to middle categories of this norm study.[13] Isometric strength has been determined in an inactive group with SCI performing lab-based wheelchair ergometer test, which was similarly low as in our study (on average 288N vs. 211N in our study).[11] Reduced wheelchair-specific isometric strength has not only been associated with higher strain in ADL[33], but also to increased upper-body pain.[34]

Wheelchair-specific peak aerobic work capacity was also relatively low, as exemplified by the relatively low POpeak in comparison to previous studies on people with SCI using similar outcomes.[12,13,28,35] POpeak in the subgroup with paraplegia would be ranked in the lowest category of a study on norm values of fitness of people with SCI including both active as well as inactive people.[13] Average POpeak in the subgroups with paraplegia (51W) and tetraplegia (19W) were about 30% lower compared to average POpeak determined in a systematic review of studies on fitness of people with paraplegia (74W) and tetraplegia (26W).[12] Such low POpeak values are alarming, as POpeak has been negatively associated with strain during ADL, health, participation and even quality of life.[3-5,33] Furthermore, average POpeak in our study (41W) was about equal to a group of people at the start of inpatient SCI rehabilitation (35W).[28] That group showed an increase in mean POpeak to 52W at discharge from inpatient rehabilitation, which was eventually maintained up to 5 years after discharge (56W).[28] Apparently, the people in our study never reached such a level of POpeak or, alternatively, they might not have been able to maintain it over their relatively long SCI-lifespan due to an inactive lifestyle and/or incidence of secondary health complications that can lead to reduced wheelchair-specific fitness.[7-10]

An explanation for the group's highly variable fitness levels might be found in the group's variance in factors such as age, gender, body mass, physical activity levels, time since injury, lesion level and completeness,[13] in addition to factors such as spinal deformities and history of secondary health complications.[9] This remains a topic for future study, given the cross-sectional design and relatively small sample size in our study. For example, cross-sectional studies on larger samples of inactive people with long-term SCI can be used to study the participant and lesion characteristics in multiple regression analyses.[13] The influence of activity and fitness-impairing secondary complications on fitness in people with long-term SCI can further be investigated using longitudinal designs.

Although a comprehensive review was beyond the scope of this study, it seems that physically inactive people with long-term SCI are a group in the population with SCI with relatively low wheelchair-specific anaerobic work capacity, isometric strength as well as peak aerobic work capacity. Possible causes for these low levels may lie in their inactive lifestyle and higher incidence of fitness-impairing secondary complications with increasing time since injury.[7-10]

Associations among the fitness components

Associations among the group's wheelchair-specific fitness components were lower than found in a previous study in which people with SCI performed lab-based wheelchair ergometer tests (r=0.81-0.90).[16] A possible explanation for this may be found in differences between our tests and the ergometer tests. For example, the 15 m-overground sprint test has been suggested to depend more on skill than the 30-s wheelchair ergometer sprint test, as high handrim velocities may occur in an overground sprint that are prevented in the ergometer test due to a body-mass standardized load.[25] The higher dependence on skill in the 15-m test might therefore have resulted in a relatively weak association between anaerobic work capacity and the other fitness components. This skill dependence might also be part of the explanation why associations among the fitness components in our study were lower than found in most previous studies on people with SCI performing non-wheelchair specific fitness tests such as arm cranking and strength-dynamometry tests.[17,19]

Although associations among the fitness components were weaker than in previous studies on people with SCI, they do seem stronger than what has been found in able-bodied groups.[16,18,36] In these groups, no or weaker associations were apparent among upper-body and lower-body fitness components of able-bodied people.[16,18,36] A possible explanation for this difference is that, on a group level, wheelchair users with SCI are more homogenous in their development of upper-body aerobic, lactic and alactic metabolism compared to upper-body and lower-body metabolism of able-bodied people.[37] Wheelchair users with SCI always depend on their upper-body in daily life, for example in ADL such as propelling a long distance (aerobic), ascending a ramp (lactic) and body-weight transfers (alactic).[14,37] A more homogenous development of aerobic, lactic and alactic metabolism might be specific for disability groups, as relatively strong associations were also found among lower-body fitness components of people with cerebral palsy compared to able-bodied people.[18] Another explanation for the difference with able-bodied people might be in coordination problems and low muscular strength levels seen in groups with tetraplegia and cerebral palsy.[18] Low strength and coordination levels could limit oxygen transport during a peak test due to impediment of local muscle blood flow, leading to a relatively strong association between peak aerobic work capacity and strength.[17]

Anthropometrics such as body mass have been suggested to influence associations among fitness components.[16] Therefore, we checked whether correlations were different among outcomes divided by body mass and found that correlations were similar to those shown in table II (for example r=0.83 for POpeak·kg^{-1} with P5-15m·kg^{-1} vs. r=0.79 for POpeak with P5-15m). Other possible influences on associations among fitness component require further study in a larger sample, for example on heterogeneity over a group in fitness level, lesion characteristics and physical activity level.[17,18,27]

Implications and limitations

The low fitness levels in our study imply that physically inactive people with long-term SCI are a group in the population with SCI that is in specific need of interventions to improve wheelchair-specific fitness. Low-intensity wheelchair exercise training may be such an intervention, since it might lead to less dropout and upper-body overuse in a deconditioned group.[22] Furthermore, the low fitness levels in our study suggest that rehabilitative aftercare models are needed to prevent low wheelchair-specific fitness in people with long-term SCI.[38] Systematic monitoring of wheelchair-specific fitness after inpatient rehabilitation could be part of such a model,[6] since it can support maintenance of fitness.[1] Maintaining wheelchair-specific fitness in people with long-term SCI can help to support health, participation in society and quality of life.[3-5,9] Monitoring can also help to target those in most need of interventions; this need may differ between inactive people with long-term SCI, as indicated by the high variance in fitness in our study.

For systematic monitoring, tests feasible for use in rehabilitation centers are recommended,[15] such as the tests used in our study. The relatively weak associations among fitness components imply that separate tests are needed to assess each component when monitoring wheelchair-specific fitness of inactive people with long-term SCI. For example, it does not seem possible to predict performance on a peak wheelchair exercise test using the 15-m test or isometric-push test due to the weak correlations among outcomes of the tests. However, it does seem possible to use P5-15m for a rough estimate of POpeak, which can be used for the purpose of individualizing power output increments in a peak wheelchair exercise test. For example, estimating that an inactive person with long-term SCI needs only small increments in the peak test can help to reach peak performance, which was difficult for some participants with tetraplegia in our study (respiratory exchange ratio of the subgroup with tetraplegia on average 0.88). Whether peak performance was reached during the 15-m test and isometric-push remains a topic for future study, as parameters indicating peak performance are not yet available for these tests.

A limitation of our study might be generalization to the inactive population with long-term SCI given the relatively small sample size and possibility of selection bias. Participants voluntarily took part in our study upon invitation, based on archival information of rehabilitation centers and a patient organization.[22] Perhaps people with somewhat higher fitness levels did not participate due to work or social obligations, while people with very low fitness levels might have experienced too many barriers to visit the rehabilitation center and perform exercise tests.[39]

A set-up was chosen with participants using their own wheelchair, since it was expected that wheelchair configuration would be optimal and support reaching peak performance in the tests. However, a limitation of this type of testing is that wheelchair configuration differs between participants. For example, variation between participants in horizontal axle position could have influenced wheelchair propulsion in the 15-m test and peak test,[40] while results in the isometric-push test might have been influenced by variation in the ratio between handrim and wheel radii. Furthermore, it remains unclear whether results on peak aerobic work capacity were influenced by between-participant variation in peak inclination angle, as varying inclination angles are suggested to influence propulsion technique.[40]

Care has been recommended when interpreting P5-15m as an outcome of wheelchair-specific work capacity given the role of wheelchair skill in the 15-m test.[25] Still, nearly all participants were able to perform the 15-m test and reached P5-15m in the first five seconds of the test, including those with the lowest fitness levels. This suggests that the additional weight of the instrumented wheels did not limit performance of participants with the lowest fitness levels, which was also indicated by the non-significant difference in time over the 15 m-sprint with and without the instrumented wheels (respectively 8.2s [7.2-10.8] vs. 8.1s [7.1-9.9], $Z=-1.25$ $p=0.21$; times recorded as part of wheelchair skills tests in the RCT[22]).

CONCLUSION

It seems that physically inactive people with long-term SCI are a group in the population with SCI with relatively low wheelchair-specific anaerobic work capacity, isometric strength as well as peak aerobic work capacity, implying they are a group in the SCI population in specific need of interventions to improve wheelchair-specific fitness. The weak to moderate associations among their fitness components imply that separate tests should be used for each component when monitoring wheelchair-specific fitness with the 15-m test, isometric-push test and peak exercise test.

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Chapter 6

Low-intensity wheelchair exercise in inactive people with long-term spinal cord injury:

a randomized controlled trial on fitness, wheelchair skill performance and physical activity levels

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ABSTRACT

Aim: To investigate whether low-intensity wheelchair exercise training leads to improved wheelchair-specific fitness, wheelchair skill performance and physical activity levels of physically inactive people with long-term spinal cord injury (SCI).

Design: Multicenter, non-blinded randomized controlled trial (RCT) on an exercise group (n=14) and a non-exercise control group (n=15) with repeated measurements at baseline (T1), 8 weeks (T2) and 16 weeks (T3).

Participants: Physically inactive manual wheelchair users with SCI and a time since injury > 10y (22 men, 20 with paraplegia, median age: 57y).

Exercise training: Supervised wheelchair treadmill propulsion in a rehabilitation center (30-40% heart rate reserve or rate of perceived exertion of 1-3, 16 weeks, two times per week, 30 min per session).

Primary outcomes: Participants performed tests in their own wheelchairs. Fitness was determined as the highest 5 s-power output over 15 m-overground sprinting (P5-15m); the highest 3 s-isometric push-force; mechanical efficiency and oxygen uptake over two submaximal exercise blocks; and peak power output and peak oxygen uptake over a peak exercise test. Skill was determined as the performance time score, ability score and strain score over a wheelchair circuit. Activity was determined as odometer-based weekly propulsion and a questionnaire-based activity score.

Primary results: Exercise adherence was on average 97%. Three participants stopped training after 3-5 weeks due to kidney stones or lack of time/motivation. Changes in outcomes over time were not significantly different between the exercise and control group, except for the exercise group's improvements in P5-15m (+14% vs. -4%, $p=0.01$, $r_U=0.70$) and performance time score (-7% vs. 0%, $p=0.03$, $r_U=0.49$).

Conclusions: The low-intensity wheelchair training seemed to have limited effect on fitness, skill and activity of inactive wheelchair users with long-term SCI, possibly due to a too low exercise frequency. Alternative interventions need to be developed, for example by studying feasible higher-frequency low-intensity wheelchair training.

INTRODUCTION

Wheelchair-specific fitness is often low in people with spinal cord injury (SCI) due to muscle paralysis and an inactive wheelchair-bound life.[1-3] Lower wheelchair-specific fitness, defined as physical fitness measured during manual wheelchair propulsion tests, has not only been associated with reduced wheelchair skill performance and physical activity levels,[1,4] but also with impaired health, participation in society and quality of life.[5-7] Low wheelchair-specific fitness is especially expected in people with long-term SCI given their relatively high incidence of secondary health complications such as pressure sores and upper-body pain,[8,9] which are suggested to lead to reduced wheelchair-specific fitness.[10]

Moderate-to-vigorous exercise has been shown effective in improving wheelchair-specific fitness in people with SCI.[11] Wheelchair propulsion exercise is an accessible exercise mode specific for improving wheelchair-specific fitness. However, moderate to vigorous-intensity wheelchair exercise may lead to dropout, low adherence and upper-body overuse in inactive or deconditioned populations, which is suggested not to occur in low-intensity wheelchair exercise.[12,13] Low-intensity exercise using the lower body has already been shown effective in improving fitness of inactive or deconditioned people such as older adults and cancer survivors (25-40% heart rate reserve [HRR], 9-40 weeks, 3-5 times per week, 14-45 min per session).[14-16] Promising results have also been found in preliminary studies on low-intensity wheelchair exercise performed by able-bodied novices (treadmill propulsion at 30-35% HRR for seven weeks, three times per week, 30 or 70 min per session).[17-19] Large improvements in wheelchair-specific fitness were found, for example in outcomes of anaerobic work capacity (31%), peak work capacity (34%) and submaximal fitness (15-23%), while upper-body overuse symptoms did not worsen 18. However, it has not yet been investigated whether these promising effects also occur in inactive wheelchair users with long-term SCI.

The aim of our study was to investigate whether low-intensity wheelchair exercise leads to improved wheelchair-specific fitness (anaerobic work capacity, isometric strength, submaximal fitness and peak aerobic work capacity), wheelchair skill performance and physical activity levels of inactive wheelchair users with long-term SCI. A multicenter randomized controlled trial (RCT) was conducted, in which a non-exercising control group was compared to a group performing a 16-week exercise training consisting of wheelchair treadmill propulsion at 30-40% HRR or its equivalent in rate of perceived exertion (RPE), two times per week, 30 min per session. Improvements were expected in the exercise group, in contrast to the control group, as based on above-mentioned research on able-bodied populations performing low-intensity exercise.[13-19]

METHODS

Design

The study was a non-blinded RCT in two rehabilitation centers on an exercise group and a non-exercising control group with repeated measurements in both groups at baseline (T1), eight weeks after baseline (T2) and 16 weeks after baseline (T3). The exercise group followed a 16-week training in a rehabilitation center, while the control group was asked to refrain from lifestyle changes and was offered an exercise training after completion of the study. A standardized measurement procedure in the rehabilitation centers consisted of wheelchair-specific exercise tests and a wheelchair skill circuit .[4,20-22] In addition, measurements were conducted on physical activity levels in the community over the week after the exercise tests.[23,24] A detailed description of the design of the study is given elsewhere.[24]

Ethical approval was obtained from committees of the VU University Medical Center and the participating rehabilitation centers.[24] The study was registered in the Dutch Trial Register (www.trialregister.nl, NTR3037).

Participants

Participants were physically inactive manual wheelchair users with long-term SCI (table 1). Paramedic research assistants preselected people potentially eligible for participation from archives of the rehabilitation centers and the Dutch SCI patient organization (figure 1). Participants were included after voluntary agreement, provision of written informed consent and eligibility screening. Inclusion criteria[24] comprised time since injury > 10y and an inactive lifestyle as defined by a score < 75th percentile of a Dutch SCI cohort on the Dutch Physical Activity Scale for Individuals with Physical Disabilities (PASIPD).[23] Exclusion criteria comprised cardiovascular contraindications for exercise testing[25]; musculoskeletal complaints contraindicating manual wheelchair propulsion; mental problems or progressive disease expected to lead to dropout; planning to change lifestyle; and insufficient mastery of Dutch language.[24] To increase sample size, small adjustments were made in original selection criteria (age ≤ 66 vs. ≤ 65, and age at onset SCI ≥ 12y vs. ≥ 18y).[24] After inclusion, participants were randomized by the investigators using a blocked randomization procedure with sealed envelopes (figure 1).

Exercise training

The exercise group performed a 16-week low-intensity wheelchair exercise training, consisting of treadmill propulsion at 30-40% HRR or its equivalent in RPE, two times per week, 30 min per session.[24] The RPE equivalent was used in participants with an impaired autonomic nervous system and was 1-3 on a 10-point scale.[26,27] Exercise took place under supervision of a trained paramedical research assistant in one of the two centers. To maintain equal relative intensity, power output was adjusted by changing treadmill velocity or weight in a pulley system.[24] Protocols consisted of 18 or 24 min of exercise in the first four sessions and 30 min of exercise in the subsequent 28 sessions (total exercise: 924 min). Dependent on baseline fitness levels, rest intervals in the protocols differed between participants (no rest or rest intervals of 1-2 min).[24] Adherence, overuse symptoms and relative intensity were logged using parameters shown in table 2 and 3.

Outcomes

Wheelchair-specific fitness

Wheelchair-specific fitness was assessed based on anaerobic work capacity, isometric strength, submaximal fitness and peak aerobic work capacity. Exercise tests were conducted in participant's own wheelchair using a standardized procedure, which is described in more detail elsewhere.[24]

Anaerobic work capacity was determined as the highest mean unilateral power output over successive 5 s-intervals in a 15 m-overground sprint test (P5-15m [W]), as validated in a preliminary study on able-bodied people.[28] The test was conducted with the participant's rear wheels replaced with instrumented wheels used to determine power output (OptiPush, MAX Mobility, Antioch, USA).

Isometric strength was determined as the highest mean consecutive 3 s-force interval over three successful trials of an isometric-push test (Fiso [N]).[24,29] In the test, participants performed a maximal isometric-wheelchair push for 5 s with both hands on top of their handrim, while their wheelchair was attached via a rope and a force transducer to the wall.

Submaximal fitness was determined as mean mechanical efficiency (%) and oxygen uptake ($L \cdot min^{-1}$) over the last 30 s of two three-min submaximal exercise blocks,[21] which were performed on a treadmill at different inclination angles (0% or 0.5-0.6%). The protocol was similar to that in previous SCI cohort studies.[20,21] Predetermined treadmill velocity was <0.56, 0.56, 0.83 or 1.11 $m \cdot s^{-1}$. Reference for submaximal performance was respiratory exchange ratio (RER) < 1.00, as assessed based on the highest 30 s-RER over each block.

Peak aerobic work capacity was determined as mean power output over the last 30 s of a peak exercise test on a treadmill (POpeak), in addition to the highest mean 30 s-oxygen uptake (VO2peak) over the test.[21] The inclination angle of the treadmill increased every minute by about 0.3 degrees until the participant could no longer maintain treadmill velocity, similar to a protocol previously used in SCI cohort studies.[4,20,22] Treadmill velocity was identical to that in the submaximal blocks. Reference for peak performance was RER > 1.00, as assessed based on the highest 30 s-RER of the test.

Wheelchair skill performance

Wheelchair skill performance was determined as performance time score, ability score and strain score over the Wheelchair Circuit, a validated battery of eight tests used in previous SCI cohort studies.[4,7,21] All tests were performed in a participant's own wheelchair. The performance time score was time over an overground 15 m-sprint and figure-of-eight circuit. The ability score depended on how many of the eight tests could be performed (range: 0-8). The strain score was mean % HRR over 10 s-treadmill propulsion on a 3% and 6% slope.

Physical activity levels

Physical activity levels were determined as distance propelled in a week in the community based on an odometer placed on the participant's daily wheelchair (weekly propulsion [km]),[24] in addition to the score on the Dutch PASIPD-questionnaire (metabolic equivalent [MET] h·week^{-1} on a 0-180 scale.[23]

Exercise training

Absolute intensity during the exercise training was determined as mean power output and velocity over the last exercise block of each session. Overuse symptoms were determined as mean upper-body local perceived discomfort on a 0-10 scale over the last 30 s of exercise in a session,[24,30] in addition to session RPE on a 0-10 scale assessed seven min after a session.[24,26] Participant's perceived effects of the training was determined as effects on fitness, wheelchair skill performance and physical activity rated on five-point scales (1=worsened a lot; 2=somewhat worsened; 3=not changed; 4=somewhat improved; and 5=improved a lot).

Statistics

Required sample size for both subgroups was estimated to be n=18.[18,24,27] Descriptive statistics of participant characteristics and outcomes were determined over the control and exercise group. Many outcomes were not normally distributed so analyses were based on non-parametric tests. Significance was set at $p<0.05$ for all tests.

To detect possible differences between the groups at baseline, participant characteristics and outcomes at T1 were compared using Fisher's tests or Mann-Whitney U-tests. Effects of the training were analyzed by comparing the exercise and control group on changes in outcomes over time. For each participant, difference scores (ΔT2-T1 and ΔT3-T1) were calculated for fitness, skill and activity. These difference scores were compared between the exercise and control group using Mann-Whitney U-tests. Effect sizes of these comparisons were based on non-parametric rank order correlations ($r_U = 1 - [2U - n_{exercise} * n_{control}]$), which represented how many scores in one group were higher than those in the other group.[31] A negative sign was added when the comparison favored the control group (opposite of our hypotheses). Absolute intensity and overuse symptoms during the training were compared among the fifth, 16th and last training session using Friedman's ANOVA and post-hoc Bonferroni-corrected Wilcoxon tests.

The intention-to-treat principle was applied to all analyses: outcomes of participants were included who stopped training but still performed measurements. Outcomes of these participants were excluded in exploratory analyses identical to those describe above.

RESULTS

Participants

About 200 potentially eligible people were invited for participation between October 2011 and October 2013 (figure 1). Twenty-nine eligible people agreed to participate (table 1) and were randomly allocated to the exercise group (*n*=14) or the control group (*n*=15).

Table 1. Participant characteristics at baseline.

	Total	**Exercise**	**Control**	**Ex vs. Con**
	N	*n*	*n*	*p*
Group size	29	14	15	
Men / women	22/7	12/2	10/5	0.39
Paraplegia / tetraplegia[a]	20/9	9/5	11/4	0.70
Complete / incomplete[a]	20/9	10/4	10/5	1.00
	Mdn (25-75th)	**Mdn (25-75th)**	**Mdn (25-75th)**	
Age (y)	57 (45-63)	55 (42-64)	57 (46-62)	0.72
Height (m)	1.80 (1.69-1.86)	1.80 (1.71-1.87)	1.78 (1.68-1.86)	0.53
Body mass (kg)	88 (78-100)	88 (81-99)	88 (73-100)	0.62
BMI (kg/m^2)	28 (25-32)	28 (25-30)	27 (23-33)	0.59
TSI (y)	17 (14-29)	16 (13-29)	20 (14-31)	0.35
Age at onset SCI (y)	30 (23-44)	30 (25-49)	31 (20-44)	0.59
PASIPD (MET $h \cdot week^{-1}$)[b]	8.0 (4.2-14.6)	6.4 (1.7-9.0)	10.6 (6.9-17.4)	0.07

Statistical comparison based on Fisher's tests and Mann-Whitney U-tests ($p<0.05$).

[a] Para defined as lesion <Th1; Complete defined as motor complete lesion.[26]

[b] PASIPD < 30 used as an inclusion criterion[24]; n=2 missing in total and exercise group.

Abbreviations: Mdn (25-75th) = median (interquartile range); BMI = body mass index; TSI = time since injury; SCI = spinal cord injury; PASIPD = Physical Activity Scale for Individuals with Physical Disabilities[23]; MET = metabolic equivalent.

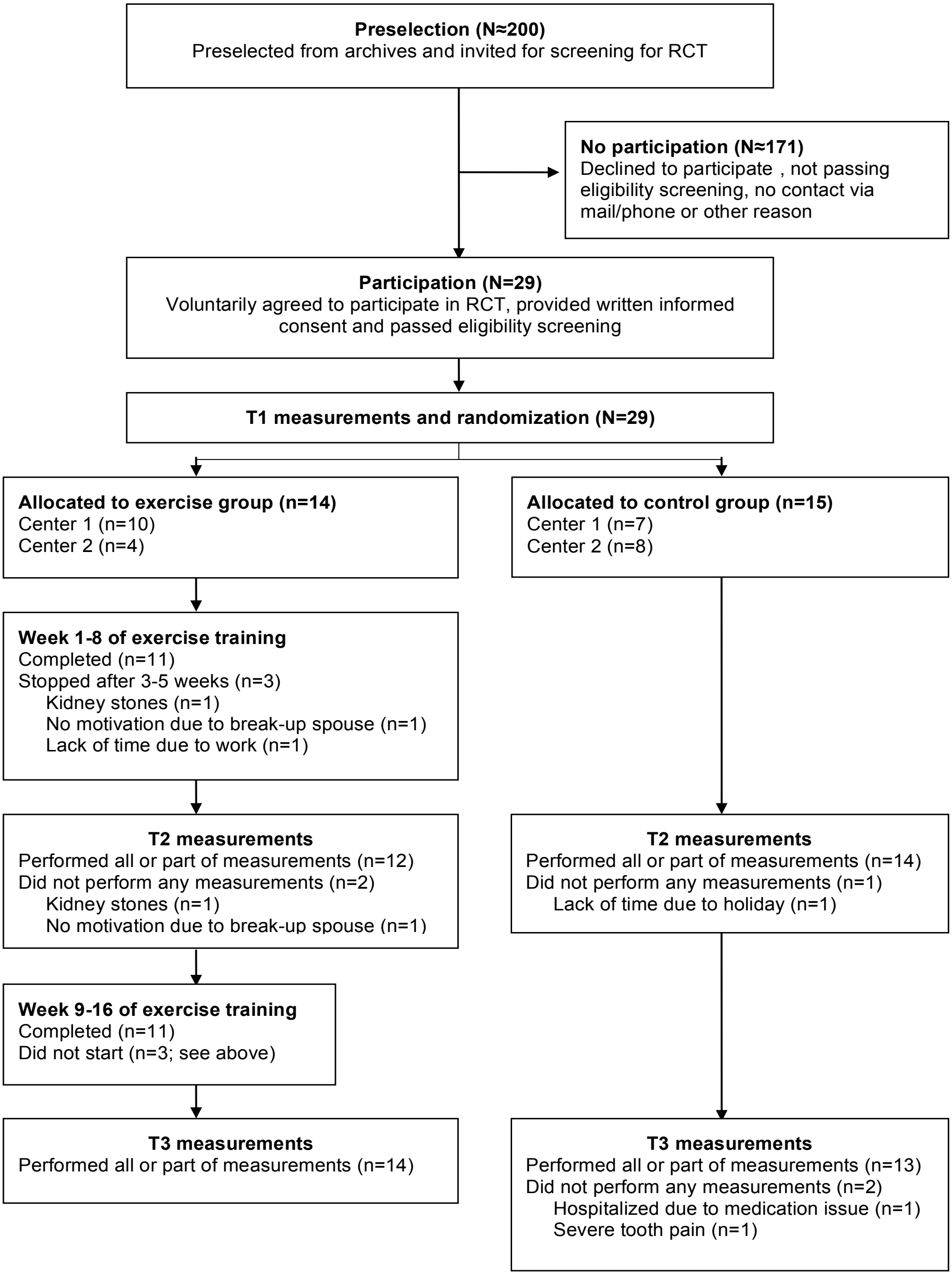

Figure 1. CONSORT flow diagram: inclusion, randomization, allocation, follow-up and analysis. It was estimated that about three in four people eligible for the study declined to participate.

Abbreviations: SCI = spinal cord injury; RCT = randomized controlled trial; instr. = instrumented wheel; T1 = baseline measurements; T2, T3 and T4: measurements eight, 16 and 42 weeks after baseline, respectively.

Exercise training

Exercise adherence over the training was on average 97% (table 2). Participants completed on average 894 min of exercise over 31 sessions in 17 weeks (table 2). Three participants stopped training after 3-5 weeks (table 2). Reasons for stopping were kidney stones and lack of time or motivation (figure 1).

Table 2. Exercise training: adherence and relative intensity in the exercise group.

	Total (*n*=14)	**Completed** (*n*=11)	**Stopped** (*n*=3)
Adherence	Mdn (range)	Mdn (range)	Mdn (range)
Exercise adherence[a] (%)	97 (22-100)	100 (78-100)	22 (22-28)
Sessions performed (#)	31 (7-32)	32 (25-32)	7 (7-9)
Weeks (#)	17 (5-18)	17 (16-18)	5 (5-7)
Total min exercise	834 (174-924)	894 (423-924)[b]	174 (174-233)
Relative intensity			
Mean % HRR[c]	38 (34-43)	38 (36-42)	No Mdn[c] (34-43)
Mean RPE	2 (0-4)	2 (0-4)	2 (1-3)

[a] Attended sessions divided by 32 planned sessions.
[b] Two participants completed 32 sessions, but their motor abilities were too limited for 30 min per session (protocols therefore individualized to 423 or 766 total min exercise).
[c] Based on n=8 for the total group (completed: n=6 and stopped: n=2). In others, HRR not used due to an impaired autonomic nervous system.

Abbreviations: Mdn = median; HRR = heart rate reserve; RPE = rate of perceived exertion on a 0-10 scale.[24,27]

Table 3. Exercise training: absolute intensity and overuse symptoms in the group that completed the training (*n*=11).

	Fifth session[a]	**16th session**	**Last session**		Friedman's ANOVA
Absolute intensity	Mdn (range)	Mdn (range)	Mdn (range)	*n*	*p*
Power output (W)	11.1 (1.8-16.4)	12.0 (4.3-18.9)	14.0 (2.9-21.4)	11	0.005*
Velocity ($m \cdot s^{-1}$)	0.7 (0.1-1.1)	0.7 (0.3-1.1)	0.9 (0.2-1.1)	11	0.012**
Overuse symptoms					
Upper-body LPD	11 (0-54)	9 (0-44)	8 (0-44)	11	0.102
Session RPE	2 (0-4)	2 (0-4)	2 (0-3)	9	0.135

[a] First session consisting of 30 min of exercise.
*Significant overall effect (p<0.05) with significant differences in post-hoc Wilcoxon tests (p<0.05/3): fifth > 16th session and fifth > last session.
**Significant overall effect (p<0.05) with no significant differences in post-hoc Wilcoxon tests (p>0.05/3).

Abbreviations: Mdn = median; LPD = mean upper-body local perceived discomfort on a 0-10 scale over the 30 s of exercise a session[24,31]; session RPE = rate of perceived exertion on a 0-10 scale assessed seven min after the session.[24,27]

Outcomes at baseline (T1)

Outcomes could not be collected in all participants at T1 due to technical and participant-related reasons. For example, missing P5-15m occurred due to the technical problems or due to the instrumented wheels not fitting the participants' wheelchair; strain score due to participants not being able to perform the 6% slope or due to unreliable heart rate measurements in those with an impaired autonomic nervous system; and weekly propulsion due to participants' unwillingness to use the odometer. Resulting sample sizes varied from n=8-14 in the exercise group and n=8-15 in the control group for the different outcomes at T1 (tables 4-6).

Participant characteristics and outcomes at T1 did not differ significantly between the exercise and control group (tables 1, 4-6). Variance was high in outcomes over the exercise as well as the control group, as indicated by the group descriptives (table 4 and 5) and range over the group (figure 2 and 3).

Outcomes over the 16-week period (ΔT2-T1 and ΔT3-T1)

Outcomes could not be collected in all participants at T2 and T3 due to reasons similar to those at T1 and incidence of secondary health complications (figure 1). Resulting sample sizes for ΔT2-T1 and ΔT3-T1 are shown in table 4-6.

Wheelchair-specific fitness

Difference scores of fitness were not significantly different between the exercise and control group (table 4), except for ΔT3-T1 of P5-15m (+14% in exercise group vs. -4% in control group, p=0.01, r_U=0.70). Significance was almost reached in the comparison between the groups on ΔT2-T1 of MEsub2 (p=0.05, r_U=0.56), but this was not found in ΔT3-T1 (p=1.00 and r_U=0.02). Similar results were found in the exploratory analyses excluding outcomes of participants that stopped training (table S1). Observations in plots with outcomes of individual participants also indicated that the training did not improve fitness: participants showed little to no change in any of the outcomes over time (figure 2).

Wheelchair skill performance

Difference scores of skill were not significantly different between the exercise and control group (table 4), except for ΔT3-T1 of performance time score (time reduced by 7% in the exercise group vs. 0% in control group, p=0.03, r_U=0.49). Significance was almost reached in the comparison between the groups on ΔT2-T1 of the ability score (p=0.09, r_U=0.40), but this was not found in ΔT3-T1 (p=0.49, r_U=-0.16). Similar results were found in the exploratory analyses (table S2). Observations in outcomes of individual participants indicated that only two participants in the exercise group showed a clear improvement in outcomes over time (figure 3).

Table 4. Wheelchair-specific fitness: outcomes at baseline (T1) and changes in outcomes over time (ΔT2-T1 and ΔT3-T1) compared between the exercise and control group.

		Exercise (*n*=14)			**Control** (*n*=15)			**Statistical comparison**		
		Mdn	25-75th	*n*	Mdn	25-75th	*n*	U	*p*	Effect size (r_u)
POpeak^a (W)	T1	47.5	10.2-54.5	14	38.4	25-57	14	94.0	0.87	N.A.
	ΔT2-T1	0.3	-4.9-4.2	11	0.4	-2.5-3.0	11	54.0	0.70	-0.11
	ΔT3-T1	-0.5	-7.8-4.4	12	0.1	-5.6-4.7	12	69.0	0.89	-0.04
VO2peak^a (L·min^{-1})	T1	1.51	0.59-1.77	13	1.14	0.89-1.61	15	90.0	0.75	N.A.
	ΔT2-T1	-0.01	0.08-0.15	10	0.01	-0.17-0.07	11	48.0	0.65	-0.13
	ΔT3-T1	-0.04	0.23-0.08	12	-0.08	-0.21-0.07	13	75.0	0.89	0.04
P5-15m (W)	T1	14.5	7.9-24.3	12	16.2	11.9-20.9	11	49.0	0.32	N.A.
	ΔT2-T1	1.5	-0.7-2.6	9	-0.1	-1.4-1.3	9	27.0	0.26	0.33
	ΔT3-T1	2.0	0.5-5.0	10	-0.7	-2.8-0.2	10	15.0	0.01*	0.70
Fiso (N)	T1	516	179-659	14	335	284-538	14	84.0	0.54	N.A.
	ΔT2-T1	-57	-87-9	12	-36	-69--3	11	56.0	0.57	-0.15
	ΔT3-T1	-27	-141-11	14	-51	-90--15	12	70.0	0.49	0.17
MEsub1^b (%)	T1	4.9	3.5-6.1	11	4.1	3.4-5.4	14	64.0	0.50	N.A.
	ΔT2-T1	0.5	-0.8-1.4	9	-0.2	-0.9-0.0	9	23.0	0.14	0.43
	ΔT3-T1	0.1	-0.9-0.6	11	0.2	-0.8-0.8	12	56.0	0.57	-0.15
MEsub2^b (%)	T1	5.2	3.4-6.4	11	4.6	3.3-6.3	14	66.0	0.57	N.A.
	ΔT2-T1	0.6	-0.2-1.8	9	-0.5	-1.4-0.2	9	18.0	0.05	0.56
	ΔT3-T1	0.1	-0.5-0.6	11	0.0	-0.8-0.8	12	65.0	1.00	0.02
VO2sub1^b (L·min^{-1})	T1	0.70	0.54-0.83	11	0.65	0.52-0.81	15	76.0	0.76	N.A.
	ΔT2-T1	-0.06	-0.11--0.06	10	-0.04	-0.10--0.03	11	51.0	0.81	0.07
	ΔT3-T1	-0.05	-0.09-0.06	11	-0.01	-0.14-0.07	13	69.0	0.91	0.03

Table continues on next page

Table 4 continued. Wheelchair-specific fitness: outcomes at baseline (T1) and changes in outcomes over time (ΔT2-T1 and ΔT3-T1) compared between the exercise and control group.

VO2sub1[b] (L·min^{-1})	T1	0.76	0.55-0.95	11	0.68	0.61-0.86)	15	76.0	0.76	N.A.
	ΔT2-T1	-0.08	-0.11--0.01	10	-0.07	-0.09-0.13	11	44.5	0.47	0.19
	ΔT3-T1	-0.04	-0.10-0.04	11	-0.06	-0.08-0.05	13	69.0	0.91	-0.03

Statistical comparison based on Mann-Whitney U-tests ($p<0.05$). Effect sizes were rank order correlations [32], to which a negative sign was added when the comparison favored the control group (r_U).

[a] Respiratory exchange ratio at T1, T2 and T3 in the peak test: median>1.00 and no significant differences between the groups (table S4).

[b] Respiratory exchange ratio at T1, T2 and T3 in the submaximal blocks: median<1.00 and no significant differences between the groups (table S4).

Abbreviations: Mdn = median; 25-75th = interquartile range; U = Mann-Whitney U; r_U = rank order correlation[32]; T1, T2 and T3 = respective measurements at baseline, after 8 weeks and 16 weeks; N.A. = not applicable; POpeak = mean power output over last 30s of the peak test; VO2peak = highest mean 30s-oxygen uptake over peak test; P5-15m = highest mean unilateral power output over successive 5-s intervals of the 15-m test; Fiso = highest mean consecutive 3s-force interval over 3 successful trials of the isometric push-test; MEsub1, MEsub2, VO2sub1 and VO2sub2 = mean mechanical efficiency and oxygen uptake over last 30s of the two submaximal blocks.

Table 5. Wheelchair skill performance: outcomes at baseline (T1) and changes in outcomes over time (ΔT2-T1 and ΔT3-T1) compared between the exercise and control group.

		Exercise (*n*=14)			**Control** (*n*=15)			**Statistical comparison**		
		Mdn	25-75th	*n*	Mdn	25-75th	*n*	U	*p*	Effect size (r_u)
Performance time (s)	T1	20.5	14.5-28.3	14	17.6	16.3-20.9	15	95.0	0.56	N.A.
	ΔT2-T1	-0.9	-1.6--0.3	12	-0.1	-1.5-0.6	13	55.0	0.26	0.29
	ΔT3-T1	-1.4	-3.9--0.4	14	0.0	-1.3-1.0	13	46.5	0.03*	0.49
Ability score (0-8 scale)	T1	6.8	3.9-8.0	14	7.5	6.5-8.0	15	80.0	0.29	N.A.
	ΔT2-T1	0.0	0.0-0.8	12	0.0	-0.5-0.0	13	46.5	0.09	0.40
	ΔT3-T1	0.0	-0.1-1.0	14	0.0	0.0-0.0	13	76.5	0.49	-0.16
Strain score (% HRR)	T1	33	25-42	8	26	-2-40	8	27.0	0.65	N.A.
	ΔT2-T1	-10	-14-36	4	3	-20-44	6	11.0	1.00	0.08
	ΔT3-T1	1	-10-24	6	1	-22-49	5	14.0	1.00	-0.07

Statistical comparison: see table 4 for explanations.

Abbreviations: HRR = heart rate reserve; other abbreviations: see table 4.

Table 6. Physical activity levels: outcomes at baseline (T1) and changes in outcomes over time (ΔT2-T1 and ΔT3-T1) compared between the exercise and control group.

		Exercise (*n*=14)			**Control** (*n*=15)			**Statistical comparison**		
		Mdn	25-75th	*n*	Mdn	25-75th	*n*	U	*p*	Effect size (r_u)
Weekly propulsion (km^{-1})	T1	9.0	2.7-16.3	10	15.9	5.2-37.0	13	47.0	0.28	N.A.
	ΔT2-T1	1.8	-0.3-2.6	7	0.5	-5.9-6.6	9	31.0	1.00	0.02
	ΔT3-T1	-0.6	-4.7-0.0	8	1.6	-25.3-8.0	9	23.00	0.24	-0.36
PASIPD (MET h·$week^{-1}$)	T1	6.4	1.7-9.0	12	10.6	6.9-17.4	15	52.0	0.07	N.A.
	ΔT2-T1	0.6	-3.1-11.4	10	-1.4	-7.2-5.5	11	46.0	0.56	0.16
	ΔT3-T1	1.2	-5.8-2.9	8	0.6	-5.4-7.9	13	48.00	0.80	0.08

Statistical comparison: see table 4 for explanations.

Abbreviations: PASIPD = Physical Activity Scale for Individuals with Physical Disabilities[23]; MET = metabolic equivalent; other abbreviations: see table 4.

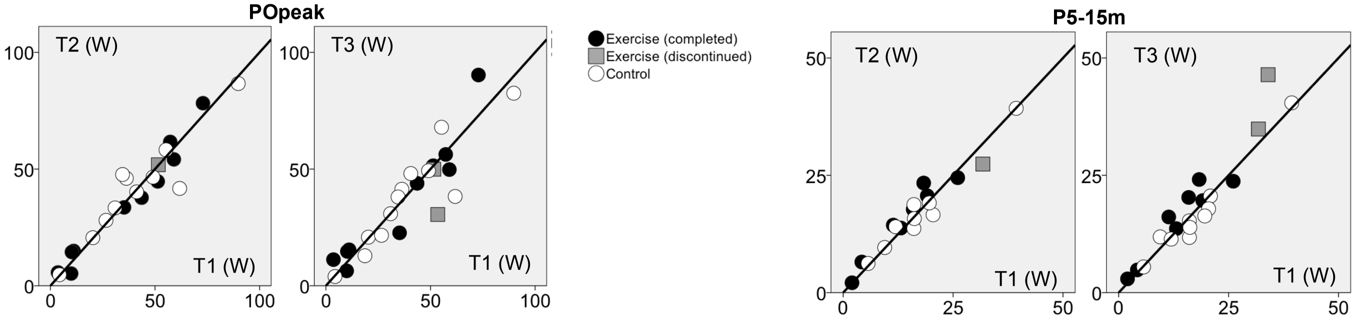

Figure 2. Wheelchair-specific fitness: POpeak (left graphs) and P5-15m of individual participants at T1 plotted against T2 and T3. Diagonal line serves as a reference: for example, when a participant's outcome increased from T1 to T2, the data point will fall above the diagonal line. Legend: individuals completing the exercise program (black dots), discontinuing the program after 3-5 weeks (grey squares) or being part of the non-exercising control group (white dots).
Abbreviations: see table 2.

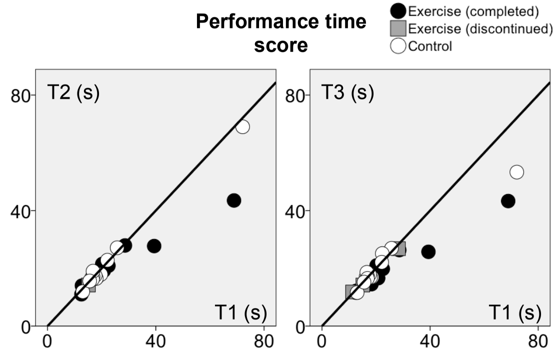

Figure 3.
Wheelchair skill performance: performance time of individual participants at T1 plotted against T2 and T3.
Diagonal line and legend: see figure 2 for explanations.

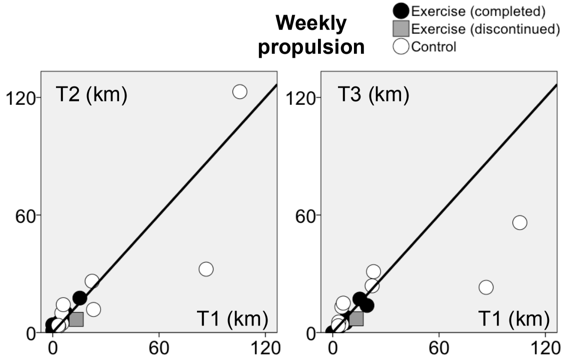

Figure 4.
Physical activity level: weekly propulsion of individual participants at T1 plotted against T2 and T3.
Diagonal line and legend: see figure 2 for explanations.

Table S1. Exploratory analyses excluding participants that stopped training (wheelchair-specific fitness).

		Exercise (*n*=14)			**Control** (*n*=15)			**Statistical comparison**		
		Mdn	25-75th	*n*	Mdn	25-75th	*n*	U	*p*	Effect size (r_u)
POpeak[a] (W)	T1	43.6	10.2-57.3	11	38.4	25-57	14	73.0	0.85	N.A.
	ΔT2-T1	0.2	-5.1-4.2	10	0.4	-2.5-3.0	11	50.0	0.78	-0.09
	ΔT3-T1	0.2	-5.0-5.2	10	0.1	-5.6-4.7	12	56.0	0.82	0.07
VO2peak[a] (L·min^{-1})	T1	1.27	0.58-1.77	11	1.14	0.89-1.61	15	80.0	0.91	N.A.
	ΔT2-T1	0.01	-0.05-0.17	9	0.01	-0.17-0.07	11	40.0	0.50	0.19
	ΔT3-T1	0.00	-0.09-0.10	10	-0.08	-0.21-0.07	13	49.0	0.34	0.25
P5-15m (W)	T1	13.1	6.2-18.7	9	16.2	11.9-20.9	11	30.0	0.15	N.A.
	ΔT2-T1	1.7	0.2-2.8	8	-0.1	-1.4-1.3	9	18.0	0.09	0.50
	ΔT3-T1	0.8	0.5-4.6	8	-0.7	-2.8-0.2	10	15.0	0.03*	0.63
Fiso (N)	T1	466	190-652	11	335	284-538	14	67.0	0.61	N.A.
	ΔT2-T1	-69	-88-16	11	-36	-69--3	11	48.0	0.44	-0.21
	ΔT3-T1	-34	-285-29	11	-51	-90--15	12	58.0	0.65	0.12
MEsub1[b] (%)	T1	4.9	3.5-6.9	9	4.1	3.4-5.4	14	49.0	0.40	N.A.
	ΔT2-T1	0.4	-1.1-1.4	8	-0.2	-0.9-0.0	9	23.0	0.24	0.36
	ΔT3-T1	-1.3	-0.5-0.5	9	0.2	-0.8-0.8	12	40.0	0.35	-0.26
MEsub2[b] (%)	T1	5.6	3.5-7.6	9	4.6	3.3-6.3	14	48.0	0.37	N.A.
	ΔT2-T1	0.4	-0.3-1.7	8	-0.5	-1.4-0.2	9	18.0	0.09	0.50
	ΔT3-T1	-0.1	-1.5-0.3	9	0.0	-0.8-0.8	12	47.0	0.65	-0.13
VO2sub1[b] (L·min^{-1})	T1	0.66	0.51-0.79	9	0.65	0.52-0.81	15	64.0	0.86	N.A.
	ΔT2-T1	-0.04	-0.10-0.07	9	-0.04	-0.10--0.03	11	42.0	0.60	0.15
	ΔT3-T1	-0.05	-0.11-0.05	9	-0.01	-0.14-0.07	13	56.0	0.90	-0.04

Table continues on next page.

Table S1 continued. Exploratory analyses excluding participants that stopped training (wheelchair-specific fitness).

VO2sub1[b] (L·min^{-1})	T1	0.66	0.54-0.82	9	0.68	0.61-0.86	15	61.0	0.73	N.A.
	ΔT2-T1	-0.08	-0.11-0.10	9	-0.07	-0.09-0.13	11	44.5	0.71	0.10
	ΔT3-T1	-0.02	-0.09-0.06	9	-0.06	-0.08-0.05	13	51.0	0.65	-0.13

See table 4 for explanations and abbeviations.

[a] Respiratory exchange ratio at T1, T2 and T3 in the peak test: median>1.00 and no significant differences between the groups (table S4).

[b] Respiratory exchange ratio at T1, T2 and T3 in the submaximal blocks: median<1.00 and no significant differences between the groups (table S4).

Table S2. Exploratory analyses excluding participants that stopped training (wheelchair skill performance).

		Exercise (*n*=14)			**Control** (*n*=15)			**Statistical comparison**		
		Mdn	25-75th	*n*	Mdn	25-75th	*n*	U	*p*	Effect size (r_u)
Performance time (s)	T1	20.8	15.9-28.6	11	17.6	16.3-20.9	15	63.0	0.33	N.A.
	ΔT2-T1	-0.8	-1.6--0.2	11	-0.1	-1.5-0.6	13	50.0	0.23	0.30
	ΔT3-T1	-2.3	-4.2--0.5	11	0.0	-1.3-1.0	13	32.0	0.02*	0.55
Ability score (0-8 scale)	T1	6.5	4.0-8.0	11	7.5	6.5-8.0	15	56.0	0.18	N.A.
	ΔT2-T1	0.0	0.0-1.0	11	0.0	-0.5-0.0	13	41.5	0.08	0.42
	ΔT3-T1	0.0	0.0-1.0	11	0.0	0.0-0.0	13	45.0	0.13	0.37
Strain score (% HRR)	T1	32	19-37	6	26	-2-40	8	22.0	0.85	N.A.
	ΔT2-T1	-7	-13-N.A.	3	3	-20-44	6	9.0	1.00	0.00
	ΔT3-T1	4.4	-16-31	5	1	-22-49	5	12.0	1.00	-0.04

See table 5 for explanations and abbeviations.

Table S3. Exploratory analyses excluding participants that stopped training (physical activity levels).

		Exercise (*n*=14)			**Control** (*n*=15)			**Statistical comparison**		
		Mdn	25-75th	*n*	Mdn	25-75th	*n*	U	*p*	Effect size (r_u)
Weekly propulsion (km^{-1})	T1	7.7	0.9-14.0	8	15.9	5.2-37.0	13	30.0	0.12	N.A.
	ΔT2-T1	2.0	0.7-3.0	6	0.5	-5.9-6.6	9	25.0	0.86	0.07
	ΔT3-T1	-0.3	-2.4-0.0	7	1.6	-25.3-8.0	9	21.0	0.30	-0.33
PASIPD (MET h·week^{-1})	T1	7.5	3.1-8.8	9	10.6	6.9-17.4	15	37.0	0.07	N.A.
	ΔT2-T1	0.0	-3.1-9.5	9	-1.4	-7.2-5.5	11	44.0	0.71	0.11
	ΔT3-T1	1.2	-4.5-3.0	7	0.6	-5.4-7.9	13	43.0	0.88	0.05

See table 6 for explanations and abbeviations.

Table S4. Respiratory exchange ratio in the submaximal blocks and peak test at T1, T2 and T3.

		Exercise (*n*=14)			**Control** (*n*=15)			**Statistical comparison**	
		Mdn	25-75th	*n*	Mdn	25-75th	*n*	U	*p*
RERpeak	T1	1.02	0.90-1.15	13	1.01	0.91-1.12	15	93.0	0.86
	ΔT2-T1	1.06	0.87-1.19	10	1.01	0.95-1.11	11	51.0	0.81
	ΔT3-T1	1.04	0.89-1.10	12	1.02	0.89-1.28	13	71.5	0.73
RERsub1	T1	0.83	0.80-0.91	11	0.77	0.77-0.90	15	76.0	0.76
	ΔT2-T1	0.83	0.80-0.91	10	0.82	0.82-0.88	11	47.0	0.61
	ΔT3-T1	0.86	0.83-0.91	13	0.81	0.81-0.94	13	81.5	0.88
RERsub2	T1	0.86	0.79-0.88	11	0.79	0.79-0.90	15	68.0	0.47
	ΔT2-T1	0.82	0.80-0.88	9	0.81	0.81-0.88	11	40.0	0.50
	ΔT3-T1	0.83	0.79-0.87	12	0.83	0.83-0.93	13	44.5	0.07

Statistical comparison based on Mann-Whitney U-tests ($p<0.05$).
Abbreviations: Mdn = median; 25-75th = interquartile range; T1, T2 and T3 = respective measurements at baseline, after 8 weeks and 16 weeks; U = Mann-Whitney U; RERpeak = highest 30s-respiratory exchange ratio over the peak test; RERsub1 and RERsub2 = highest 30s-respiratory exchange ratio of the two submaximal blocks

Physical activity levels

Difference scores of activity were not significantly different between the exercise and control group (table 6), while results were similar in the exploratory analyses (table S3). Observations in outcomes of individual participants also indicate that the training did not improve activity in the exercise group (figure 4).

Exercise training

Absolute intensity during the training increased significantly in the 11 participants that completed the training (table 3). On average, power output was 26% higher (+2.9 W) and treadmill velocity was 31% higher (+0.2 $m \cdot s^{-1}$) at the end of the training. Overuse symptoms did not worsen over the training period (table 3).

Ten participants that completed the training rated perceived effects of the training. They reported their fitness had not improved (*n*=2), somewhat improved (*n*=6) or improved a lot (*n*=2). Most reported that wheelchair skill performance and physical activity levels had not improved, as indicated by the median scores of three ('no change').

DISCUSSION

The low-intensity wheelchair exercise training in this RCT had only limited effect on wheelchair-specific fitness, wheelchair skill performance and physical activity levels of the group of physically inactive wheelchair users with long-term SCI. Although absolute intensity during the training increased significantly, no or only small improvements were found in fitness, skill and activity. When compared to the control group, P5-15m and the performance time score were the only outcomes that significantly improved in the exercise group (respectively 14% and 7%).

We have to conclude that positive effects of the training were absent or small under the current experimental conditions, even though the group had relatively low initial levels of fitness and activity when compared to findings in previous studies on people with SCI.[3,22,23,33,34] Low fitness in our study is exemplified by POpeak in the subgroup with paraplegia, which would be ranked as 'poor' based on a study on norm values of fitness of people with SCI.[33] Furthermore, average activity scores were about half of what has been found in a cohort study on PASIPD of people with SCI one year after discharge from in-patient rehabilitation.[23] Wheelchair skill performance seemed less impaired, as average levels were similar to findings in a cohort study on people with SCI five years after discharge.[7]

The cause for the absence of substantial effects on fitness might be based in the choice of exercise frequency in our study, which was two times per week. Exercise frequency was at least three times per week in previous studies on low-intensity exercise in which relatively large improvements in fitness were found.[13-19,35] Training at least three times per week allows between-session intervals of no more than 72h, which has been suggested to be a prerequisite for acute fitness adaptations to turn into more lasting adaptations.[36] However, training more than two times per week was expected to lead to dropout and low adherence in this deconditioned, community-dwelling group in our study. This expectation was based on a study on people with tetraplegia performing handcycle training: it was found that participants had difficulty adhering to 24 sessions in the designated 8-12 weeks.[27] This difficulty was in contrast to another study on people with SCI (relatively high adherence in a nine-month exercise training performed two times per week).[37] The limited fitness effects in our study were probably not caused by the exercise period (16 weeks) or duration of exercise per session (30 min), since relatively large fitness improvements have been found in low-intensity training with periods and durations as low as 9 weeks and 14 min per session.[14,16,17]

Another possible cause for the small effects on fitness of the training, compared to the relatively large effects found in studies on low-intensity wheelchair exercise in able-bodied people, is initial experience in wheelchair propulsion. Novices in wheelchair propulsion have shown to improve submaximal fitness as a result of a more efficient propulsion technique.[38] Perhaps less change in propulsion technique occurred in the more experienced wheelchair users in our study, but this requires further study.

The small or absent improvements in the exercise group in wheelchair skill performance and physical activity levels might be explained by the limited fitness effects. Prospective cohort studies on people with SCI indicated that wheelchair-specific fitness is positively associated with wheelchair skill performance as well as with physical activity levels.[1,4]

Perhaps P5-15m and the performance time score improved significantly given their basis on a 15 m-overground sprint test, which may have resembled participants' daily-life tasks more than the treadmill tests and the isometric-push test. However, further study is required to establish whether P5-15m and the performance time score are indeed more responsive to change in this population than the other outcomes.

The limited effect in outcomes of fitness seems in contrast to perceived effects of the training: most participants reported their fitness had at least somewhat improved. This suggests they overestimated training effects on their fitness levels. Such erroneous estimation might be explained by low or only moderate associations between self-perceived fitness and performance-based fitness as found in able-bodied older adults.[39]

Limitations

Although the relatively small sample size and missing data might have limited statistical power, we do not think it influenced findings in our study: nearly all non-significant changes had high p-values and effect sizes < 0.20 (tables 4-6). Furthermore, average changes in the exercise group were $< 10\%$ in nearly all outcomes (tables 4-6), while observations in outcomes of individual participants also indicated small or no effects of exercise (figure 2-4).

A limitation of our study is that three participants stopped after 3-5 weeks of training. Although it might be expected that this mitigated effects of the training, this was not apparent in the plots with individual outcomes (tables 4-6) and also not in exploratory analyses without outcomes of these participants (tables S1-S3).

Generalization to the inactive population with long-term SCI of our findings might be limited by selection bias. For example, perhaps people with relatively high fitness and activity levels did not participate due to work or social obligations, while relatively deconditioned or inactive people might have experienced other barriers to participate in this study.[40]

Clinical implications and future research

We suggest an exercise frequency of at least three times per week when utilizing low-intensity wheelchair exercise training in inactive people with long-term SCI. However, further study is required on the effects of such higher-frequency training and, first of all, how it can be made feasible for this population. A supervised home-based setting is suggested to be more feasible for deconditioned or inactive populations.[13] This suggestion is supported by the relatively high adherence and little dropout found in a two-year home-based exercise training performed by older adults.[41]

Other approaches may be to gradually build up wheelchair exercise intensity over an extensive period so that more effective intensities can be sustained. Building up wheelchair exercise intensity might also be supported with the use of a combination of low-intensity wheelchair exercise and higher-intensity handcycling exercise, which could allow customization to higher-intensity exercise without risking upper-body overuse.[12,27] In addition, the population with long-term SCI might benefit from more focus on prevention of deconditioning and inactivity so that more effective wheelchair exercise intensities remain within reach. This asks for aftercare rehabilitative models that span the lifetime with SCI.[42]

CONCLUSIONS

We conclude that 16 weeks of low-intensity wheelchair exercise performed two times per week for 30 min per session seems insufficient for substantial improvements in wheelchair-specific fitness, wheelchair skill performance and physical activity levels of physically inactive wheelchair users with long-term SCI. As their relatively low wheelchair-specific fitness can impair health, participation in society as well as quality of life,[5-7] alternative interventions need to be developed to help prevent and improve low wheelchair-specific fitness in this population, for example feasible low-intensity wheelchair exercise at a higher exercise frequency.

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Chapter 7

Low-intensity wheelchair training in inactive people with long-term spinal cord injury:

a randomized controlled trial on propulsion technique

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ABSTRACT

Objective: To investigate the effects of low-intensity wheelchair training on propulsion technique in inactive manual wheelchair users with long-term SCI.

Design: In this multicenter non-blinded randomized controlled trial, participants (N=29, 22 men, 20 with paraplegia, time since injury>10 years) were allocated to an exercise (n=14) or non-exercise control group. Exercise consisted of wheelchair treadmill-propulsion at 30-40% heart rate reserve or equivalent rate of perceived exertion, 16 weeks, two times per week, 30 min per session. Propulsion technique was assessed at baseline as well as after eight, 16 and 42 weeks during two submaximal treadmill-exercise blocks using a measurement wheel attached to a participant's own wheelchair. Changes between the groups over time were compared using Mann-Whitney U-tests ($p<0.05$).

Results: Comparing the exercise (n=8) to the control group (n=8), the only significant change was found in peak force after eight weeks (respectively -20 N vs. 1 N, p=0.01, r_U=0.78). No significant changes were found after 16 and 42 weeks.

Conclusions: The low-intensity wheelchair training seemed ineffective for changing propulsion technique in the inactive group with long-term SCI, possible due to a too low intensity or frequency. Alternative interventions might be needed to reduce risk of upper-body joint damage during daily wheelchair propulsion.

INTRODUCTION

People with spinal cord injury (SCI) often experience upper-body pain and pathology.[1-3] One of the causes could be joint damage as a consequence of manual wheelchair propulsion, which is the primary form of mobility in many people with SCI.[4-6] Factors that contribute to risk of joint damage during wheelchair propulsion include deconditioning and years as a wheelchair user.[4,5] Deconditioned or inactive manual wheelchair users with long-term SCI might therefore be in particular need of risk reduction of joint damage during wheelchair propulsion.[7]

Risk reduction is considered possible through an improved propulsion technique[1] For example, reducing push frequency and peak forces over a push are assumed to lead to less joint damage during wheelchair propulsion[1]

Such changes in propulsion technique might be attained through exercise training, as suggested by findings in long-term wheelchair users and able-bodied people novice in wheelchair propulsion.[8-10] For example, reduced push frequency was found in a group of long-term wheelchair users after a six-week training, which included high-resistance strength exercises and rowing exercise at 60% heart rate reserve (HRR)[9] Such relatively high exercise intensities, however, have been suggested to lead to low adherence, dropout and musculoskeletal injury in deconditioned or inactive populations[11] For these populations, low-intensity training (30-40% HRR) is suggested as a safer and more feasible alternative.[11] At this exercise intensity, a reduction in push frequency was found in a group of able-bodied novices performing wheelchair training (seven weeks of wheelchair propulsion on a treadmill at 30% HRR, three times per week, 70 min session).[8]

The effects of low-intensity wheelchair training on propulsion technique have not yet been investigated in inactive manual wheelchair users. In this population, it is considered feasible to perform exercise two times per week, 30 min per session.[12-14]

The aim of this study was to investigate the effects of low-intensity wheelchair training on propulsion technique in inactive manual wheelchair users with long-term SCI. A multicenter randomized controlled trial (RCT) was conducted, in which an exercise group was compared to a non-exercising control group. The exercise group performed 16 weeks of wheelchair propulsion on a treadmill at 30-40% HRR or equivalent in rate of perceived exertion (RPE), two times per week, 30 min per session.[14] Based on findings in a previous study,[8] it was hypothesized that the exercise group would show more change in propulsion technique than the control group.

METHODS

Design

A non-blinded RCT was conducted in two rehabilitation centers. The exercise group performed a 16-week low-intensity wheelchair exercise training, while no intervention was employed in the control group.[14] Both groups were measured at baseline (T1), eight weeks after baseline (T2), 16 weeks after baseline (T3) and 42 weeks after baseline

(T4). During measurements, participants performed submaximal wheelchair propulsion on a treadmill, using their own wheelchair equipped with an instrumented wheel. The design of the RCT is described elsewhere in more detail.[14]

Ethical approval

Ethical approval was obtained from committees of the VU University Medical Center (Amsterdam, the Netherlands) and the two participating rehabilitation centers (Heliomare, Wijk aan Zee and University Medical Center Groningen, Groningen, the Netherlands).[14] The RCT was registered in the Dutch Trial Register (www.trialregister.nl, NTR3037).

Participants

Participants were inactive manual wheelchair users with long-term SCI (table 1). Paramedical research assistants preselected potentially eligible people (figure 1). Participants were included after their written informed consent and eligibility screening. After that, the investigators used a blocked randomization procedure with sealed envelopes to allocate participants to the exercise or control group.

Inclusion criteria comprised time since injury > 10 years and inactivity as defined by a reference score on a physical activity questionnaire (score < 30 on the Dutch Physical Activity Scale for Individuals with Physical Disabilities).[14-16] Other inclusion criteria of the RCT's original design[14] were adjusted to increase sample size for the present study (age: < 65 to < 67 years; age at onset SCI: > 18 to > 11 years). Exclusion criteria comprised musculoskeletal complaints contraindicating wheelchair propulsion, cardiovascular contraindications for exercise, progressive disease, psychiatric problems, insufficient mastery of Dutch language and plans to change lifestyle.[14]

Intervention

The exercise group performed a 16-week low-intensity wheelchair training in a rehabilitation center.[14] The training consisted of wheelchair propulsion on a treadmill at 30-40% HRR or its RPE equivalent, two times per week, 30 min per session. The RPE equivalent was 1-3 on a 10-point scale, which was used in participants with an impaired autonomic nervous system.[13,17] To maintain relative intensity, power output was adjusted by changing treadmill velocity or weight in a pulley system.[14] Protocols of all participants consisted of 18 or 24 min of exercise in the first four sessions, followed by 28 sessions consisting of 30 min of exercise (total exercise: 924 min). Protocols differed between participants dependent on baseline fitness and skill levels (no rest or rest intervals of 1-2 min).[14] Adherence, overuse symptoms, relative intensity and absolute intensity were monitored throughout the training. A paramedical research assistant supervised the training.

Procedures

A protocol was used similar to that in previous SCI cohort studies.[18,19] It consisted of two three-min blocks of submaximal wheelchair propulsion on a motor-driven treadmill

(1.2 m x 5.30 or 1.2 m x 5.47 m; ForceLink B.V., Culemborg, The Netherlands). The two blocks were separated by a rest period of two minutes and were performed at different inclination angles (0% or 0.5-0.6%). Treadmill velocity was constant over all measurement occasions (< 0.56, 0.56, 0.83 or 1.11 $m \cdot s^{-1}$). This velocity was chosen at T1, depending on a participant's fitness and skill observed in a two-minute familiarization procedure on the treadmill.[14]

Participants performed both blocks using their own wheelchair with the rear right wheel replaced with a force and torque-instrumented measurement wheel (OptiPush, MAX Mobility, Antioch, USA), while the left wheel was replaced with an inertia-compensated dummy wheel. Both wheels weighed 5.7 kg, had a tire pressure of $6 \cdot 10^5$ Pa and matched the participant's wheel radius (0.30, 0.31 or 0.33 m). The instrumented wheel recorded three-dimensional forces and torques applied to the handrim, in addition to the angle over which the wheel rotated (sample frequency: 200 Hz). In data processing, forces and torques were low-pass filtered at 20 Hz and angle data at 5 Hz (Butterworth filter).[20,21] Custom-written MATLAB routines were used to calculate force and timing parameters, as adopted in a previous study.[21]

Propulsion technique

Propulsion technique was determined as a set of force and timing parameters based on contact between hand and handrim (table 2).[21] These parameters were selected based on their possible sensitivity to change as a result of low-intensity wheelchair training,[8,21] in addition to recommendations for improving propulsion technique in people with SCI (minimizing push frequency and peak force over a push).[1] Parameters were determined as mean over all completed cycles during the last 30 s of each exercise block.

Statistics

Required sample size was based on the primary outcome of the RCT (peak power output in a graded wheelchair exercise test).[14] It was estimated at n=18 for both the exercise and the control group.[13,14,22]

Many parameters in the group were not normally distributed so analyses were based on non-parametric tests. Median and interquartile ranges were determined over the total group, the exercise group and the control group. Comparisons between the exercise and control group were conducted using Fisher's tests or Mann-Whitney U-tests ($p<0.05$). Effect sizes of comparisons were based on non-parametric rank order correlations ($r_U = 1 - [2U - n_{exercise} * n_{control}]$).[23]

Possible differences between the exercise and control group at baseline were evaluated by comparing the groups on participant characteristics, propulsion technique, treadmill velocity and submaximal power output. Possible changes between groups in submaximal power output over time, for example due to weight gain of participants,[24] were evaluated by comparing difference scores over measurement occasions (ΔT2-T1, ΔT3-T1 and ΔT4-T1). To evaluate effects of the training, groups were compared on difference scores of propulsion technique.

Difference scores for participants with missing data at T1, T2 or T3 were excluded from analyses over time, thereby matching participants and group sizes over first 16 weeks. Included in analyses were difference scores of participants that did not complete the training but continued performing measurements (intention-to-treat principle). For exploratory purposes, analyses were repeated excluding participants that did not complete the training (auxiliary analyses).

RESULTS

Participants

Between October 2011 and October 2013, about 200 potentially eligible people were invited for participation (figure 1). Twenty-nine people agreed to participate and passed eligibility screening (table 1). Fourteen participants were allocated to the exercise group. Women represented about a fourth of the total group, while about a third of the group had a tetraplegia. Most participants were middle-aged and were active for less than 10 MET h·week^{-1}.

Table 1. Participant characteristics at baseline

	Total	**Exercise**	**Control**	**Ex vs. Con**
	N	*n*	*n*	*p*
Group size	29	14	15	
Men / women	22/7	12/2	10/5	0.39
Paraplegia / tetraplegia[a]	20/9	9/5	11/4	0.70
Complete / incomplete[a]	20/9	10/4	10/5	1.00
AIS A / B / C / D	17 / 3 / 7 / 2	9 / 1 / 4 / 0	8 / 2 / 3 / 2	N.A.
C4-6 / C7-8 / Th1-9 / Th10-L5	5 / 4 / 13 / 7	3 / 2 / 5 / 4	2 / 2 / 8 / 3	N.A.
	Mdn (25-75th)	**Mdn (25-75th)**	**Mdn (25-75th)**	
Age (y)	57 (45-63)	55 (42-64)	57 (46-62)	0.72
Height (m)	1.80 (1.69-1.86)	1.80 (1.71-1.87)	1.78 (1.68-1.86)	0.53
Body mass (kg)	88 (78-100)	88 (81-99)	88 (73-100)	0.62
BMI (kg/m^2)	28 (25-32)	28 (25-30)	27 (23-33)	0.59
TSI (y)	17 (14-29)	16 (13-29)	20 (14-31)	0.35
Age at onset SCI (y)	30 (23-44)	30 (25-49)	31 (20-44)	0.59
PASIPD (MET h·week^{-1})[b]	8.0 (4.2-14.6)	6.4 (1.7-9.0)	10.6 (6.9-17.4)	0.07
POpeak (W)[c]	40.9 (19.1-54.9)	47.5 (10.2-54.5)	38.7 (25.0-57.0)	0.87

Statistical comparison based on Fisher's tests and Mann-Whitney U-tests ($p<0.05$).

[a] Para defined as lesion <Th1; Complete defined as motor complete lesion[25]

[b] PASIPD < 30 used as an inclusion criterion[14]; $n=2$ missing in total and exercise group

[c] $n=1$ missing in control group

Abbreviations: Mdn (25-75th) = median (interquartile range); BMI = body mass index; TSI = time since injury; SCI = spinal cord injury; PASIPD = Physical Activity Scale for Individuals with Physical Disabilities[25]; MET = metabolic equivalent; POpeak = mean power output over last 30s over a peak wheelchair exercise test on a treadmill, performed at baseline[14].

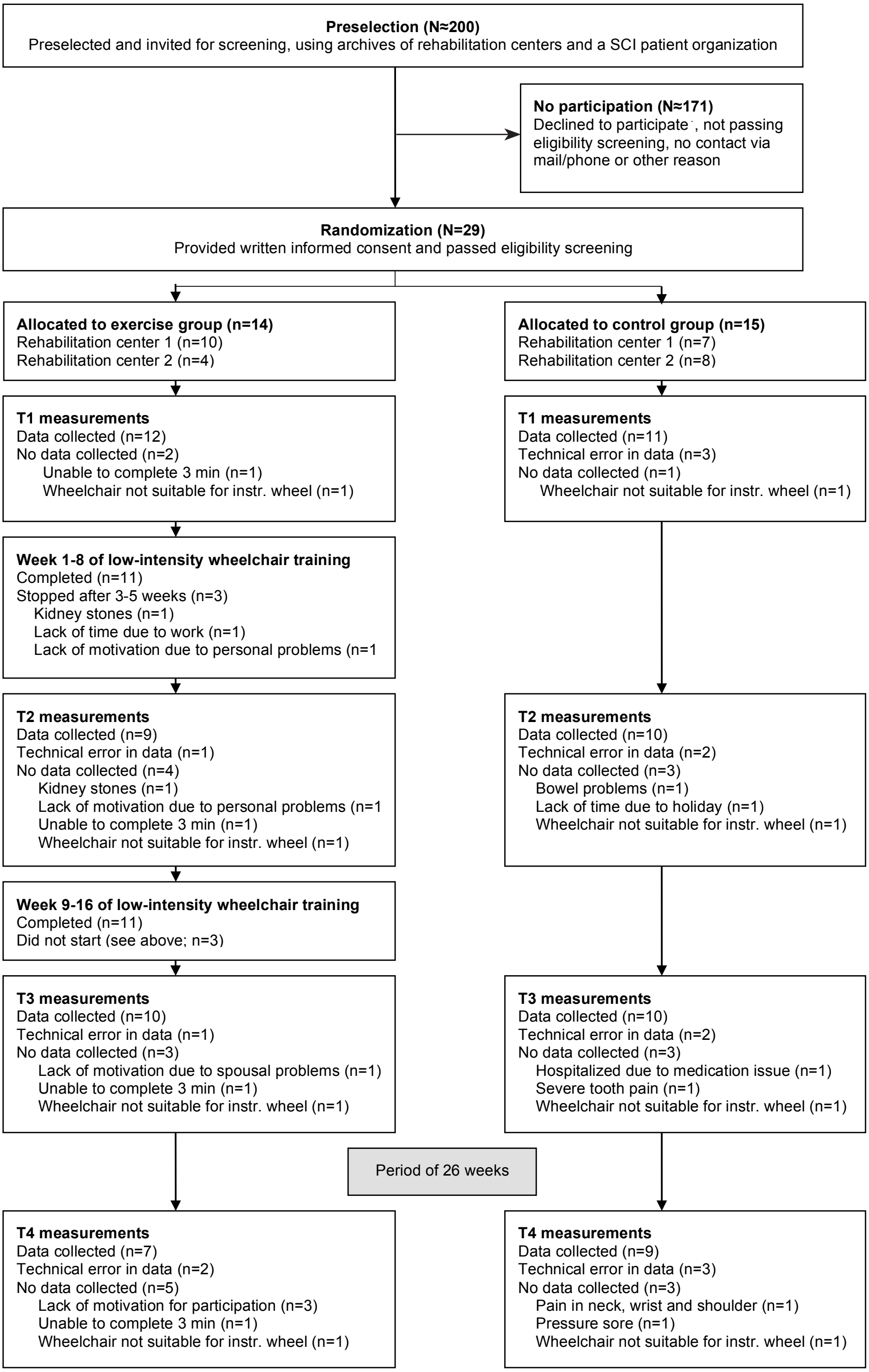

Figure 1. Details on inclusion, randomization, allocation, measurements and intervention (CONSORT flow diagram). An estimated three in four eligible people declined to participate.

Abbreviations: instr. = instrumented; T1 = baseline measurements; T2, T3 and T4: measurements eight, 16 and 42 weeks after baseline, respectively.

Low-intensity wheelchair training

The exercise group (n=14) performed on average 834 min of exercise (range: 174-929) over 31 sessions (range: 7-32) in 17 weeks (range: 5-18). Three participants stopped exercise after three to five weeks due to incidence of kidney stones, lack of time due to new job obligations or lack of motivation due to personal problems (figure 1).

Baseline (T1)

Not all outcomes at T1 could be collected due to technical issues and a participant being unable to complete three consecutive min of treadmill propulsion (figure 1). At T1, no significant differences between the exercise and control group were found in participant characteristics, propulsion technique (tables 1 and 2) and treadmill velocity in both blocks (median [interquartile range] of exercise vs. control: 1.0 $m \cdot s^{-1}$ [0.8-1.1] vs. 0.9 $m \cdot s^{-1}$ [0.8-0.9]; $p = 0.33$). Also in submaximal power output, no significant differences were found between groups in both blocks. Median power output in the first block was 14.0 W (interquartile range: 8.5-17.2) in the exercise group, while it was 12.9 W (10.7-15.6) in the control group (p=0.88). In the second block, it was 16.3 W (13.5-20.1) versus 14.2 W (12.1-17.5) (p=0.57).

Effects of the training

Outcomes of some participants could not be collected at T2, T3 and T4 (figure 1). Reasons for missing data included technical issues and incidence of medical complications such as kidney stones and bowel problems (figure 1). Resulting sample sizes were n=8 for comparisons in propulsion technique (table 2). Submaximal power output in both blocks did not change significantly between the exercise and control group over time (first block: p=0.54-1.00, r_U=-0.27-0.09); second block: p=0.13-0.65, r_U=0.16-0.47).

Analyses on effects of the training did not show a significant effect in propulsion technique (table 2), except in peak force in the second block in ΔT2-T1 (exercise vs. control group: -20 N vs. 1 N, p=0.01, r_U=0.78). Such a reduction in peak force was not found in ΔT3-T1 (-7 N vs. 1 N, p=0.19, r_U=0.41). Near-significant effects in propulsion technique were seen in push frequency in the second block in ΔT2-T1 (exercise vs. control group: -11 vs. -1 $push \cdot min^{-1}$, p=0.05, r_U=0.59. Such a reduction in push frequency was also seen in ΔT3-T1 (-16 vs. 1 $push \cdot min^{-1}$, p=0.08, r_U=0.53).

Variance was large in the exercise group's changes in propulsion technique, as indicated by the interquartile ranges (table 2) and data of individual participants over time (figure 2). The auxiliary analyses, excluding participants that stopped training, showed similar results to those described above.

Table 2. Effects of the training on propulsion technique.

		Exercise group				Control group				Comparison groups		
		Mdn	25th	75th	*N*	Mdn	25th	75th	*N*	*p*	*U*	Effect size (r_U)
Push frequency (push·min^{-1})	**Block 1**											
	T1	57	46	65	8	52	48	64	8	0.80	35	N.A.
	ΔT2-T1	-11	-16	-4	8	-2	-7	3	8	0.06	14	0.56
	ΔT3-T1	-10	-16	-5	8	-3	-10	2	8	0.16	18	0.44
	ΔT4-T1	-9	-15	-6	5	-8	-13	-1	6	0.54	11	0.27
	Block 2											
	T1	50	45	72	8	55	47	59	8	1.00	32	N.A.
	ΔT2-T1	-11	-16	-5	8	-1	-3	4	8	0.05	13	0.59
	ΔT3-T1	-16	-20	-4	8	1	-7	4	8	0.08	15	0.53
	ΔT4-T1	-17	-21	-13	5	-3	-19	1	6	0.18	7	0.53
Net work per cycle (J)	**Block 1**											
	T1	16	11	20.9	8	17	16	19	8	0.80	29	N.A.
	ΔT2-T1	0.4	-1.4	1.9	8	1.4	-0.2	4.2	8	0.80	29	0.09
	ΔT3-T1	3.9	-0.7	6.1	8	2.3	1.0	3.6	8	0.65	37	-0.16
	ΔT4-T1	5.6	-0.9	6.1	5	0.7	-0.8	3.9	6	0.66	18	-0.20
	Block 2											
	T1	20	15	24	8	19	16	23	8	1.00	32	N.A.
	ΔT2-T1	-1.0	-1.7	0.5	8	1.1	-0.6	4.2	8	0.13	17	0.47
	ΔT3-T1	1.5	-0.5	4.2	8	1.0	-0.6	6.0	8	0.88	30	0.06
	ΔT4-T1	3.3	1.9	4.7	5	0.2	-3.0	6.6	6	0.66	18	-0.2

Table continues on next page.

Table 2 continued. Effects of the training on propulsion technique.

		Exercise group				Control group				Comparison groups		
		Mdn	25th	75th	*N*	Mdn	25th	75th	*N*	*p*	*U*	Effect size (r_U)
Contact angle (degrees)	**Block 1**											
	T1	61	49	68	8	62	59	64	8	0.80	29	N.A.
	ΔT2-T1	11	1	12	8	4	-3	11	8	0.51	39	-0.22
	ΔT3-T1	15	2	20	8	1	-4	6	8	0.13	47	-0.47
	ΔT4-T1	10	4	20	5	5	3	10	6	0.54	19	-0.27
	Block 2											
	T1	62	56	75	8	66	64	70	8	0.44	24	N.A.
	ΔT2-T1	4	-1	10	8	3	-6	10	8	0.72	36	-0.13
	ΔT3-T1	5	3	15	8	-6	-7	8	8	0.23	44	-0.38
	ΔT4-T1	16	4	19	5	4	0	9	6	0.25	22	-0.47
Peak torque (N·m)	**Block 1**											
	T1	9.2	6.4	12	8	9.5	8.4	11	8	0.80	29	N.A.
	ΔT2-T1	-0.3	-1.3	0.8	8	0.5	0.0	2.0	8	0.38	23	0.28
	ΔT3-T1	1.5	-2.1	2.7	8	1.4	0.7	1.8	8	1.00	32	0.00
	ΔT4-T1	-0.1	-1.1	2.8	5	0.1	-0.5	1.8	6	1.00	15	0.00
	Block 2											
	T1	11	7.9	14	8	10	8.5	13	8	0.96	33	N.A.
	ΔT2-T1	-0.8	-1.4	-0.1	8	0.6	-0.3	2.0	8	0.06	14	0.56
	ΔT3-T1	0.5	-1.4	2.2	8	1.0	0.2	2.7	8	0.72	28	0.13
	ΔT4-T1	1.2	-0.1	1.7	5	-0.4	-2.4	3.2	6	0.79	17	-0.13

Peak force (N)	**Block 1**											
	T1	66	48	104	8	56	50	63	8	0.51	39	N.A.
	ΔT2-T1	-9	-27	-5	8	2	-3	6	8	0.05	13	0.59
	ΔT3-T1	0	-9	8	8	2	-3	10	8	0.72	28	0.13
	ΔT4-T1	5	-13	8	5	-3	-16	11	6	0.93	16	-0.07
	Block 2											
	T1	76	59	101	8	60	49	73	8	0.16	46	N.A.
	ΔT2-T1	-20	-22	-15	8	1	0	7	8	0.01*	7	0.78
	ΔT3-T1	-7	-11	1	8	1	-3	10	8	0.19	19	0.41
	ΔT4-T1	-4	-16	5	5	-4	-16	0	6	0.93	16	-0.07

Propulsion technique was assessed during two submaximal blocks of wheelchair propulsion on a treadmill, while power output was similar over time. Parameters were determined as mean over all completed cycles during the last 30 s of an exercise block. Participants and group sizes are matching over first 16 weeks (T1, T2 and T3). Intention-to-treat principle is applied in analyses: including participants that did not complete the training.

Definition parameters[21]: push frequency (push·min^{-1}) was determined as the number of complete pushes per minute, net work per cycle (J) as the mean power output divided by the push frequency, contact angle (°) as the angle at the end of a push minus the angle at the start, peak torque (N·m) as three-dimensional torques within the push phase, peak force (N) as three-dimensional forces within the push phase.

*$p < 0.05$ in Mann-Whitney U-test.

Abbreviations: Mdn = median; 25th and 75th = interquartile range; U = Mann-Whitney U; rU = non-parametric rank order correlation ($r_U = 1 - [2U - n_{exercise} * n_{control}]$)[23]; T1 = measurements at baseline; ΔT2-T1, ΔT3-T1, ΔT4-T1 = difference scores between baseline and eight weeks, 16 weeks and 42 weeks, respectively; N.A. = not applicable.

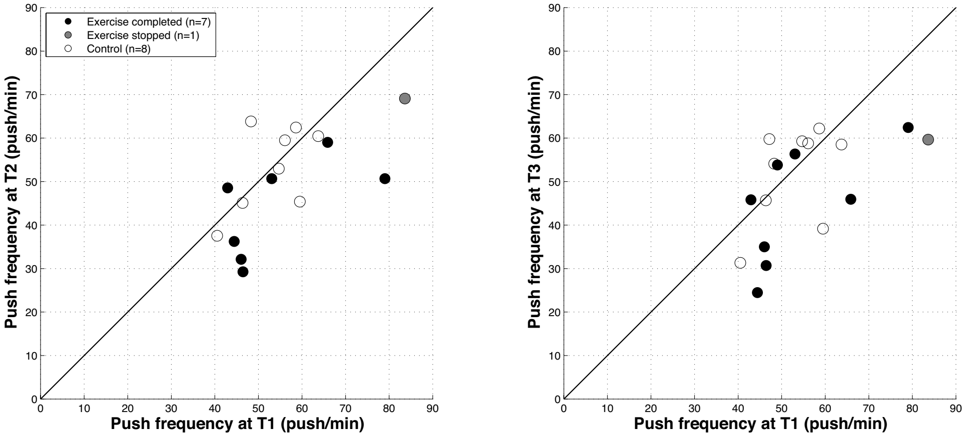

Figure 2. Push frequency in the second block: T1 plotted against T2 and T3. A dot represents a participant's push frequency. Diagonal line serves as a reference. For example, when a participant's frequency reduced from T1 to T2, the data point will fall below the diagonal line.

Abbreviations: T1 = baseline; T2: eight weeks after baseline; T3: 16 weeks after baseline.

DISCUSSION

The low-intensity wheelchair training in this RCT did not result in significant changes in propulsion technique in the group of inactive manual wheelchair users with long-term SCI. The only significant change was found in peak force after eight weeks (-20 N in the exercise group and 1 N in the control group), while no significant changes were found after 16 weeks. Near-significant reductions were seen in push frequency when comparing the exercise to the control group after eight and 16 weeks. Furthermore, variance over the exercise group was large in changes in propulsion technique.

The training seemed ineffective for changing propulsion technique in this group, which might be related to the low intensity and twice-weekly frequency in the training. Significant changes in propulsion technique were found in previous training studies in which intensity or frequency were higher.[8-10] For example, a significant reduction in push frequency was found in a study on long-term wheelchair users performing exercise three times per week at relatively high intensities (high-resistance strength exercises and moderate-intensity rowing).[9] Significant changes in propulsion technique, including reduced push frequency, were also found in able-bodied novices performing low-intensity wheelchair exercise three times per week[8] Perhaps the higher intensities or frequencies in those trainings induced fitness improvements, as indicated by significant improvements in mechanical efficiency and peak power output.[8-10] Such fitness improvements might have resulted in delayed onset of muscle fatigue, allowing a different propulsion technique.[26] If so, it could explain ineffectiveness of the training in our study, as training effects were not found in mechanical efficiency and peak power output (chapter 6).

An additional explanation for ineffectiveness of the training in our study might be found in experience in wheelchair propulsion. Absence of significant training effects is in contrast to findings in able-bodied novices performing low-intensity wheelchair training.[8,10] The relatively large changes in propulsion technique in these able-bodied novices could have resulted from motor learning effects.[21,27] It seems such motor learning effects do not occur in low-intensity wheelchair training performed by inactive wheelchair users with long-term SCI.

Although peak force significantly reduced after eight weeks of training, a significant reduction was not found after 16 weeks. The discrepancy between these effects remains unclear, but might be related to statistical power in our study. Power was limited, as only 29 participants could be included, while missing data occurred frequently in these participants (figure 1). *A priori*-power was set at 0.80 to detect a meaningful difference.[14] In our study, when using similar power calculations, power was only 0.65. It can therefore not be excluded that non-significant changes in propulsion technique in our study were in fact a Type II error. However, this seems unlikely given the high p-values and small effect sizes in most comparisons (table 2). Still, it could have occurred in push frequency, as suggested by near-significant p-values and moderate effect sizes found after eight as well as after 16 weeks of training (table 2).

Perhaps the training had an effect on propulsion technique in some of the exercising participants, as suggested by the large variance in changes in propulsion technique (table 2 and figure 2). This suggests that there could be responders and non-responders to low-intensity wheelchair training. If so, responders and non-responders could be expected to differ in initial propulsion technique, personal characteristics or lesion characteristics.[28,29] A clear indication what characteristics could differ between potential responders and non-responders cannot be derived from an overview in our study (table 3). Whether such responders exist in the SCI population is a topic for further study, in addition to what characteristics could distinguish responders from non-responders.

Table 3. Responders and non-responders to the training in reduced push frequency

	Responders	**Non-responders**
	n	*n*
Group size	5	2
Men / women	4/1	2/0
Paraplegia / tetraplegia[a]	3/2	2/0
Complete / incomplete[a]	3/2	2/0
AIS A / B / C / D	3 / 0 / 2 / 0	2 / 0 / 0 / 0
C4-6 / C7-8 / Th1-9 / Th10-L5	2 / 0 / 2 / 1	0 / 0 / 1 / 1
	Mdn (25-75th)	**Mdn (25-75th)**
Age (y)	47 (39-65)	62 (57-66)
Height (m)	180 (165-187)	188 (183-193)
Body mass (kg)	86 (66-134)	102 (83-121)
BMI (kg/m^2)	28 (23-38)	29 (22-36)
TSI (y)	17 (14-34)	21 (14-28)
Age at onset SCI (y)	25 (16-50)	40 (29-51)
PASIPD (MET h·week-1)[b]	8.6 (5.2-12.0)	7.5 (7.5-N.A.)
POpeak (W)[c]	53.6 10.3-72.9)	51.3 (43.6-59.0)
Push frequency at T1 (push/min)	46 (44-79)	48 (43-53)

Responder defined as > 10% increase in push frequency in the second block after 16 weeks. Participants that did not complete the training were excluded from this overview as well as those that had missing data at T1, T2 or T3.

Abbreviations: N.A. = not available due to missing data. See table 1 for other abbreviations and definitions.

Limitations

The relatively small sample size and missing data in our study limited statistical power. Therefore, the possibility of a type II error cannot be excluded. Furthermore, effects of the training could have been mitigated as a result of participants that did not complete the training (n=3). However, this seems unlikely: results in auxiliary analyses excluding these participants were similar to those shown in table 2.

Propulsion technique may have been influenced by the extra weight of the instrumented and dummy wheel (11.4 kg) on the participants' wheelchairs, as suggested by findings in able-bodied novices.[24] However, since the extra weight did not differ over time, we do not expect it influenced changes in propulsion technique over time.

Clinical implications

Our findings do not provide sufficient evidence to recommend low-intensity wheelchair training as an intervention to improve propulsion technique in inactive manual wheelchair users with long-term SCI. Perhaps a high intensity or frequency of wheelchair exercise is required, but this is not considered safe and feasible for deconditioned or inactive people with SCI.[11-14] The population might benefit from development of alternative interventions, as even small improvements in propulsion technique are assumed to be clinically relevant for reducing risk of upper-joint damage during daily wheelchair propulsion.[1,28]

CONCLUSIONS

Results in this RCT indicate that low-intensity wheelchair exercise for 16 weeks, two times per week, 30 min per session is not effective for changing propulsion technique in inactive manual wheelchair users with long-term SCI. The low intensity and twice-weekly frequency seem insufficient to induce changes in propulsion technique in this population. A limitation in these conclusions is that it cannot be excluded that some of the non-significant findings in our study were caused by lack of statistical power. Furthermore, large variance in changes in propulsion technique in our study suggests the possibility of responders and non-responders to the training, which could be a topic for further study. Currently, there is insufficient evidence to recommend low-intensity wheelchair training as an intervention to improve propulsion technique in inactive manual wheelchair users with long-term SCI. Alternative interventions might be needed when aiming to prevent or reduce risk of upper-body joint damage, pain and pathology in people with SCI.

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Chapter 8

General discussion

INTRODUCTION

This thesis presents results about the effects of low-intensity wheelchair training on wheelchair-specific fitness, wheelchair skill performance, physical activity levels and propulsion technique in physically inactive people with long-term spinal cord injury, as part of the multicenter research program 'Active LifestyLe Rehabilitation Interventions in aging Spinal Cord injury' (ALLRISC).[1] In this chapter, main findings are discussed within the contexts of wheelchair-specific fitness of people with long-term SCI, effects of low-intensity wheelchair training and assessment of wheelchair-specific fitness in rehabilitation centers. Aim of this discussion is to provide suggestions for future research and clinical practice.

WHEELCHAIR-SPECIFIC FITNESS OF PEOPLE WITH LONG-TERM SCI

Physical inactivity and a relatively long time since injury (TSI) seem to have a negative impact on wheelchair-specific fitness in people with SCI, as indicated by findings in the cross-sectional studies (chapters 2 and 5). Less physical activity and a longer TSI were found to be negatively associated to wheelchair-specific peak aerobic work capacity in the ALLRISC-cohort study on people with long-term SCI (chapter 2). Although this negative influence did not appear in the subgroup with tetraplegia, it seems they were a positive selection of the total group: people with tetraplegia were often not able to perform the peak wheelchair exercise test, while these non-participants appeared to have a longer TSI and lower activity levels than participants who were able to perform the peak test. Furthermore, findings in chapter 5 also indicate that wheelchair-specific fitness is low in most inactive people with a long-term SCI. Group levels in several wheelchair-specific fitness components were lower compared to previous studies on wheelchair-specific fitness in people with SCI.[2-4] One cause of low fitness in inactive people with long-term SCI might be that they suffer more from secondary health complications than people with a more recent SCI,[5,6] further contributing to a vicious cycle of physical inactivity and deconditioning.[1,7-9] Alternatively, it can be argued that some inactive people with long-term SCI never had good wheelchair-specific fitness. In people with SCI, low wheelchair-specific fitness has been found at the start of inpatient rehabilitation, but most seem able to improve fitness during inpatient rehabilitation and maintain it up to five years after discharge.[10] Perhaps this was not possible for some inactive people with long-term SCI during and after inpatient rehabilitation due to an inactive lifestyle or occurrence of secondary health complications.[5,6,9,11]

Variance in fitness was large over the group of inactive people with long-term SCI, suggesting that some participants were not physically deconditioned, while others were very deconditioned (chapter 5). A wide range for example appeared in peak aerobic work capacity expressed as peak power output (3.6 to 92.8 W) and peak oxygen uptake (0.39 to 2.03 $L \cdot min^{-1}$). Fitness may vary among people with SCI due to differences in personal and lesion characteristics such as found in age, gender, activity level and lesion level.[2] Lesion level, for example, appeared to influence variance in fitness in chapter 5: the subgroup with paraplegia had fitness levels that were about two times higher than those in the subgroup with tetraplegia. The influence of other differences in personal and lesion characteristics remained unclear in this study, as further statistical differentiations required a larger sample.[2] Furthermore, fitness might differ among inactive people with long-term SCI due to the extent in which secondary health complications contributed to deconditioning.[1,7-9] Another explanation for differences among the group in chapter 5 might be found in determining inactivity using the Physical Activity Scale for Individuals with Physical Disabilities (PASIPD).[12] Such a self-report questionnaire may not accurately reflect physical activity in some individuals, as suggested by the weak relationship between the PASIPD and objective physical activity levels.[13] This implies that not all participants may have been as inactive as seen in their PASIPD-score. Perhaps some had relatively high activity levels that prevented low wheelchair-specific fitness,[11,14] thereby contributing to the large variance in fitness over the group.

A limitation in chapters 2 and 5 is that causality of relationships among physical activity, TSI and wheelchair-specific fitness could not be determined due to the cross-sectional design of the studies. It is also not clear whether these relationships were influenced by measuring physical activity using the PASIPD.[13,14]

Generalization of findings in chapters 2 and 5 is only possible to the wheelchair-dependent population with long-term SCI, while this generalization may also be limited by selection bias. It remains unclear to what extent relatively fit individuals (negative selection bias) or people with very low fitness levels were underrepresented (positive selection bias). Perhaps fitter individuals did not have time to participate, since they appear to be more engaged in social activities and work,[15,16] while people with very low fitness may have declined or been unable to participate due to physical and motivational barriers.[17,18] Positive selection bias seemed more likely in the studies in this thesis, as suggested by findings in chapter 2: people that were not able to perform the peak wheelchair exercise test appeared to be older, had a longer TSI and more often a tetraplegia, while they also appeared to experience more upper-body pain and be less physically active.

Low-intensity wheelchair training

In the RCT, little or no training effects were found in wheelchair-specific fitness, wheelchair skill performance, physical activity levels and propulsion technique (chapters 6 and 7). It appears that low-intensity wheelchair exercise for 16 weeks, twice a week, 30 min per session does not lead to substantial training effects in inactive people with long-term SCI. Although the relatively small sample size and missing data in the RCT limited statistical power, a Type II error is not likely: effect sizes were small in comparisons between the exercise and control group, while individual changes were less than 10% in most of the exercising participants.

Alternatives for the training in the RCT should be developed when aiming to induce substantial training effects in this population. As discussed below, potentially safe and more effective alternatives could consist of low-intensity wheelchair training at a higher frequency or over a longer period, training using other modalities or programs aimed at stimulating physical activity and sports.

Low-intensity wheelchair training at a high exercise frequency

Larger training effects than found in the RCT might be expected from low-intensity wheelchair exercise performed more than twice a week, as based on previous studies on low-intensity training[19-21] and theory on exercise physiology.[22,23] Previous studies on low-intensity wheelchair training showed relatively large effects on fitness and propulsion technique in able-bodied novices exercising three times a week (appendix),[19-21] while low-intensity training in inactive or deconditioned people was also found to result in relatively large fitness effects when utilizing lower-body exercise three times a week or more.[24-26] In theory on exercise physiology, it has been described that fitness adaptations after a single session only last when another session follows within 72 h.[22] This is only possible when exercising more than twice a week. Furthermore, a dose-response relationship between exercise and fitness has been described, as based on evidence in lower-body exercise.[23] However, whether such a dose-response relationship exists in wheelchair training is currently not clear. For example, it was not apparent in a previous study in which wheelchair exercise intensities of 30% and 70% as well as durations of 30 and 70 min per session were found to be equally effective in improving wheelchair-specific fitness of able-bodied novices (appendix). Still, exercise frequency in that study was three times a week, suggesting that this might be a prerequisite for substantial training effects.

Exercising more than twice a week does not seem feasible in inactive people with long-term SCI when utilizing a training format that consists of exercise sessions located at rehabilitation centers. Center-based exercise might be too much of a burden for participants when having to travel to a rehabilitation center more than twice a week.[27,28] Not only could this lead to low exercise adherence or dropout, but it might also contribute to barriers experienced by people with SCI to initiate training.[29] For example, about three out of four potentially eligible people declined to participate in the RCT, in part due to having to travel to the rehabilitation center for an exercise session. These phenomena are notorious in exercise programs and RCTs in people with SCI.[17,27]

Travelling to another location is not necessary in home-based training, which might therefore be more feasible for inactive people with long-term SCI performing exercise three times a week or more. Home-based training was found to be more feasible than center-based training in some studies on inactive able-bodied populations, as suggested by a higher exercise adherence and lower dropout rate found in the home-based formats.[23,30-33]

Research on home-based training in people with SCI is limited,[28,34,35] but for the general population some guidelines are available.[23,36,37] These guidelines include access to home-based equipment, social support and continued supervision.[23,36,37] Access to home-based equipment in wheelchair training in people with SCI for example implies the use of an ergometer or elastic bands to mimic propulsion.[34] Social support could constitute of contact with other exercising peers and contact with a trainer through telecommunication.[38] Continued supervision might be provided through telecommunicating with a trainer, while center-based exercise tests can be used to monitor progress.[28,38] Furthermore, a prerequisite for home-based wheelchair training is that participants learn to self-monitor upper-body overuse symptoms and relative intensity.[28]

Another feasible alternative for center-based training might be found in a format that includes community-based exercise, for example at a local fitness center.[23,39] Burden for travelling may be relatively low, while such a location can offer social support and supervision by a trainer.[39] Community-based exercise for people with SCI and other disabilities has not yet been implemented, as it is hampered by societal barriers and lack of qualified staff.[29]

Low-intensity wheelchair training over a long period

Perhaps larger training effects than found in the RCT occur in low-intensity wheelchair exercise over a period longer than 16 weeks. Observations in the RCT suggest that some of the inactive people with long-term SCI experienced secondary health complications that could have mitigated training effects during the 16-week period (chapter 6). For example, one participant improved power output over the first 13 weeks of exercise, but regressed in the last three weeks when experiencing an urinary tract infection. Whether a longer period would have induced larger training effects is currently not clear, nor is it clear whether a longer period allows a gradual, safe build-up to more effective exercise intensities.

Training using other modalities

Besides more frequent exercise or exercising for a longer period, another alternative to the low-intensity wheelchair training in the RCT could be found in the use of other exercise modalities. For example, handcycling may be a safe modality for use at higher, potentially more effective exercise intensities: it is found to involve relatively low upper-body joint loads and cardiovascular strain.[40-42] Handcycling training at a moderate to vigorous-intensity (70% heart rate reserve) was indeed found safe and effective for improving fitness in a group with tetraplegia,[28] but effects on wheelchair-specific fitness, wheelchair skill performance and physical activity levels were not studied. These outcome domains were incorporated in another RCT in research program ALLRISC, in which effects of moderate to vigorous-intensity handcycle training were evaluated in inactive people with long-term SCI.[43] Although improved physical activity levels were found, training effects did not appear in wheelchair-specific fitness and wheelchair skill performance. Perhaps these components required the higher specificity of wheelchair training, or, alternatively, the twice-weekly exercise frequency was again insufficient. If so, this also suggests the need for a feasible format for people with SCI performing exercise more than twice a week, in addition to the need for combining wheelchair and handcycling exercise.

Although resistance training has been recommended for improving fitness in people with SCI,[44] it is not yet clear which intensities and exercises are safe as well as feasible for inactive people with long-term SCI. For example, the recommended intensity in resistance training is relatively high (8-10 RM).[44] Such an intensity is suggested to lead to lower exercise adherence and more dropouts in inactive or deconditioned populations.[23] Furthermore, some resistance exercises involve high upper-body joint load, a risk factor for injury.[45]

Programs aimed at stimulating physical activity and sports

An indirect approach to reaching substantial training effects in inactive people with long-term SCI may be found in programs aimed at stimulating physical activity and sports.[46,47] For example, self-management interventions and exercise counseling are thought to contribute to improved physical activity levels and participation in sports.[46,47] If so, these improvements could consequently lead to higher wheelchair-specific fitness, as previously suggested.[11,48]

ASSESSMENT OF WHEELCHAIR-SPECIFIC FITNESS IN REHABILITATION CENTERS

Testing in rehabilitation centers may be a prerequisite for assessment of wheelchair-specific fitness in people with SCI. Testing seems necessary, as predicting wheelchair-specific fitness using personal and lesion characteristics can be inaccurate.[2] Rehabilitation centers appear convenient as testing locations, since a rehabilitation center is easy accessible and familiar to most people with SCI, while clinicians working in these centers have specific knowledge of exercise physiology in people with SCI.

Wheelchair-specific fitness is comprised of different components, as previously described.[49] Components such as anaerobic work capacity, isometric strength, submaximal fitness and peak aerobic work capacity are assumed to reflect the capacity needed in various wheelchair activities of people with SCI.[49] Such activities include propelling a long distance, propulsion over uneven surfaces and ascending a ramp.[50] Each of these components appears to require a separate test when using wheelchair-specific fitness tests feasible for use in rehabilitation centers: only weak or moderate associations were found among different wheelchair-specific fitness components in the group of inactive people with long-term SCI (chapter 5).

Prerequisites for widespread implementation of wheelchair-specific fitness tests in rehabilitation centers include availability and affordability of testing tools, minimizing time and burden of each test for clinicians as well as participants, in addition to showing acceptable psychometric test properties.[51] Within this context, wheelchair-specific fitness tests are discussed below, while making use of findings in chapters 4-6. Tests discussed cover the wheelchair-specific fitness components anaerobic work capacity, isometric strength, submaximal fitness and peak aerobic work capacity.

Anaerobic work capacity

To assess wheelchair-specific anaerobic work capacity, it has been accepted to use peak or mean power output over a Wingate-like 30 s-sprint test on a wheelchair roller or ergometer.[4,52,53] Such immobile lab-based equipment is currently not feasible or available for use in rehabilitation centers. More feasible and available are mobile commercialized measurement wheels.[54] These force and torque-instrumented wheels allow determining power output over an overground wheelchair sprint, such as in a 15 m-sprint presented in chapter 4. The evaluation in chapter 4 suggests that peak power output over a 15 m-overground wheelchair sprint is acceptable for assessment of wheelchair-specific anaerobic work capacity.

Feasibility of this 15-m test for use in rehabilitation centers is indicated by positive experiences of test leaders as well as participants in the RCT (chapter 6). For example, preparing and conducting the test took about 10-15 min, which included replacing the participant's wheel with the instrumented wheel, setting up the software, explaining test instructions and performing the test. A transfer to another measurement device was not necessary, while participants felt they recovered quickly from the test. Feasibility could be improved by solving technical problems that occurred while using the instrumented wheel. For example, software problems led in some occasions to time loss, while force and torque sensors required repairs over the three-year period of the RCT. Further study is required on psychometric properties of the 15-m test such as its sensitivity to individual changes over time,[55] while purchasing costs of the instrumented wheel might limit widespread implementation. Affordability could be improved by developing low-cost methods to determine power output in an overground-wheelchair sprint, which might be found in a commercially available wheel only tailored towards measurement of power output.[56]

An alternative for overground sprinting with a measurement wheel could be to develop a feasible, affordable wheelchair roller that allows high resistances. These resistances are generally not found in overground wheelchair sprinting, leading to relatively high handrim velocities (chapter 4). Higher handrim velocities in wheelchair-sprint tests may imply that peak power output is more dependent on motor coordination and less on anaerobic energy systems.[57] This could be prevented when using a wheelchair roller that allows resistance to be adjusted to fit a participant's capacity.

Instead of using power output to assess wheelchair-specific anaerobic work capacity, it has been proposed to use time or distance in overground wheelchair sprints.[58,59] For example, distance over a 30-s overground wheelchair sprint test was considered valid in assessment of wheelchair-specific anaerobic work capacity of wheelchair athletes.[59] However, feasibility and validity of such tests have not yet been evaluated in non-athletic people with SCI. Furthermore, any overground wheelchair test is only valid for evaluating changes when not only wheelchair configuration, but also floor surface does not vary over time.[60]

Isometric strength

Assessment of wheelchair-specific isometric strength is considered acceptable based on peak force over an isometric-push test on a wheelchair ergometer,[2,61] but such equipment is currently not available or feasible for use in rehabilitation centers. The ergometer is not required in a similar test using a participant's own wheelchair attached to a force transducer.[62] This test requires relatively low-cost hardware (strain gauge transducer, a lightweight pulley and cord that can handle forces up to 1000 N). The test was employed in studies in chapter 5 and 6 and seemed feasible for use in rehabilitation centers: time to prepare and conduct the test in the RCT was about 10-15 min, software allowed immediate determination of its peak force outcome and most participants did not experience the test as a large burden. The test's psychometric properties have not yet been evaluated in detail.

Submaximal fitness and peak aerobic work capacity

To assess wheelchair-specific submaximal fitness and peak aerobic work capacity, a protocol consisting of wheelchair propulsion on a motor-driven treadmill has been developed.[10,63] This treadmill protocol comprises submaximal propulsion blocks and a peak graded exercise test, through which mechanical efficiency, peak power output and peak oxygen uptake are determined.[10,63] These measures are considered valid for assessment of wheelchair-specific submaximal fitness and peak aerobic work capacity in people with SCI.[10,49,63]

The treadmill protocol requires some adaptations to improve assessment of submaximal fitness and peak aerobic work capacity in people with very low fitness levels. These people require a relatively low power output in the submaximal test (chapter 6). Lower power output implies a higher sensitivity to measurement error in mechanical efficiency.[64] Less sensitivity to measurement error will occur when using oxygen uptake kinetics.[65,66] Although determining oxygen uptake kinetics requires longer periods of propulsion,[66] it might be employed when accurate assessment of submaximal fitness is required. However, it is not yet clear whether such a protocol is feasible in people with very low fitness levels.

An adaptation in the peak graded exercise tests could be to use smaller incremental steps in people with relatively low fitness levels. When using the current protocol, some floor effects were observed in participants with the lowest fitness levels (chapter 5). For example, some participants already reached peak performance after two minutes, while six to 12 minutes is considered optimal for reaching peak performance.[67] Ideally, what step size is required to reach peak performance in six to 12 minutes should be estimated beforehand. This might be possible using peak power output over the 15-m test, as suggested by its moderate association to peak power output in the graded exercise test (chapter 5). Such a method has been adopted in a wheelchair ergometer protocol (appendix).[20,61]

The treadmill protocol requires equipment that is relatively expensive and only available in some rehabilitation centers.[51,68] However, currently no valid alternative is available based on more accessible and affordable equipment. Low-cost alternatives based on field tests have been proposed, for example distances covered in field-based overground wheeling tests.[60,69] However, these distances do not accurately reflect peak aerobic work capacity, as for example found in a six-minute overground wheeling test.[60,69] Still, such a test does allow a rough estimate of peak aerobic work capacity. It might be employed as a screening tool for low fitness when equipment for the peak graded exercise test is not available,[69] but only when floor surface and wheelchair configuration are standardized over time.[60]

DIRECTIONS FOR FUTURE RESEARCH

Below, recommendations for future research will be formulated based on the findings in chapters 2-7 and the discussion in this chapter. These recommendations are presented within the contexts of wheelchair-specific fitness of people with long-term SCI, alternative interventions to the low-intensity training in the RCT and assessment of wheelchair-specific fitness in rehabilitation centers.

Wheelchair-specific fitness of people with long-term SCI

Longitudinal studies are recommended to further investigate causality of relationships among physical activity, fitness and secondary health complications in people with long-term SCI. Such longitudinal studies should cover relatively long periods of life with SCI (> 10 years). These could be set up as continuations of earlier research programs on fitness and physical activity.[70] For example, in a previous research program in the Netherlands, people with SCI were followed during rehabilitation and up to five years after discharge.[71] These people could be invited for measurements over the years after that.

Further research is also recommended on selection bias in cross-sectional and longitudinal studies on physical activity and fitness in people with SCI, providing more insight into generalization of findings to the population with long-term SCI. For this purpose, eligible people that agree or decline to participate in such studies should be compared to each other on personal and lesion characteristics, physical activity levels as well as barriers and facilitators to participation.[29,72]

Alternative interventions to the low-intensity training in the RCT

Future research is recommended on alternative interventions to the low-intensity training in the RCT, for example on effects of low-intensity wheelchair training at a frequency of three times a week or more. For this purpose, a feasible training format should first be developed that enables inactive people with long-term SCI to exercise more than twice a week. Potentially feasible formats may be found in community-based exercise, for example in a local fitness center, or home-based exercise.

Another recommendation for future research is effectiveness of wheelchair training over periods longer than 16 weeks. This research should focus on the question whether a relatively long period of low-intensity wheelchair training allows gradually building up to higher, more effective wheelchair exercise intensities.[73]

Further study is also recommended on effectiveness, safety and feasibility of training consisting of other modalities than wheelchair propulsion. For example, a study could focus on effects of a combination of moderate-intensity handcycle training and low-intensity wheelchair training on wheelchair-specific fitness and wheelchair skill performance in inactive people with long-term SCI. Furthermore, risk of injury in resistance training should be evaluated in inactive people with long-term SCI, in addition to investigating what intensities are feasible for this population, for example the maximum number of repetitions at different percentages of 1 RM.[23]

When evaluating effectiveness of exercise interventions such as those described above, RCTs are considered to provide the strongest evidence to support use of an intervention in clinical practice.[74,75] However, RCTs on exercise interventions in people with SCI commonly show inconclusive results.[74] These inconclusive results for example rise from insufficient sample size, high dropout rates and large heterogeneity in a study group with SCI,[17] as also appeared in the RCT in this thesis. Although inconclusive results in an RCT could be used in future meta-analyses,[74,76] this might not always be possible due to the variety in test protocols over different studies. Relatively large samples may be recruited in internal multicenter RCTs, but these will probably remain rare due to high financial costs and challenges in feasibility.[17] Alternatively, a large sample may be recruited in RCTs on disability groups with similar functional capacity, for example manual wheelchair users with paraplegia, post-polio and amputee.[75] In such RCTs, differences among groups could be studied using multilevel analyses,[77] but interpreting results may still be difficult due to physiological variations in muscle paralysis and the autonomic nervous system. Another disadvantage of RCTs is that their focus for high internal validity reduces ecological validity, comprising implementation in practice.[78,79]

Research on alternative exercise interventions in people with SCI is therefore recommended to start with the use of other study designs than an RCT.[79] For example, a single-case design should first be used to study effects and feasibility of low-intensity wheelchair training at a high frequency in a supervised home-based format. Such a study requires mixed methods, consisting of quantitative and qualitative measurements, to assess effects and feasibility.[79,80] In addition, multiple measurement occasions need to be conducted before, during and after the intervention period to evaluate day-to-day variations in fitness. Furthermore, the need for ecological validity should precede the need of internal validity,[79] implying that the training protocol can be optimized based on quantitative and qualitative measurements during the intervention period. In such a feasibility study, it is recommended to use a process that includes combining the experience of researchers, clinicians and participants.[81]

Following, when studying training effects on a group level, it is recommended to use a step-by-step approach that consists of studies with designs of increasing sample size, robustness and number of outcome domains. For example, a first step in evaluating effectiveness of an exercise intervention is an uncontrolled study on a relatively small sample, including only one outcome domain. If the intervention appeared effective, a larger sample may be recruited for a study in which participants serve as their own control (cross-over design), while using two outcome domains. An alternative is a study in which a control group is formed of participants that live too far from the location where exercise takes place (non-randomized design).[17] Based on these studies, it may be decided whether evidence of an RCT is required.

In any study concerning training effects on a group level, additional insight is gained by performing analyses on interindividual differences.[82,83] This may for example help to discern potential responders and non-responders to an exercise intervention.

Last, it is recommended to investigate whether programs aimed at stimulating physical activity and sports through teaching self-management skills and exercise counseling are effective for improving wheelchair-specific fitness and physical activity levels in inactive people with long-term SCI. This question may be answered using currently ongoing studies: a self-management intervention within research program ALLRISC[47] and a study that recently started on physical activity and exercise counseling for people with a disability.[46]

Assessment of wheelchair-specific fitness in rehabilitation centers

Future research on wheelchair-specific fitness tests feasible for use in rehabilitation centers should be directed at psychometric properties such as sensitivity to individual changes over time.[55] This research could also be used to develop reference scores on the tests for subgroups differing in personal and lesion characteristics.[55] Furthermore, future study is needed to investigate to what extent field-based wheelchair-specific tests such as a 30-s overground wheelchair sprint[59] and a six-minute wheeling test[69] are valid and feasible for assessment of wheelchair-specific fitness in inactive people with long-term SCI. Focus is also recommended on developing more affordable test equipment, as this can facilitate implementation of wheelchair-specific fitness tests in rehabilitation centers.

In gaining knowledge on affordable, feasible tests with acceptable psychometric properties, the following process could be employed: 1) researchers developing ideas for a test; 2) companies developing affordable equipment for the test; 3) clinicians and people with long-term SCI assessing feasibility of the test; 5) researchers investigating psychometric properties; 6) implementing the test in clinical practice; and 7) evaluating the implementation process.[51] Such a process requires close collaboration between researchers, companies, clinicians and people with SCI.

Clinical implications

Physical inactivity and a long TSI seem to contribute to low or declining wheelchair-specific fitness in people with SCI. This implies that inactive people with long-term SCI are likely to enter a vicious cycle of physical inactivity, deconditioning and secondary health complications.[1,7-9] Such a cycle may expose people to impaired participation in society and lower quality of life, while also leading to higher health care costs.[84,85] Mitigating these negative effects is possible through supporting people with SCI in preventing physical inactivity and deconditioning.[1,35,86-88] Effective, safe and feasible interventions may need to be offered when low physical activity and fitness levels are already present.[8,87]

Low-intensity wheelchair training is a safe exercise intervention for inactive people with long-term SCI, but little effect can be expected when participants exercise for 16 weeks, twice a week, 30 min per session on a treadmill in a rehabilitation center. Unfortunately, more effective interventions are not yet available. Perhaps more effects are found in interventions such as low-intensity wheelchair training at a higher frequency or training using other modalities, but this is currently not clear. When developing more effective exercise interventions, safety and feasibility for participants is of primary concern.[29,72] If not, there is risk of dropout as well as low exercise participation and adherence.[23] Feasibility for participants might be better in supervised exercise at home or at local fitness center than in a rehabilitation center[23,39]: center-based exercise can be more burdening due to time and effort for travelling.[27-29] Feasibility may also be optimized by structured exercise counseling, in which people are supported in finding what type of intervention best fits their needs.[46]

The current absence of more effective, safe and feasible exercise interventions for inactive people with long-term SCI emphasizes that preventing physical inactivity and deconditioning requires more focus in health care for people with SCI.[35,88] If successful, people with SCI may not enter a vicious cycle of physical inactivity, deconditioning and secondary health complications. Preventing negative effects of this cycle may be supported by regular screening and structured aftercare that covers the lifespan of people with SCI.[1,86]

Regular screening for low or declining wheelchair-specific fitness may be implemented during and after inpatient rehabilitation.[10,89] For this purpose, fitness could be assessed in rehabilitation centers using wheelchair-specific fitness tests discussed and evaluated in this thesis. Reference scores might be based on fitness levels presented in chapters 2 and 5 as well as in previous studies.[55] People identified with low or declining fitness should be offered counseling on benefits and ways to increase physical activity.[46,90] Such counseling does not yet seem part of regular clinical practice, although patients have reported to be looking for it.[91] Perhaps implementation requires further education of clinicians in counseling on physical activity and exercise.[90,91] Furthermore, clinicians should be provided with allocated time for such counseling, similar to time reserved for drug counseling and therapies.[90,91]

Structured aftercare of people with SCI could also include screening for risk of secondary health complications, supporting prevention of physical inactivity and low fitness.[92] If risk is high, clinicians could offer educational or self-management interventions aimed at preventing secondary health complications.[47]

CONCLUSIONS

Most inactive people with long-term SCI seem to have low wheelchair-specific fitness levels, implying they are likely to enter a vicious cycle of physical inactivity, deconditioning and secondary health complications. Relatively little improvement in their wheelchair-specific fitness may be expected as a result of low-intensity wheelchair exercise for 16 weeks, two times per week, 30 min per session. This training also seems to have little effect on wheelchair skill performance, physical activity levels and propulsion technique in inactive people with long-term SCI. Research on more effective exercise interventions should start with developing feasible training formats for this population. Such research may be facilitated by using other designs than an RCT.

Challenges in finding effective, safe and feasible exercise interventions for inactive people with long-term SCI indicates that more focus should lie on preventing physical inactivity and deconditioning. For this purpose, screening and exercise counseling could become part of an aftercare system that covers the lifespan of people with SCI. For example, screening for low or declining fitness could be implemented in rehabilitation centers, for which the wheelchair-specific fitness tests in this thesis seem feasible. Counseling on physical activity and exercise may support people with long-term SCI in finding what best fits their needs in preventing physical inactivity and deconditioning.

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Appendix

Hand rim wheelchair training:

Effects of intensity and duration on physical capacity

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ABSTRACT

Purpose: The purpose of this study was to compare the effects of intensity and duration of training on physical capacity in a 7 weeks hand rim wheelchair training in able-bodied men.

Methods: Thirty-six able-bodied men participated in three groups: a 30%heart rate reserve (HRR) 70 min training group (*N*=14), a 70%HRR 30 minutes training group (*N*=13) and a 30%HRR 70 minutes training group (*N*=9). All groups trained 3 times per week for 7 weeks on a treadmill. Pre and post-tests on a wheelchair ergometer comprised a submaximal test at 20% and 40% of the estimated peak power output, in which submaximal heart rate, oxygen uptake and mechanical efficiency were determined. In maximal exercise tests, maximal isometric strength, sprint power, peak power output and peak oxygen uptake were measured.

Results: No significant differences were found between the training groups on submaximal and maximal parameters.

Conclusion: It can be concluded that, in persons new to wheelchair use, seven weeks of wheelchair endurance training at an intensity of 30%HRR for 30 minutes is as effective as a training at a higher intensity (70%HRR) or with a longer duration (70 min).

INTRODUCTION

During almost all activities of daily living, wheelchair-dependent persons rely on their upper-body only. Because the physical strain can be very high during wheelchair-related activities of daily living,[1] upper-body strength and cardiovascular endurance are extremely important for the independence of individuals who use manual wheelchairs.[2] The physical capacity of wheelchair-dependent individuals is often low as a result of the disability and sedentary lifestyle,[3] however, can be improved by training.[2]

Regular training programs are often based on the guidelines of the American College of Sports Medicine (ACSM) recommending minimum exercise intensities of 40% of the heart rate reserve (HRR).[4] These guidelines are initially meant for large leg muscle training and are effective in full-cyclic and more efficient upper-body exercise, such as cycling but also handcycling.[5] Van der Woude *et al.*[2] showed that a 70%HRR as well as a 50%HRR intensity hand rim wheelchair training (30 minutes, 3 times per week) were effective in improving the physical capacity of able-bodied men. However, such training intensities are deemed to lead to fatigue and pain in hand rim wheelchair propulsion at the start of inpatient rehabilitation. This might be due to the small muscle mass involved and the discontinuous movement pattern introducing high mechanical and physiological peak strains.[6] Van Drongelen and colleagues[7] showed that 39% of the persons with a spinal cord injury had shoulder musculoskeletal pain at the start of inpatient rehabilitation. They concluded that at the beginning of inpatient rehabilitation, one should be very careful to prevent overload and, therefore, should focus on a balanced training of the upper-body muscular system.[7] Furthermore, at the start of the rehabilitation process it might be difficult for patients to get motivated for high-intensity exercise training at all. In that respect, low-intensity wheelchair training might be very useful in the early rehabilitation setting when the physical capacity of patients is often low[8] and musculoskeletal complaints occur frequently.[7] Haskell[9] was among the first to stress the importance of low-intensity exercise for rehabilitation populations and frail elderly. A previous study[10] showed that a 30%HRR intensity hand rim wheelchair training (30 minutes, 3 times per week) was also effective in improving the physical capacity in able-bodied men compared to a non-training control group. From the above-mentioned wheelchair training studies we know that all training groups (at 30%, 50% or 70%HRR)[2,10] showed an improvement in physical capacity compared to a control group and that there were no statistical differences between the 50% and 70%HRR training groups. However, the very low (30%) and high (70%) intensity groups have not been compared yet. Furthermore, the effect of duration of training has not yet been investigated. Therefore, in the present study, a group was trained at a low-intensity (30%HRR) but the duration of this training was lengthened to 70 minutes per training session. In this way, a comparable dose (frequency x duration x intensity) is achieved as the high intensity training group in the previous study of Van der Woude et al. (70%HRR for 30 minutes).[2] Furthermore, the effect of duration of the training can be evaluated by comparing the results of this new training group (3 times per week for 70 minutes at 30%HRR) with the results of the low-intensity training group of Van den Berg *et al.*[10] with an identical frequency and intensity but a shorter duration (30 minutes).

The purpose of the present study was to investigate the effects of intensity and duration of wheelchair training on the physical capacity (maximal isometric strength, sprint power, peak aerobic capacity and submaximal performance) of able-bodied men inexperienced in wheelchair propulsion.

METHODS

Participants

Fourteen able-bodied men who were inexperienced in wheelchair propulsion were included in this study. Inclusion criteria were: male, 18-30 years of age, no engagement in sports that extensively train the upper extremities over the last year, no experience in wheelchair propulsion, and no medical contra-indications. The experiment was approved by the ethics committee of the Faculty of Human Movement Sciences, VU University Amsterdam, the Netherlands. Prior to experimentation, the participants gave their written informed consent. Characteristics of the participants are summarized in table 1.

Table 1. Mean and standard deviation (SD) of the participant characteristics for the three groups and results of the one-way ANOVA among groups at pre and post-test.

		30%-70min (*n*=14)	**30%-30min** (*n*=10)	**70%-30min** (*n*=13)	*p*
		Mean ± SD	Mean ± SD	Mean ± SD	
Age (y)		23.5 ± 3.5	22.7 ± 2.0	21.9 ± 3.2	0.41
Height (cm)		180.9 ± 10.5	183.7 ± 4.8	184.2 ± 8.3	0.57
Body mass (kg)	pre-test	73.0 ± 12.5	76.8 ± 4.9	71.8 ± 6.0	0.39
	post-test	73.2 ± 12.0	77.0 ± 5.1	71.5 ± 6.4	0.36

Statistical comparisons based on one-way ANOVA's.

Design

A group of 14 men was trained at a low-intensity and with a long-duration (30%HRR-70min), and compared with previously trained and measured groups: a low-intensity short-duration training group (30%HRR-30min, N=9)[10] and a high-intensity short-duration training group (70%HRR-30min, N=13)[2]. All training groups participated in a 7-week wheelchair training, with a frequency of three times per week. The training was performed on two motor-driven treadmills (Vrije University (VU): Enraf Nonius, model 3446, Delft, the Netherlands. Reade, centre for Rehabilitation & rheumatology (Reade): Bonte BV, model GTR 2.50, En-Bo systems, Zwolle, the Netherlands) with two standardized wheelchairs (VU: Quickie Triumph, Reade: Sopur® Starlight). Before and after training, participants performed an isometric strength test, sprint test, submaximal and peak exercise test on a wheelchair ergometer.[2] All post-tests were identical to the pre-tests in terms of speed, resistance (and thus submaximal power output settings), wheelchair ergometer settings and protocols.

Wheelchair ergometer tests

Participants performed an exercise test on a computer-controlled wheelchair ergometer, which measures forces and torques applied to the hand rims.[11]

Isometric strength tests

First the maximal isometric strength test was conducted to determine the maximal force (Fiso) that the participant could exert on the hand rim. Three consecutive 5-s maximal force exertions were performed with the hands placed on top of the blocked hand rims. The effective force was averaged over the highest three seconds of each trial. The highest value of the three trials was defined as the maximal isometric strength of the person. With the results of the isometric strength test, the individual's peak power output was estimated ($\text{POpeak}_{\text{est-I}}$) according to the equation of Janssen *et al.*[12]

$$\text{POpeak}_{\text{est-I}}\ (\text{W}\cdot\text{kg}^{-1}) = 0.34 \cdot \text{Fiso}\ (\text{N}\cdot\text{kg}^{-1}) - 0.02$$

Sprint test

On completion of the isometric strength test participants rested for 8 minutes. Then they performed a warming up for 3 minutes, and rested again 3 minutes. Before starting the sprint test, estimated sprint power (P30_{est}) was determined by using the equation between Fiso and the sprint power[12] to be able to set an individualized resistance level, i.e.:

$$\text{P30}_{\text{est}}\ (\text{W}\cdot\text{kg}^{-1}) = 0.51 * \text{Fiso}\ (\text{N}\cdot\text{kg}^{-1}) - 0.18$$

The resisting force (F_r) was calculated from P30_{est} and an average velocity that had to stay below the 2 $\text{m}\cdot\text{s}^{-1}$ to prevent coordination problems[12]:

$$F_r\ (\text{N}\cdot\text{kg}^{-1}) = (\text{P30}_{\text{est}} \cdot v^{-1} \cdot \text{W}^{-1})$$

The sprint test started at zero velocity and then the participants performed an all-out sprint for 30 s. Sprint power (P30) was defined as the mean power output during the 30-s test period (sum of right and left wheel).

Submaximal exercise test

Following a 10 minute resting period the submaximal exercise test was performed, which consisted of two blocks of three minutes wheelchair propulsion with an intensity of respectively 20% and 40% of the estimated POpeak[2] and a velocity of 1.39 $\text{m}\cdot\text{s}^{-1}$. The estimated POpeak was calculated[12] as follows:

$$\text{POpeak}_{\text{est-II}}\ (\text{W}\cdot\text{kg}^{-1}) = 0.67 \cdot \text{P30}\ (\text{W} \cdot \text{kg}^{-1}) + 0.11$$

During the test, oxygen uptake (VO2) was measured breath-by-breath with a computerized gas analyzing system (Oxycon Alpha, Jaeger, Bunnik, the Netherlands), which was calibrated before each test. Furthermore, heart rate (HR) recordings were made with a sporttester (Polar sport tester, Polar electro Inx, Kemple, Finland). Average values over the third minute of each exercise block were determined ($VO2_{20}$, $VO2_{40}$, HR_{20}, HR_{40}). During the last 15 s of each block, ergometer data (torque [M] and angular velocity [ω]) were recorded to calculate the power output (PO)[2]:

$$\text{PO} = \text{M} \bullet \omega\ (\text{W})$$

Energy expenditure (En) was calculated with the VO2 and respiratory exchange ratio (RER) values[13] and subsequently, the gross mechanical efficiency (ME_{20} and ME_{40}) was calculated with the equation:

$$\text{ME} = \text{PO} \cdot \text{En}^{-1} \cdot 100\%$$

Peak exercise test

Immediately after the submaximal exercise blocks the peak exercise test started with a workload of 20% estimated POpeak. The intensity increased every minute with 10% estimated POpeak, with a constant velocity of 1.39 $m \cdot s^{-1}$, until exhaustion. The absolute PO and speed for each individual were identical at the pre and post-tests. The VO2 values obtained during the last 30 s of the peak exercise test were averaged and considered as peak value (VO2peak). Furthermore, the power output was determined as the average of the last 15 s of a block. POpeak was defined as the highest PO achieved during the test. Peak work capacity was operationally defined as volitional fatigue, limiting symptoms, or the point at which increasing the workload failed to provoke further increased oxygen uptake, and evidently the inability to maintain the required speed.

Training

Participants received a 7 week training on a treadmill, three times per week at 30%HRR for 70 min, and were compared to groups that trained at 30%HRR for 30 min or 70%HRR for 30 min per session.[2,10] Before the first training session a drag test was performed to determine rolling resistance and internal friction of the wheelchair. The required HR during the training (HRtraining) was determined according to the formula

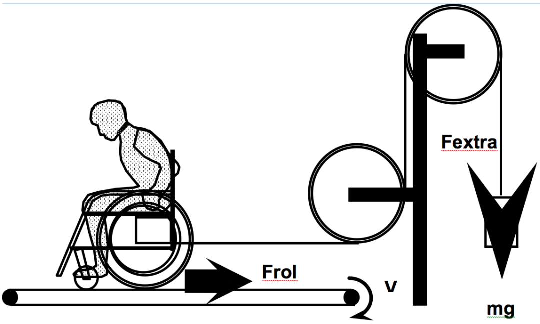

Figure 1. To impose the desired power output during the training a pulley-system attaches to the instrumented wheelchair on the treadmill.

of Karvonen *et al.*[14] by using the peak heart rate (HRpeak) and HR during rest, both measured during the pre-test. The required PO, which elicited an intensity of 30%, was determined by the linear relation between HR and PO, measured during the peak aerobic exercise test pre-training.[2] When needed, the resistance was increased by an additional pulley force (figure 1).[2]

The training stimuli varied according to three different patterns of the training intensity (figure 2).[2] The patterns were designed such that the mean product of resisting force and velocity resembled a heart rate response of 30%HRR over the session. Every three minutes the velocity or resistance force was changed. In the velocity training, the resistance force was kept constant over the training session, while the velocity was changed. In the resistance training, the velocity was kept constant over the training session at 1.39 $m \cdot s^{-1}$, while the resistance force was changed. The HR was closely monitored and recorded during the training to make sure that the proper training intensity was maintained as the training progressed.

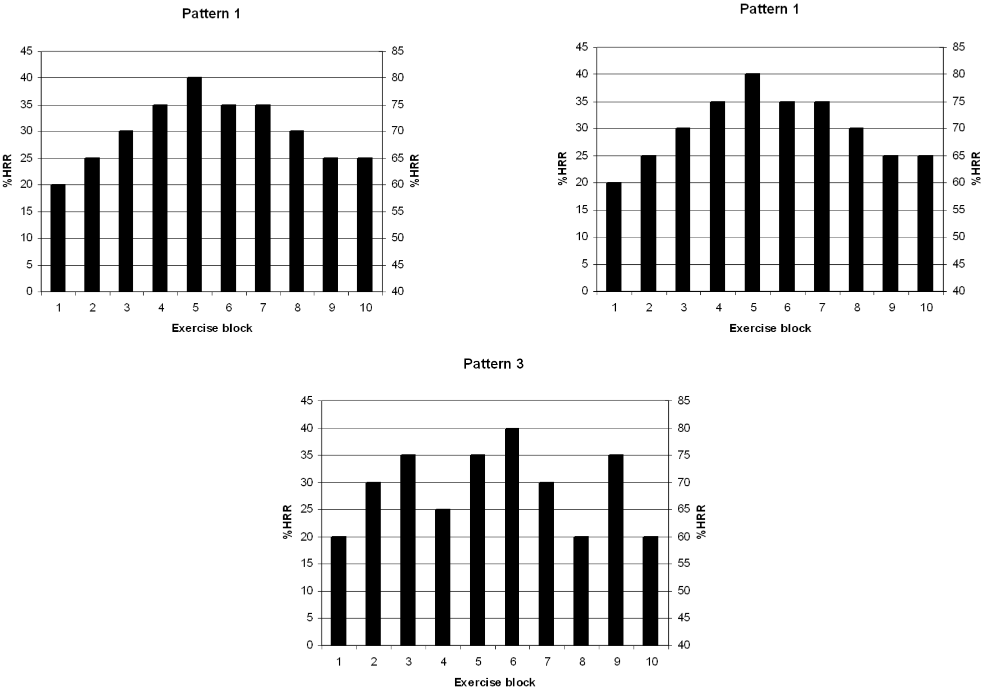

Figure 2. Representation of temporal patterns of the training sessions for the low-intensity (30%HRR, left y-axis) and norm-intensity (70%HRR, right y-axis) training groups.

Statistics

To evaluate possible differences between the three training groups regarding participant characteristics (age, height, body mass) or physical capacity (Fiso, P30, POpeak, VO2peak, $VO2_{20}$, $VO2_{40}$, HR_{20}, HR_{40}, ME_{20}, ME_{40}) at the start of the study a one-way ANOVA was executed.

Effects of training on physical capacity were analyzed using a repeated measures ANOVA for each of the parameters individually. The between-subject factor was group (30%HRR for 70min, 30%HRR for 30min, 70%HRR for 30min), the within-subject factor was test (pre-post). If necessary, the outcomes of the pre-test were added as a covariate (ANCOVA) to adjust for significant differences between the groups at baseline. Interaction of the within and between variables (group x time) was of special interest and considered significant when $p<0.05$. To identify the potential differences found with the repeated measures ANOVA, post-hoc repeated measures ANOVAs were performed with a Bonferroni correction of $p< 0.0167$ (0.05/3 tests).

RESULTS

No differences in participant characteristics were found between the groups at the pre-test (table 1), however, significant differences were found between the groups for Fiso, POpeak, VO2peak, ME20 and ME40 (table 2). Analysis of the HRR data obtained during the training revealed that the average training intensity was 33%HRR for the 30%HRR-70min group, 28.8%HRR for the 30%-30min group and 67%HRR for the 70%HRR-30min group. All participants completed all training sessions.

Isometric strength

Fiso showed an increase in all training groups (30%HRR-70min: +55 N; 30%HRR-30min: +29 N; 70%HRR-30min: +41 N), but this increase was not significantly different between the groups (interaction term group*time: p=0.56; table 2).

Sprint power

Changes in P30 over time were not significantly different between the training groups (interaction term group*time: p=0.28). The 30%HRR-70min group showed a significant increase from pre to post-tests in P30 of 30W, the 30%HRR-30min group of 35W and the 70%HHR-30min group of 22 W (table 2, figure 3).

Peak exercise test

All training groups showed an increase in POpeak and this improvement was not significantly different between the groups (interaction term group*time: p=0.27, table 2). The increase in POpeak varied between 23-29 W (table 2, figure 3). VO2peak significantly improved between pre and post-tests, but appeared not different among the training groups (interaction term group*time: p=0.25, table 2, figure 3).

Submaximal exercise

No significant differences were found between the three training groups in the submaximal parameters VO2, mechanical efficiency and heart rate (table 3, figure 3). All groups showed a comparable decrease in submaximal VO2 and heart rate and an increase in mechanical efficiency from pre to post-tests.

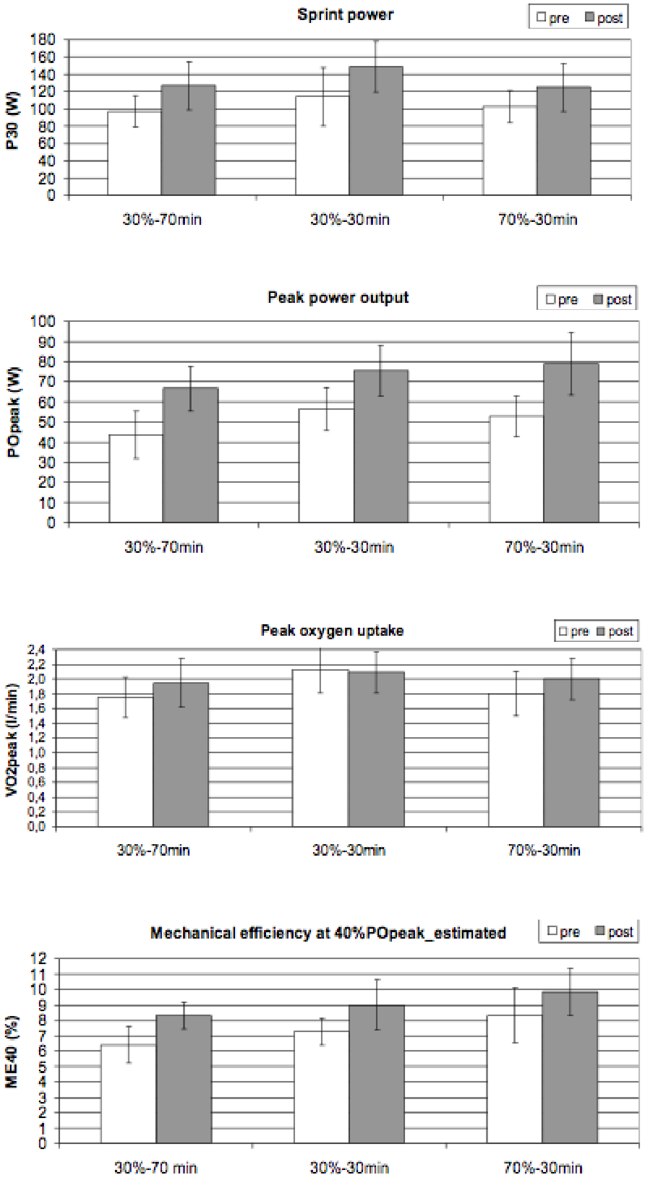

Figure 3. Mean and SD of the pre and post-test values for sprint power (P30), peak power output (POpeak), peak oxygen uptake (VO2peak) and the mechanical efficiency (ME_{40}) for the low-intensity, long-duration training group (30%-70 min), the low-intensity, short-duration training group (30%-30min) and norm-intensity, short-duration training group (70%-30 min).

Table 2. Mean and SD for isometric strength (Fiso), sprint power (P30), maximal power output (POpeak), peak oxygen uptake (VO2peak), and peak heart rate (HRpeak) for the three groups pre and post-training and the results of the repeated measurements ANOVA.

		30%-70 min		**30%-30 min**		**70%-30 min**		**Pre vs. post**	**Group*time**
		Mean ± SD	*N*		*N*		*N*	*p*	*p*
Fiso (N)*	pre	391.0 ± 92.9	14	475.8 ± 84.3	9	243.5 ± 75.1	13	0.78	0.56
	post	446.0 ± 150.9		494.8 ± 109.0		285.8 ± 84.7			
P30 (W)	pre	97.0 ± 18.2	14	114.0 ± 33.5	9	102.7 ± 18.9	13	<0.001	0.28
	post	126.7 ± 27.5		148.7 ± 29.2		124.8 ± 27.8			
POpeak (W)$^{+}$	pre	43.7 ± 11.9	14	56.5 ± 10.7	9	52.9 ± 10.2	13	<0.001	0.27
	post	66.7 ± 11.2		75.6 ± 12.6		79.0 ± 15.4			
VO2peak (l/min)$^{\#}$	pre	1.75 ± 0.27	14	2.13 ± 0.32	9	1.80 ± 0.30	13	0.014	0.25
	post	1.95 ± 0.33		2.09 ± 0.28		2.00 ± 0.28			
HRpeak	pre	182 ± 12	13	171 ± 17	9	175 ± 13	13	0.38	0.19
	post	176 ± 17		171 ± 21		176 ± 12			

* = 70%HRR-30min showed a significantly lower Fiso than the 30%HRR training groups at the pre-test.

$^{+}$ = 30%HRR-70min showed a significantly lower POpeak than the 30%HRR-30min training group at the pre-test.

$^{\#}$ = 30%HRR-30min showed a significantly lower VO2peak than the 30%HHR-30min and 70%HRR-30min training groups at the pre-test.

Table 3. Results of the submaximal tests: mean and SD of oxygen uptake (VO2), mechanical efficiency (ME) and heart rate (HR) at 20% estimated POpeak and at 40% estimated POpeak for the three groups pre and post-training, and the results of the repeated measurements ANOVA.

		30%-70 min		**30%-30 min**		**70%-30 min**		**Pre vs. post**	**Group*time**
		Mean ± SD	*N*		*N*		*N*	*p*	*p*
$VO2_{20}$ (l/min)	pre	0.86 ± 0.15	14	0.86 ± 0.17	9	0.79 ± 0.14	13	<0.001	0.44
	post	0.68 ± 0.10		0.69 ± 0.12		0.67 ± 0.08			
$VO2_{40}$ (l/min)	pre	1.17 ± 0.23	14	1.17 ± 0.21	9	1.15 ± 0.20	13	<0.001	0.43
	post	0.92 ± 0.14		0.95 ± 0.11		0.98 ± 0.13			
ME_{20} (%)*	pre	4.32 ± 1.27	14	5.36 ± 0.99	9	6.25 ± 1.59	13	<0.001	0.30
	post	5.65 ± 0.82		6.27 ± 0.98		7.36 ± 1.60			
ME_{40} (%)*	pre	6.41 ± 1.17	14	7.25 ± 0.88	9	8.33 ± 1.80	13	<0.001	0.88
	post	8.32 ± 0.89		9.00 ± 1.61		9.85 ± 1.54			
HR_{20} (bpm)	pre	125 ± 22	14	111 ± 19	9	111 ± 14	13	<0.001	0.46
	post	105 ± 13		97 ± 16		98 ± 10			
HR_{40} (bpm)	pre	143 ± 25	14	127 ± 22	9	132 ± 17	13	<0.001	0.32
	post	114 ± 16		106 ± 16		112 ± 12			

* = Significant difference between the 30% for 70 min and 70% for 30 min training groups at the pre-test;

DISCUSSION

No significant differences in changes in maximal and submaximal physical capacity parameters were found between the three training groups. This indicates that, in persons new to wheelchair use, a 30 min low-intensity training induces the same effects as training with a longer duration (70 min per session) or at a higher intensity (70%HRR). The intensity of training in the 30%HRR groups was much lower than recommended by the guidelines of the ACSM,[4] which state a minimal training intensity of 40%HRR to improve the physical capacity.

Physiological adaptations to exercise are dependent on the mass of muscle involved. Aerobic exercise with large muscle groups leads to central and peripheral adaptations while exercise with small muscle groups may only lead to peripheral adaptations.[15] Wheelchair exercise may lead to peripheral adaptations specific to the trained arm muscles but central adaptations will be less pronounced due to the lower blood flow and cardiac output requirements during arm exercise. However, efficiency can be improved due to peripheral adaptations, such as for example capillary density, or changes in propulsion technique due to practice. The effect of the duration of training sessions, and thus of practice time, was studied by training a group at an intensity of 30%HRR but for 70 min per session, which has not been done before. The extra training time of 40 min per session did not lead to more improvement in physical capacity. However, a minimum amount of practice time seems to be important. With more practice time, participants might be able to improve the propulsion technique more and subsequently their metabolic cost. When comparing results from previous wheelchair training studies, an increase in practice time from 12 min[16] to 84 min[17] to 630 min (30% or 70%HRR-30min)[18] to 1470 min (30%HRR-70min) showed larger changes in ME (from +0.08% to +0.95% to +1.8% to +1.9%, respectively), with most change in the beginning of a practice period (between 12-630 min). This increase in ME in the above-mentioned studies was accompanied by an improvement in propulsion technique, i.e. a lower push frequency and subsequently increase in work per cycle. However, the study groups were tested approximately at the same power output (23-27 W) but practiced at a different power and intensity so no strong conclusion can be drawn regarding the effect of practice time on physical capacity.

Our previous study showed that the 70%HRR-30min group showed a significant improvement in VO2peak compared to a control group.[2] However, the 50%HRR group[2] and 30%HRR group[10] did not show a significant increase in VO2peak compared to a control group. In contrast, previous studies found a significant increase in VO2peak in low, moderate or high intensity training groups in elderly[19], patients with chronic heart failure[20] and cancer survivors.[21] One of the differences between these studies and our study is the type of training, i.e. lower-body (large muscle mass) versus upper-body (small muscle mass) exercise. From the above-mentioned results, it seems that for an increase in VO2peak high-intensity upper-body exercise or exercise with a larger muscle mass is necessary.

Little is known about the benefit of low-intensity training in healthy as well as in disabled participants. Low-intensity lower-body aerobic exercise training (25-35%

or 40-50%HRR, 3x 14-32 min per week for 10 weeks) performed by cancer survivors revealed that both training groups did show a significant decrease in body fat, an improvement in aerobic capacity and in quality of life compared to the non-training control group.[21] Another study[19] found that cycling exercise at a low intensity (30-45%HRR, 3x 25 min per week for 9 weeks) is an adequate training stimulus in older individuals and produces changes in peak oxygen uptake that are comparable to those elicited by high-intensity (60-75%HRR) training. Similar increases in VO2peak were found between low (30%HRR) and high (70%HRR) walking exercise intervention groups in postpartum women.[22] The results of these studies and our study strongly indicate that a low-intensity training might be very useful for wheelchair users in early rehabilitation. Even in our fit able-bodied participants, yet untrained with respect to upper-body cyclic wheelchair exercise, favorable changes in physical capacity were found. These changes are probably due to peripheral physiological adaptations and changes in propulsion technique, which also occur at a low intensity and short duration. Since the results of this low-intensity wheelchair training were promising, we will perform a future study including wheelchair users with a spinal cord injury and will investigate the effect of low-intensity wheelchair training (30%HRR for 30 min) on overuse problems, propulsion technique, physical capacity, active lifestyle and health.[23]

Limitations

Since the 70%HRR-30 min and 30%HRR-30 min training groups participated in earlier studies,[2,10] it was not possible to randomize the total group of participants. Although the same inclusion criteria were used, some physical capacity parameters showed a significant difference between the three groups at the pre-test. However, we statistically corrected for pre-test differences between the groups.

Because there was no knowledge available regarding the effect of such a low-intensity wheelchair training on the physical capacity, the present study made a start by including able-bodied men inexperienced in wheelchair propulsion. Relative trends may carefully be generalized to novice wheelchair users in early rehabilitation. Indeed our study population as such they partly mimic novice wheelchair users in early rehabilitation. The absolute values cannot be generalized automatically to wheelchair users with a disability.

CONCLUSION

The present study showed that a low-intensity wheelchair training at 30%HRR and a duration of 30 or 70 min was as effective in improving the physical capacity as a regular intensity training (70%HHR, 30 min) in able-bodied men without wheelchair experience. An improvement in sprint power, peak power output, submaximal VO2, HR and gross mechanical efficiency was found in all training groups. A longer duration of the training sessions (from 30 to 70 min) did not result in more improvement in the physical capacity.

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Summary

SUMMARY OF THIS THESIS

Aim of this thesis was to study the effects of low-intensity wheelchair training on wheelchair-specific fitness, wheelchair skill performance, physical activity levels and propulsion technique in physically inactive people with long-term spinal cord injury (SCI). **Chapter 1** provides the background of this thesis. Muscle paralysis and wheelchair dependence makes it difficult for many people with spinal cord injury to be physically active and fit. They are at risk of entering a vicious cycle of physical inactivity, low fitness and secondary health complications. People with long-term SCI are likely to enter this vicious cycle given age-related declines in physical activity and fitness levels, while also being at increased risk of developing secondary health complications. Negative effects of such a vicious cycle might be prevented or reduced by employing an aftercare system that includes interventions aimed at improving physical activity and fitness levels, while simultaneously reducing risk of secondary health complications. Given the lack of knowledge on this topic, research program 'ALLRISC' was developed. One of the studies in ALLRISC was a multicenter randomized controlled trial (RCT) on low-intensity wheelchair training in inactive people with long-term SCI. Previous research showed that people with SCI can improve fitness through wheelchair training at relatively vigorous intensities. However, it may lead to low adherence, dropout and musculoskeletal injury in inactive people with long-term SCI. The assumption in this thesis was that these problems do not occur in low-intensity wheelchair training, while still obtaining fitness improvements. Substantial fitness improvements have been found in able-bodied populations performing low-intensity training. However, effects had not yet been systematically investigated in inactive people with long-term SCI.

Chapter 2 presents a cross-sectional cohort study on the impact of physical activity and time since injury (TSI) on wheelchair-specific peak aerobic work capacity in people with SCI for at least 10 years (N=213). Participants used their own wheelchair in an incremental exercise test to determine peak power output and peak oxygen uptake. These parameters were negatively associated to longer TSI and less physical activity. This indicates that people with SCI need support in maintaining levels of physical activity and wheelchair-specific fitness over their lifespan. The test could not be performed by a third of the included participants (n=75). These non-participants seemed a negative selection of the cohort: they appeared to be older, have a longer TSI, lower activity levels and more upper-body pain than participants able to perform the peak test, while also more often having a tetraplegia. This finding shows the potential selection bias in research on fitness of people with long-term SCI.

Chapter 3 is a description of the design of the multicenter RCT on low-intensity wheelchair training. Inclusion criteria comprised TSI > 10 years, inactivity as defined by a reference score on a questionnaire, age ≤ 65 years, age at onset SCI ≥ 18 years and use of a manual wheelchair in daily life. Participants were randomly allocated to an exercise or control group. The exercise group followed a 16-week training in a rehabilitation center. The training consisted of wheelchair treadmill propulsion at 30-40% heart rate reserve or its equivalent in rate of perceived exertion, twice a week, 30 min per session. The control group was not offered any intervention. Measurements

occurred at baseline as well as after eight, 16 and 42 weeks. One hypothesis was that the exercise group would increase fitness levels, and through that, improve wheelchair skill performance and physical activity levels. Another hypothesis was training effects in propulsion technique, leading to reduced risk of joint damage during daily wheelchair propulsion.

Since the RCT took place in rehabilitation centers, feasible tests were needed to study effects on wheelchair-specific fitness. For this purpose, a new test was developed: a 15 m-overground sprint test in a wheelchair equipped with a measurement wheel to determine power output. **Chapter 4** is an evaluation on whether this test can be used to assess wheelchair-specific anaerobic work capacity. In a pilot study, an able-bodied group (N=19) performed the 15-m sprint test and a more established test of wheelchair-specific anaerobic work capacity (30-s sprint on a wheelchair ergometer using a Wingate-like protocol). A moderate association was found between peak power output over the 15-m test and mean power output over the Wingate-like test. Handrim velocities were significantly higher in the 15-m test. An explanation for these findings is that the 15-m test is more dependent on motor coordination than the Wingate-like test. When this is taken into account, peak power over the 15-m test seems acceptable for assessing wheelchair-specific anaerobic work capacity.

The group participating in baseline measurements in the RCT (N=29) performed several wheelchair-specific tests feasible for use in rehabilitation centers, including the 15-m sprint test, an isometric-push test and a peak wheelchair exercise test. **Chapter 5** is a description of these results, which provide insight into wheelchair-specific anaerobic work capacity, isometric strength and peak aerobic work capacity of inactive people with long-term SCI. The majority of the group had relatively low levels in all fitness components. This implies that most inactive people with long-term SCI seem to require support in prevention or improvement of low wheelchair-specific fitness levels. The fitness components in the group were only weakly or moderately associated. This implies that separate tests should be used when assessing different components of wheelchair-specific fitness in rehabilitation centers.

Chapter 6 and 7 are evaluations of the training effects in the RCT. The low-intensity wheelchair training appeared to have little or no effect. This implies that substantial training effects require other forms or doses of exercise. Suggestions for more effective training than that used in the RCT are: more than twice-weekly low-intensity wheelchair exercise using a feasible training format; wheelchair training in which exercise intensity is gradually increased over a relatively long period; a combination of low-intensity wheelchair training and moderate-intensity handcycling; and moderate forms of resistance training. Another approach is to use programs aimed at stimulating an active lifestyle through exercise counseling and teaching self-management skills.

Chapter 8 is a discussion of main findings in this thesis. The impact of secondary health complications occurring over the lifespan with SCI may be an explanation for the negative associations among fitness, activity and TSI. These health complications may also explain the low fitness levels. Alternatively, it could be that were already present during inpatient rehabilitation, while these never improved after that. Longitudinal studies are required for inferences about causality of the relationships among physical activity, fitness and secondary health complications in people with long-term SCI. Such studies should include an evaluation of selection bias.

Future research on training interventions in people with long-term SCI should start with simpler study designs than an RCT. An RCT such as in this thesis often leads to inconclusive results due to insufficient sample size, high dropout rates and large heterogeneity in a study group with SCI. Another difficulty in an RCT is that the need for high internal validity can compromise ecological validity, challenging implementation in practice. These difficulties are less likely in studies based on non-randomized designs, cross-over designs or single-case designs that include multiple baseline measurements and mixed methods. Also recommended is to use study designs that allow analyses of interindividual differences, which can help to discern potential responders and non-responders to an intervention.

The 15-m test, isometric-push test and peak wheelchair exercise test used in this thesis seem to be exercise tests feasible for assessing wheelchair-specific fitness in rehabilitation centers. Widespread implementation of such tests is facilitated by: improving availability and affordability of test equipment; minimizing time and burden of test protocols; and providing more information about psychometric properties such as sensitivity of test outcomes to changes in individual participants.

The training in this thesis presumably has little or no effect on preventing or breaking a vicious cycle of physical inactivity, deconditioning and secondary health complications in people with long-term SCI. It seems challenging to find effective and feasible exercise interventions for the inactive population with long-term SCI. This implies that focus of health care in people with SCI should be on preventing physical inactivity and deconditioning. This may be supported by aftercare that covers the lifespan with SCI, including regular fitness screening as well as counseling on how to prevent secondary health complications and physical inactivity. In any approach, the focus should be on the individual needs of each person with SCI.

Nederlandse samenvatting

SAMENVATTING VAN DIT PROEFSCHRIFT

Doel van dit proefschrift is het onderzoeken van de effecten van laag-intensieve rolstoeltraining op rolstoelspecifieke fitheid, rolstoelvaardigheden, fysieke activiteit en propulsietechniek in fysiek inactieve mensen met een chronische dwarslaesie (10 jaar of langer een dwarslaesie). **Hoofdstuk 1** geeft achtergrondinformatie. Door verlamming en een rolstoelgebonden leven is het moeilijk voor mensen met een dwarslaesie om fysiek actief en fit te blijven. Dit komt vooral voor bij mensen met een chronische dwarslaesie, aangezien fysieke activiteit en fitheid afnemen als men ouder wordt. Ook hebben mensen met een chronische dwarslaesie relatief vaak last van secundaire gezondheidscomplicaties, wat ook een negatief effect kan hebben op fysieke activiteit en fitheid. Hierdoor kan een neerwaartse spiraal ontstaan van inactiviteit, deconditionering en secondaire gezondheidscomplicaties. Deze neerwaartse spiraal wordt mogelijk voorkomen of doorbroken door interventies gericht op het stimuleren van fysieke activiteit, verbeteren van fitheid en de preventie van secundaire gezondheidscomplicaties. Zulke interventies kunnen onderdeel zijn van een nazorgtraject. Hierover was weinig bekend en daarom is onderzoeksprogramma 'ALLRISC' opgezet. ALLRISC bestond onder andere uit een gerandomiseerd onderzoek met een controlegroep naar laag-intensieve rolstoeltraining bij fysiek inactieve mensen met een chronische dwarslaesie. Eerder onderzoek liet zien dat fitheid van mensen met een dwarslaesie verbetert als gevolg van rolstoeltraining met een hoge inspanningsintensiteit. Deze intensiteit is mogelijk te belastend voor rolstoeltraining bij fysiek inactieve mensen met een chronische dwarslaesie. Overbelasting bij deze groep komt niet voor bij laag-intensieve rolstoeltraining, terwijl fitheid alsnog verbeterd, zo was de aanname in dit proefschrift,. Dit was ook gevonden in eerder onderzoek bij mensen zonder dwarslaesie. Deze aanname was echter nog niet systematisch onderzocht bij fysiek inactieve mensen met een chronische dwarslaesie.

Hoofdstuk 2 presenteert een cross-sectioneel onderzoek naar de samenhang tussen rolstoelspecifieke aerobe capaciteit, fysieke activiteit en het aantal jaren met een dwarslaesie bij een cohort van 213 mensen met een chronische dwarslaesie. Deelnemers voerden een maximale inspanningstest uit in hun rolstoel om piekvermogen en de hoogste zuurstofopname te bepalen. Deze fitheidsparameters bleken negatief gerelateerd aan het aantal jaren met een dwarslaesie en verminderde fysieke activiteit. Dit geeft aan dat mensen met een dwarslaesie gedurende hun leven mogelijk ondersteuning nodig hebben voor het onderhouden van fysieke activiteit en fitheid. Een derde van de deelnemers kon de test niet uitvoeren. Deze subgroep bleek significant ouder te zijn, meer jaren een dwarslaesie te hebben, vaker een hoge dwarslaesie te hebben, minder fysiek actief te zijn en meer pijn in het bovenlichaam te hebben dan de groep mensen die de test wel konden uitvoeren. Dit geeft een indruk van negatieve selectiebias in onderzoek naar fitheid bij mensen met een chronische dwarslaesie.

Hoofdstuk 3 is een beschrijving van de opzet van het gerandomiseerde onderzoek naar laag-intensieve rolstoeltraining. Criteria om mee te doen waren onder andere: langer dan 10 jaar een dwarslaesie hebben; fysieke inactiviteit gedefinieerd door een normscore op een vragenlijst; 65 jaar of jonger zijn; minimaal 18 jaar oud toen de dwarslaesie ontstond en het gebruik van een handbewogen rolstoel in het dagelijks leven. Via loting vormde zich een trainingsgroep en een controlegroep. De trainingsgroep volgde een 16-weekse training in een revalidatiecentrum, bestaande uit twee keer per week 30 minuten rolstoelrijden op een loopband. De intensiteit was 30-40% van de hartslagreserve of een vergelijkbare intensiteit gemeten met ervaren inspanningsbelasting (RPE). De controlegroep kreeg geen interventie aangeboden. Metingen vonden plaats bij aanvang van de studie en na 8, 16 en 42 weken. Een van de hypothesen was een verbeterde fitheid in de trainingsgroep, waardoor ook rolstoelvaardigheden en fysieke activiteit zou verbeteren. Een andere hypothese was dat trainingseffecten zouden optreden in propulsietechniek, waardoor het risico op gewrichtsschade tijdens het dagelijkse rolstoelrijden zou verminderen.

Omdat dit onderzoek plaatsvond in revalidatiecentra, waren rolstoelspecifieke fitheidstesten nodig die uitvoerbaar en beschikbaar zijn op zulke locaties. Het onderwerp van **hoofdstuk 4** is of een 15-m sprinttest, gebruikmakend van een rolstoel met meetwielen om het vermogen vast te stellen, gebruikt kan worden om rolstoelspecifieke anaerobe capaciteit te meten. In een pilotstudie voerden 19 gezonde deelnemers zonder handicap de 15-m sprinttest uit, naast een meer gevestigde test om rolstoelspecifieke anaerobe capaciteit te meten (30-s sprinten op een rolstoelergometer middels een Wingate-protocol). Er werd een redelijk sterke relatie gevonden tussen piekvermogen op de 15-m test en het gemiddelde vermogen op de Wingate test. Snelheden waren significant hoger tijdens de 15-m test. Een verklaring voor deze bevindingen is dat de 15-m test meer afhankelijk is van motorische coördinatie van het bovenlichaam dan de Wingate-test. Wanneer dit in acht wordt genomen, lijkt de 15-m test geschikt om rolstoelspecifieke anaerobe capaciteit te meten.

De 29 deelnemers voerden bij aanvang van het trainingsonderzoek rolstoelspecifieke fitheidstesten uit in een revalidatiecentrum. **Hoofdstuk 5** is een beschrijving van hun resultaten op de 15 m-sprinttest, een isometrische krachttest en een maximale inspanningstest. Dit geeft een overzicht van verschillende fitheidscomponenten bij fysiek inactieve mensen met een chronische dwarslaesie. De meeste deelnemers hadden een laag fitheidsniveau in alle componenten. Dit duidt erop dat het merendeel van fysiek inactieve mensen met een chronische dwarslaesie ondersteuning kan gebruiken bij de preventie of de verbetering van een lage rolstoelspecifieke fitheid. Tussen de fitheidscomponenten werden zwak tot matige associaties gevonden, wat impliceert dat het meten van elke fitheidscomponent in een revalidatiecentrum om een andere test vraagt.

Hoofdstuk 6 en 7 zijn evaluaties van de trainingseffecten in het gerandomiseerde onderzoek. De laag-intensieve rolstoeltraining bleek weinig of geen effect te hebben. Voor trainingseffecten is er kennelijk een grotere dosis of een andere trainingsvorm nodig. Suggesties voor mogelijk effectievere training zijn: vaker dan twee keer per week laag-intensieve rolstoeltraining mits een praktisch uitvoerbare opzet wordt gekozen; rolstoeltraining met een intensiteit die langzaam wordt opgebouwd over een periode van enkele maanden; een combinatie van laag-intensieve rolstoeltraining en matig-intensieve handbiketraining; en lichte vormen van krachttraining. Een andere benadering is het inzetten van programma's gericht op het stimuleren van een actieve levensstijl middels beweegadvies en het aanleren van zelfmanagementvaardigheden.

Hoofdstuk 8 is een discussie van de belangrijkste bevindingen in dit proefschrift. De impact van gezondheidscomplicaties over de levensspanne met een dwarslaesie is een mogelijke verklaring voor de negatieve relaties tussen fitheid, inactiviteit en het aantal jaren met een dwarslaesie. Dit kan ook een oorzaak zijn voor de lage fitheidsniveaus. Een andere verklaring is dat lage fitheidsniveaus al aanwezig waren tijdens de klinische revalidatie en deze daarna nooit verbeterden. Voor gevolgtrekkingen over oorzakelijkheid binnen de relaties tussen fysieke activiteit, fitheid en secondaire gezondheidscomplicaties zijn longitudinale studies nodig. Zulke studies zouden zich ook moeten richten op de karakteristieken van mensen die wel en niet deelnemen.

Het nadeel van gerandomiseerd onderzoek met een controlegroep in een trainingsstudie met mensen met een dwarslaesie is dat er een grote kans is op een incomplete dataset of niet-uitvoerbare analyses door uitval van deelnemers en heterogeniteit over de groep. Daarnaast vereist het gerandomiseerd onderzoek met een controlegroep een hoge interne validiteit. Dit kan ten koste kan gaan van ecologische validiteit, waardoor resultaten moeilijk naar de praktijk vertaald kunnen worden. Deze nadelen komen mogelijk niet of in mindere mate voor wanneer een andere onderzoekopzet wordt gebruikt, bijvoorbeeld een niet-gerandomiseerde opzet, cross-over design of een single-case design met een combinatie van kwalitatief en kwantitatief onderzoek alsmede herhaalde metingen op elk tijdstip. Een andere aanbeveling is het gebruik van een onderzoeksopzet die analyses van interindividuele verschillen mogelijk maakt. Hierdoor is onderscheid mogelijk tussen deelnemers die wel of niet baat hebben bij een interventie.

De 15-m sprinttest, isometrische krachttest en maximale inspanningstest in dit proefschrift lijken geschikt voor het meten van rolstoelspecifieke fitheid in de revalidatiepraktijk. Brede implementatie in de praktijk wordt gefaciliteerd door: het verbeteren van de aanwezigheid en betaalbaarheid van testapparatuur; het minimaliseren van benodigde tijd en inzet voor de testen; en het verschaffen van duidelijkheid over psychometrische eigenschappen, bijvoorbeeld hoe gevoelig een test is voor veranderingen binnen een individu.

De training in dit proefschrift heeft waarschijnlijk weinig effect op het voorkomen of doorbreken van een neerwaartse spiraal van fysieke inactiviteit, deconditionering en secundaire gezondheidscomplicaties bij mensen met een chronische dwarslaesie. Het blijkt lastig om effectieve en praktisch uitvoerbare trainingsvormen te vinden voor fysiek inactieve mensen met een chronische dwarslaesie. Dit impliceert dat gezondheidszorg voor mensen met een dwarslaesie zich vooral moet richten op het voorkomen van fysieke inactiviteit en een lage fitheid. Een nazorgtraject over de levenspanne met een dwarslaesie kan hieraan bijdragen. Suggesties hiervoor zijn het monitoren van fitheid en het geven van advies over de preventie van fysieke inactiviteit en secundaire gezondheidscomplicaties. De individuele behoeften van elk persoon dienen hierbij centraal te staan.

Dankwoord

DANKWOORD

Mogelijk vindt dit proefschrift zijn praktisch nut als pannenonderzetter. Voor dit gebeurt, hoop ik dat dit dankwoord gelezen wordt, aangezien alle betrokkenen bij mijn promotieonderzoek dat verdienen. Ook ik ontkom er niet aan om slechts enkele mensen persoonlijk te benoemen. Degenen die zich gepasseerd voelen, voel je vrij me de rug toe te keren. Mijn dank is er niet minder om.

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Jan.

About the author

Jan van der Scheer (1986) was born in Apeldoorn, the Netherlands. In 2004 he graduated from secondary school at the Christelijk Lyceum in Apeldoorn. Jan continued his interest in exercise and physiology at the Faculty of Human Movement Sciences at the VU University Amsterdam, where he obtained a master's degree in 2008. During his college years, Jan worked as a fitness and judo instructor. After his master, he volunteered in a nature conservancy in Kenya and travelled in East-Africa. In 2009 Jan returned to the Netherlands, where he combined work in a fitness center with a research project at the Reade Rehabilitation Center (Amsterdam). Here, Jan furthered his interest and skills in rehabilitative research. He was given the opportunity in October 2010 to start his Ph.D. project within research program 'ALLRISC' at the Center of Human Movement Sciences (University of Groningen, University Medical Center Groningen). In the project, Jan enjoyed conducting research in rehabilitation centers UMCG Beatrixoord (Haren) and Heliomare (Wijk aan Zee). Other professional activities were organizing a Ph.D. symposium and being a representative for his fellow Ph.D. students. The Ph.D. project resulted in this thesis, which is defended on March 18, 2015. Currently, Jan is looking to continue his career in health care and human movement sciences.

PUBLICATIONS

1. **van der Scheer JW**, de Groot S, Vegter RJ, den Hartog J, Veeger DH, van der Woude LH. Low-intensity wheelchair training in inactive people with long-term spinal cord injury: a randomized controlled trial on propulsion technique. Am J Phys Med Rehabil 2015. In press.
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- de Groot S, Post M, Bussmann H, Janssen TW, Adriaansen J, Kooijmans H, **van der Scheer JW**, Bakkum AJ, van der Woude LHV. Onderzoeksproject: Active LifeStyle Rehabiliation Intervention in aging person with Spinal Cord injury (ALLRISC). Nederlands Tijdschrift voor Revalidatiegeneeskunde 2011(3):6.

CONFERENCE CONTRIBUTIONS

1. VRA Congress: Dutch Congress of Rehabilitation (DCRM), Rotterdam, the Netherlands, 2014 (oral presentation)
2. ISCOS Conference 2014, Maastricht, the Netherlands, 2014 (poster presentation)
3. Rehabilitation: ‘Mobility, Exercise & Sports’ – 5th edition, Groningen, the Netherlands, 2014 (poster presentation)
4. VISTA 2013: Equipment and technology in Paralympic sports, Bonn, Germany, 2013 (oral presentation)
5. ACSM Annual Meeting 2012, San Francisco, USA, 2012 (poster presentation)
6. 2nd Alliance for Healthy Ageing Symposium, Groningen, the Netherlands, 2011 (poster presentation)
7. 25th SECEC-ESSSE European Society for Surgery of the Shoulder and Elbow Congress, Lyon, 2011 (abstract for oral presentation)

Door verlamming en een rolstoelgebonden leven is het moeilijk voor mensen met een dwarslaesie om fysiek actief en fit te blijven. Dit kan tot gezondheidsproblemen leiden en tot problemen met het dagelijks functioneren. Fitheid van mensen met een dwarslaesie kan verbeteren door training met een hoge inspanningsintensiteit, maar dat is mogelijk te belastend voor fysiek inactieve mensen die al lang een dwarslaesie hebben. Trainen met een lage inspanningsintensiteit zou misschien ook tot fitheidsverbeteringen kunnen leiden, er lijkt minder risico op overbelasting te bestaan en het is wellicht beter vol te houden. Om te weten of dit klopt zijn in dit proefschrift de effecten onderzocht van laag-intensieve rolstoeltraining bij fysiek inactieve mensen die langer dan 10 jaar een dwarslaesie hebben. Deelnemers aan het onderzoek werden middels loting ingedeeld in een trainingsgroep of een niet-trainende controlegroep. De training bestond uit 16 weken twee keer per week rolstoelrijden op een lopende band met een intensiteit van ongeveer 30-40% van de maximale capaciteit. Tegen de verwachtingen in, liet de trainingsgroep weinig tot geen verbeteringen zien in fitheid, rolstoelvaardigheden, fysieke activiteit en techniek van het rolstoelrijden. Voor grote effecten moet er kennelijk vaker getraind worden of zijn andere trainingsvormen nodig, maar hiervoor is nader onderzoek nodig. Het blijkt lastig om effectieve en praktisch uitvoerbare training te vinden voor fysiek inactieve mensen die al lang een dwarslaesie hebben. Dit is een extra reden om aandacht te hebben voor preventie van inactiviteit en verminderde fitheid bij mensen met een dwarslaesie.