University of Groningen

Good association between sprint power and aerobic peak power during asynchronous arm-crank exercise in people with spinal cord injury

de Groot, Sonja; Kouwijzer, Ingrid; Valent, Linda J M; van der Woude, Lucas H V; Nash, Mark S; Cowan, Rachel E

Published in:
Disability and Rehabilitation

DOI:
[10.1080/09638288.2019.1625978](https://doi.org/10.1080/09638288.2019.1625978)

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2021

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

de Groot, S., Kouwijzer, I., Valent, L. J. M., van der Woude, L. H. V., Nash, M. S., & Cowan, R. E. (2021). Good association between sprint power and aerobic peak power during asynchronous arm-crank exercise in people with spinal cord injury. *Disability and Rehabilitation*, 43(3), 378-385.
<https://doi.org/10.1080/09638288.2019.1625978>

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Good association between sprint power and aerobic peak power during asynchronous arm-crank exercise in people with spinal cord injury

Sonja de Groot, Ingrid Kouwijzer, Linda J. M. Valent, Lucas H. V. van der Woude, Mark S. Nash & Rachel E. Cowan

To cite this article: Sonja de Groot, Ingrid Kouwijzer, Linda J. M. Valent, Lucas H. V. van der Woude, Mark S. Nash & Rachel E. Cowan (2019): Good association between sprint power and aerobic peak power during asynchronous arm-crank exercise in people with spinal cord injury, Disability and Rehabilitation, DOI: [10.1080/09638288.2019.1625978](https://doi.org/10.1080/09638288.2019.1625978)

To link to this article: <https://doi.org/10.1080/09638288.2019.1625978>

Published online: 11 Jun 2019.

Submit your article to this journal [↗](#)

Article views: 19

View Crossmark data [↗](#)

ORIGINAL ARTICLE

Good association between sprint power and aerobic peak power during asynchronous arm-crank exercise in people with spinal cord injury

Sonja de Groot^{a,b}, Ingrid Kouwijzer^{a,b,c}, Linda J. M. Valent^c, Lucas H. V. van der Woude^{b,d}, Mark S. Nash^{e,f} and Rachel E. Cowan^{e,f}

^aAmsterdam Rehabilitation Research Center, Reade, Amsterdam, The Netherlands; ^bUniversity of Groningen, University Medical Center Groningen, Center for Human Movement Sciences, Groningen, The Netherlands; ^cDepartment of Research and Development, Heliomare Rehabilitation Center, Wijk aan Zee, The Netherlands; ^dCenter for Rehabilitation, University Medical Center Groningen, University of Groningen, Groningen, The Netherlands; ^eDepartment of Neurological Surgery, Miller School of Medicine, University of Miami, Miami, Florida; ^fThe Miami Project to Cure Paralysis, Miller School of Medicine, University of Miami, Miami, Florida

ABSTRACT

Purpose: To (1) investigate the association between sprint power and aerobic power output (POpeak_{GXT}) during a graded peak exercise test (GXT); and (2) validate the prediction models of POpeak_{GXT} based on sprint power and personal and lesion characteristics.

Materials and methods: Wheelchair users with tetraplegia ($N = 35$) and paraplegia ($N = 58$) performed a 30 s-Wingate test and GXT on an asynchronous arm-crank ergometer. Data were split into samples to develop and validate the model. Sprint power (POMean_{Wingate} and POpeak_{Wingate}, respectively) and POpeak_{GXT} were determined. Regression analyses were performed to develop POpeak_{GXT} prediction models. Candidate independent variables included POMean_{Wingate} or POpeak_{Wingate}, age (years), sex, body mass (kg) or BMI (kg/m²), time since injury (TSI, years) and lesion level (tetraplegia/paraplegia). The best model was validated by comparing the predicted POpeak_{GXT} with measured POpeak_{GXT}.

Results: The best model ($R^2 = 0.76$) to predict POpeak_{GXT} included POMean_{Wingate}, BMI and all other independent variables. No significant difference was found between measured (68 ± 35 W) and predicted POpeak_{GXT} (68 ± 30 W, $p = 0.97$). The ICC was excellent (0.89 with 95% confidence intervals: 0.75–0.95). The 95% limits of agreement for the Bland–Altman plots were wide (-30 to 31 W).

Conclusions: Strong associations were found between POMean_{Wingate} and POpeak_{GXT}. Although relative agreement was excellent, absolute agreement was low.

ARTICLE HISTORY

Received 29 January 2019
Revised 27 May 2019
Accepted 28 May 2019

KEYWORDS

Exercise/physiology;
rehabilitation/methods; aerobic exercise; anaerobic exercise; spinal cord injury

► IMPLICATIONS FOR REHABILITATION

- There is a strong relationship between peak aerobic power output and sprint power output, both tested on an arm-crank ergometer, in people with spinal cord injury.
- A prediction model for peak aerobic power output, based on sprint power output and personal and lesion characteristics, showed a high explained variance.
- The predictive model can give a guideline for choosing the right graded exercise test protocol but should be used with caution.

Introduction

Handcycling is a physiologically more efficient mode of mobility than wheelchair propulsion [1] for people with a lower-limb disability, such as people with a spinal cord injury (SCI). Furthermore, handcycling leads to a lower shoulder load than wheelchair propulsion [2]. Due to these physiological and biomechanical advantages, handcycling is already introduced during inpatient rehabilitation for people with paraplegia as well as tetraplegia [3], and thereafter is recommended for mobility and sports purposes.

One of the initiatives to promote handcycling among people with a lower-limb disability is the HandbikeBattle [4]. The HandbikeBattle is a mountain time trial (almost 20 km long and 1 km in elevation) among teams of ex-patients from twelve Dutch rehabilitation centers. The participants of the HandbikeBattle are not elite athletes but persons with, among others, a SCI, who need to become active again to improve their health and fitness.

The HandbikeBattle is a challenging event that requires training to compete. Before the start of the training period, the participants perform a peak graded exercise test (GXT) in their rehabilitation center. A training schedule is then written using the outcomes of this GXT. However, one of the problems with this GXT is to choose the right test protocol so that the person reaches a peak value around 10 ± 2 min [5]. Much shorter and longer tests might lead to lower VO_{2peak} values, which might be due to muscular force limitations (shorter tests) or conversely, higher body temperature and suboptimal substrate mobilization and utilization (longer tests) [5].

It is known that individual optimization of graded exercise test protocols (GXT) for persons with SCI requires accurate individual estimates of peak power output (POpeak_{GXT}). It is challenging to accurately estimate the peak power output in people with SCI because it is a very heterogenous group. Attempts have been

made to predict the peak power output based on personal and lesion characteristics [6]. However, these regression models showed a low explained variance ($R^2 = 42\%$), and after validation the predicted POpeak provided a low absolute agreement with the measured POpeak (95% limits of agreement: 95% LoA -69 to 54 W).

Previous studies showed a strong association between sprint power measured during a 30 s Wingate test and peak aerobic power output in people with SCI during wheelchair propulsion ($R^2 = 0.81$) [7], and in cycling for adults with cerebral palsy ($R^2 = 0.94$) [8]. A Wingate test is a low time burden assessment of sprint power that might also be associated strongly with POpeak_{GXT} during arm ergometry, and could therefore contribute to a valid and accurate prediction of POpeak_{GXT} in people with SCI, next to determinants like personal and lesion characteristics.

A Wingate test on an arm-crank ergometer, although often performed asynchronously, resembles handcycling the most. Limited data have addressed outcomes of a Wingate test on an arm-crank ergometer in people with SCI alone [9–12]. Jacobs et al. showed that the Wingate test was reliable in people with paraplegia ($N = 43$) [10] as well as tetraplegia with cervical SCI at or below the C5 level ($N = 39$) [9]. However, although Jacobs et al. [9,10] included quite a large group, no reference data were developed. This is unfortunate because reference data might be helpful in interpreting the outcomes of a Wingate test in clinical practice.

Therefore, the present study aimed to 1) investigate the association between sprint power (mean and peak value) and POpeak_{GXT}; 2) validate the prediction models of POpeak_{GXT} based on sprint power and personal and lesion characteristics; and 3) develop reference values for Wingate test outcomes based on lesion level. The overarching hypothesis is that a high correlation will be found between sprint power and peak aerobic power output in people with SCI, similar to what was found in wheelchair propulsion and cycling in people with SCI and cerebral palsy, respectively [7,8]. Furthermore, the expectation is that a high relative and absolute agreement will be found between the estimated and the measured POpeak_{GXT}.

Materials and methods

This cross-sectional study was conducted at the university research laboratory at the Miami Project to Cure Paralysis, Miller School of Medicine, University of Miami, Miami, USA. The STrengthening the Reporting of Observational studies in Epidemiology (STROBE)-guidelines [13] were used for the present report.

Participants

Ninety-three individuals with SCI were included in this secondary analysis of a pooled dataset. The dataset was created by merging the data collected under two independent IRB protocols [14–16]. Protocols 20080110 [16] and 20090887 [15] were approved by the University of Miami Medical Sciences IRB-C (IRB00006078) in March 2008 and March 2010, respectively. All participants voluntarily provided written informed consent.

Inclusion criteria were the same for both protocols, with all participants satisfying the following criteria: 1) SCI duration ≥ 1 year; 2) self-reported ability to self-propel a manual wheelchair; and 3) age ≥ 18 years. Exclusion criteria for the study of Cowan et al. (2011) [16] included: (1) surgery within 6 months or a pressure ulcer within 3 months before the study; (2) upper-limb pain limiting exercise completion; (3) recurrent acute infection or

illness requiring hospitalization or intravenous antibiotics; (4) pregnancy; and (5) previous myocardial infarction (MI) or cardiac surgery. Exclusion criteria for the study of Cowan et al. (2012) [15] included: (1) unstable angina or MI within 30 days; (2) resting heart rate >120 beats per minute (bpm); (3) resting systolic blood pressure >180 mm Hg; (4) resting diastolic blood pressure >100 mmHg.

Design

Manual wheelchair users with tetraplegia ($N = 35$) and paraplegia ($N = 58$) performed a 30 s Wingate test and a GXT on an asynchronous arm-crank ergometer to determine sprint average and peak power (POmean_{Wingate} and POpeak_{Wingate}), and POpeak_{GXT}.

Personal and lesion characteristics

Sex, age, height, time since injury, and injury level (tetraplegia or paraplegia) were self-reported by the participants. Weight was determined on a calibrated wheelchair scale by weighing the person in their wheelchair, then weighing the wheelchair and subtracting the chair weight.

Wingate asynchronous arm-crank ergometer test

The Wingate sessions were performed on a Monark 894E leg cycle ergometer (Monark, Varberg, Sweden) that was modified for arm-cranking, which was securely mounted to a height-adjustable table. Values of anaerobic power were determined with the SMI Optosensor 2000 (Sports Medicine Industries, Inc., St. Cloud, MN, USA) system. The SMI Power software calculates power output for each second of the test as a function of the resistance load applied to the flywheel and the velocity of the flywheel as measured with an optical sensor attached to the ergometer frame.

Participants performed 3 to 5 min of unloaded asynchronous arm-cranking as a warm-up activity. After the warm-up, participants were set-up for the Wingate as follows: Table height was adjusted such that the arm-crank axis was slightly lower than the participants' shoulder joints; wheelchairs were positioned to allow for a slight flexion in the elbows at the point of maximal arm extension; and persons with tetraplegia had their hands affixed to the ergometer handgrips with athletic tape and adaptive hand cuffs.

Participants were then directed to progressively increase their pedaling cadence (without resistance applied) to their own maximal velocity. Previous investigations have determined that 3.5% of body mass is appropriate for Wingate arm-crank exercise testing with the arms when testing persons with paraplegia [10]. For people with tetraplegia the load was set between 1.5–3.5% of body mass as suggested by Jacobs et al. [17]. Research staff applied the resistive load when crank velocity plateaued (visualized by the SMI Power software) and provided vigorous verbal encouragement throughout the 30 s test. Following the test, the ergometer flywheel was unloaded to allow for a 1 to 3 min cooldown.

The power parameters computed included peak power output (POpeak_{Wingate}), taken as the highest power output measured during the test, and mean power output (POmean_{Wingate}), which is the average power output sustained throughout the 30 s test.

Peak graded asynchronous arm-crank ergometer exercise test

The GXT was completed using a mechanically braked arm ergometer (Monark 881E, Vansbro, Sweden) or an electronically braked arm ergometer (Angio, Lode BV, Groningen, the Netherlands). Heart rate (HR) and oxygen uptake (VO_2) were monitored continuously breath by breath from baseline through recovery. HR was measured by standard 12-lead electrocardiography and VO_2 ($\text{mL}/\text{min}^{-1}$) via the open-circuit method on a spirometer calibrated before each session with reference gasses (Vmax ENCORE, Cardinal Health VIASYS, Dublin, OH). Participants rested quietly in their wheelchairs for 10 min before the test to establish baseline values. Thereafter, each participant began cranking on the arm ergometer at 5 W, maintaining cadence at 55 ± 5 rpm (mechanically braked ergometer) paced by metronome or 60 ± 5 rpm (electronically braked ergometer) paced by a real-time digital display.

Before each test, an American College of Sports Medicine-certified clinical exercise specialist interviewed each participant to determine the individualized wattage starting work rate and increments to target a $\text{VO}_{2\text{peak}}$ (i.e., volitional exhaustion) in 8–12 min. Increments ranged from 5 to 30 W, with smaller increments for persons with tetraplegia and sedentary individuals. The American College of Sports Medicine Guidelines for Exercise Testing and Prescription recommend that testing protocols (e.g., starting work rate and work rate increments) be individualized to the participant's perceived functional capacity to achieve a test time of 8–12 min [18]. We targeted 9 min as the floor rather than 8 min because our stages were 3 min in duration. We targeted a ceiling of 15 rather than 12 min to accommodate conservative choices of starting wattage and incremental workloads watts (e.g., lower start and/or smaller increments).

Participants continued until volition exhaustion manifesting as either a nonverbal communication of the desire to stop, or an inability to maintain cadence above 50 (mechanical) or 55 (electronic) rpm. Upon cessation, participants rested quietly for 10 min. The highest 30-s average recorded during the test was selected as $\text{VO}_{2\text{peak}}$ and HR_{peak} . The power output that was maintained for at least 30 s was selected as the PO_{peak} .

Statistics

The total sample was randomly split in two groups: 1) 70% of the data were used for building the regression model (model group, $N=68$) and; 2) 30% of the data were used to validate the model (validation group, $N=25$). Independent t -tests and Chi-squared tests were performed to check for differences between the model and validation group.

Two regression analyses (backward and enter procedure) with data of the model group ($N=68$) were performed to identify the best $\text{PO}_{\text{peakGXT}}$ prediction model (highest R^2). Candidate independent variables included $\text{POMean}_{\text{Wingate}}$ or $\text{PO}_{\text{peakWingate}}$, body mass (kg) or body mass index (kg/m^2), age (years), sex, time since injury (TSI, years) and lesion level (tetraplegia/paraplegia). Due to the high correlation between the $\text{POMean}_{\text{Wingate}}$ and $\text{PO}_{\text{peakWingate}}$ ($r=0.85$) and between body mass and BMI ($r=0.88$), these determinants were not added to the same model. In the theoretical model all independent variables that are expected to influence $\text{PO}_{\text{peakGXT}}$ were added to the model (enter procedure). In the statistical model, only independent variables that showed a significant univariate relationship ($p < 0.10$) with $\text{PO}_{\text{peakGXT}}$ were added to the model, after which a backward regression was performed until only significant determinants remained ($p < 0.05$).

All regression models were tested with the validation group. For each individual in this group, the predicted $\text{PO}_{\text{peakGXT}}$ from the model was compared with the actual measured $\text{PO}_{\text{peakGXT}}$. A paired sample t -test, intraclass correlation coefficients (ICC) and Bland-Altman plots were used for comparison. The following interpretation was used for the ICC: <0.40 "poor", 0.40 – 0.59 "fair", 0.60 – 0.74 "good", ≥ 0.75 "excellent" [19]. Lastly, scatter plots were made with 20% deviation boundaries to obtain insight in the deviation between the predicted and measured $\text{PO}_{\text{peakGXT}}$. These boundaries were based on the target to reach the peak value around 10 min with a range of 2 min around it ($= 20\%$).

Reference values of sprint power (PO_{peak} and POMean both expressed in W and W/kg) were calculated with data from the total group and for people with a tetraplegia and paraplegia separately. Quintiles were defined based on percentiles: Poor (below 20%), Fair (20% to 40%), Average (40% to 60%), Good (60% to 80%), and Excellent (above 80%), as described in previous studies [6,20,21].

Significance was set at $p < 0.05$ for all statistical analyses. IBM SPSS statistics 20 (IBM Corporation, New York, USA) was used for all analyses.

Results

Descriptives of the total group, model and validation group are shown in Table 1. The model and validation groups were not significantly different with respect to personal and lesion characteristics, or outcomes of the Wingate test and GXT. Some variables were not registered or measured well leading to some missing data.

Association

Table 2 shows the outcomes of the theoretical and statistical regression models. In the theoretical model with $\text{PO}_{\text{peakWingate}}$ as independent variable, only $\text{PO}_{\text{peakWingate}}$ and lesion level were significant determinants of $\text{PO}_{\text{peakGXT}}$ (Table 2). The same result was found for the theoretical model with $\text{POMean}_{\text{Wingate}}$ as independent variable. The theoretical model with $\text{POMean}_{\text{Wingate}}$ showed a slightly higher explained variance compared to the theoretical model with $\text{PO}_{\text{peakWingate}}$ ($R^2 = 0.761$ vs. $R^2 = 0.705$).

The univariate regression analyses showed a single significant association between $\text{PO}_{\text{peakGXT}}$ and $\text{PO}_{\text{peakWingate}}$ ($R^2 = 0.46$, $p < 0.001$), $\text{POMean}_{\text{Wingate}}$ ($R^2 = 0.65$, $p < 0.001$), and lesion level ($R^2 = 0.44$, $p < 0.001$). When adding the Wingate PO and the lesion level together in a model, both independent variables remained in the model after backward regression. The statistical model with $\text{POMean}_{\text{Wingate}}$ showed again a higher explained variance compared to the statistical model with $\text{PO}_{\text{peakWingate}}$ ($R^2 = 0.702$ vs. $R^2 = 0.578$).

Validity

Table 2 shows the outcomes of the analyses for the validation. The outcome of the independent t -test showed that no systematic difference was found between the measured and predicted $\text{PO}_{\text{peakGXT}}$ for all models. The difference between the measured and predicted value (0.15 W), as well as the ICC (0.89), was best for the theoretical model with $\text{POMean}_{\text{Wingate}}$ as one of the independent variables. The relative agreement between the measured and predicted $\text{PO}_{\text{peakGXT}}$ was excellent for all models, showing ICCs between 0.77–0.89.

Table 1. Participant characteristics of the model group (70% of data, $N = 68$), and the validation group (30% of data, $N = 25$).

	Total group		Model group		Validation group		Model vs. Validation <i>p</i> -value
	<i>N</i>	Mean ± SD or <i>N</i>	<i>N</i>	Mean ± SD or <i>N</i>	<i>N</i>	Mean ± SD or <i>N</i>	
Personal characteristics							
Age (years)	93	38.3 ± 11.8	68	38.1 ± 11.8	25	39.1 ± 11.9	0.717
Sex (male/female)	91	79/12	66	56/10	25	23/2	0.456
Body mass (kg)	93	78.0 ± 16.5	68	78.2 ± 17.3	25	77.4 ± 14.1	0.829
Height (m)	91	1.76 ± 0.09	67	1.77 ± 0.09	24	1.75 ± 0.08	0.531
Body mass index (kg/m ²)	91	25.1 ± 5.7	67	25.0 ± 5.9	24	25.3 ± 5.2	0.840
Lesion characteristics							
Injury level (tetraplegia/paraplegia)	92	35/57	67	25/42	25	10/15	0.807
Time since injury (years)	81	12.2 ± 10.2	59	11.4 ± 9.8	22	14.4 ± 11.2	0.238
Wingate							
POpeak (W)	86	187 ± 113	63	186 ± 122	23	190 ± 87	0.893
POpeak (W/kg)	86	2.4 ± 1.3	63	2.4 ± 1.4	23	2.5 ± 1.1	0.691
POmean (W)	84	122 ± 71	62	118 ± 73	22	133 ± 66	0.401
POmean (W/kg)	84	1.6 ± 0.9	62	1.6 ± 0.9	22	1.7 ± 0.8	0.395
Graded exercise test							
POpeak (W)	93	63 ± 35	68	62 ± 35	25	66 ± 34	0.644
POpeak (W/kg)	93	0.84 ± 0.48	68	0.82 ± 0.48	25	0.87 ± 0.49	0.651
VO ₂ peak (l/min)	93	1.18 ± 0.48	68	1.15 ± 0.47	25	1.27 ± 0.52	0.290
VO ₂ peak (ml/kg/min)	93	15.4 ± 6.0	68	15.0 ± 6.0	25	16.4 ± 6.1	0.296
HRpeak (bpm)	93	140 ± 32	68	140 ± 32	25	143 ± 32	0.645

p values indicate the results of the independent t -test or Chi-squared test to evaluate for possible differences between the two groups.

Table 2. Results for both theoretical models (with all potential determinants) and for both statistical models (after backward regression analyses) to predict absolute POpeak measured during a graded exercise test (upper part of the table) and the outcomes of the validation tests between the predicted and measured POpeak.

	Theoretical models POpeak _{GXT}						Statistical models POpeak _{GXT}					
	POpeak _{Wingate} ($N = 52$)			POmean _{Wingate} ($N = 51$)			POpeak _{Wingate} ($N = 62$)			POmean _{Wingate} ($N = 61$)		
Associations	β (SE)	95%CI	p -value	β (SE)	95%CI	p -value	β (SE)	95%CI	p -value	β (SE)	95%CI	p -value
Intercept	45.637 (14.682)	16.085 75.193	0.003	20.516 (14.011)	-7.704 48.736	0.150	18.451 (5.692)	7.065 29.837	0.002	12.949 (4.915)	3.115 22.784	0.011
Wingate PO	0.216 (0.035)	0.145 0.287	<0.001	0.329 (0.043)	0.242 0.417	<0.001	0.121 (0.031)	0.060 0.182	<0.001	0.304 (0.043)	0.217 0.390	<0.001
Age (years)	-0.391 (0.322)	-1.040 0.257	0.230	-0.051 (0.289)	-0.632 0.531	0.861	NS	NA	NA	NS	NA	NA
Sex (male/female)	0.144 (0.253)	-0.365 0.654	0.571	0.128 (0.225)	-0.324 0.580	0.571	NS	NA	NA	NS	NA	NA
BMI (kg/m ²)	-0.819 (0.600)	-2.026 0.388	0.178	-0.190 (0.720)	-1.255 0.874	0.720	NS	NA	NA	NS	NA	NA
Injury level (TP/PP)	22.563 (7.647)	7.170 37.956	0.005	21.563 (6.584)	8.301 34.824	0.002	32.352 (7.749)	16.851 47.853	<0.001	21.378 (6.586)	8.199 34.556	0.002
Time since injury (years)	0.064 (0.359)	-0.658 0.787	0.859	-0.175 (0.322)	-0.822 0.473	0.590	NS	NA	NA	NS	NA	NA
R^2	0.705			0.761			0.578			0.702		
Validation	$N = 21$			$N = 21$			$N = 23$			$N = 22$		
Measured POpeak _{GXT} (W)	68 $\pm$ 35			68 $\pm$ 35			66 $\pm$ 35			68 $\pm$ 34		
Predicted POpeak _{GXT} (W)	67 $\pm$ 24			68 $\pm$ 30			60 $\pm$ 24			66 $\pm$ 27		
Δ measured-predicted (W)	0.88 $\pm$ 19			0.15 $\pm$ 16			6 $\pm$ 20			2 $\pm$ 17		
p -value t -test	0.835			0.965			0.144			0.517		
ICC (95%CI)	0.81 (0.58–0.92)			0.89 (0.75–0.95)			0.77 (0.53–0.89)			0.86 (0.69–0.94)		
95% LoA	-36 to 38			-30 to 31			-33 to 46			-30 to 35		

β (SE): beta with standard error; 95%CI: 95% confidence interval; R^2 : proportion of explained variance; independent variables: sex (0 = male, 1 = female), lesion level (0 = tetraplegia (TP), 1 = paraplegia (PP)); ns: non-significant; NA: not applicable; Δ measured-predicted: difference between measured and predicted value; ICC: Intraclass correlation coefficient; 95%LoA: 95% limits of agreement.

However, the 95% Limits of Agreements (LoA) were quite wide, with the smallest LoA for the theoretical model with POmean_{Wingate} as independent variable (-30 to 31 W). This is shown in the Bland–Altman plots in Figure 1.

Figure 2 shows how many participants had a deviation of more than 20% between the predicted and measured POpeak_{GXT}. The theoretical model with POmean_{Wingate} as independent variable showed the least deviation, 5 participants of the validation sample (i.e. 24%) lie outside the 20% boundaries.

Reference values

Table 3 shows the reference values of POmean_{Wingate} or POpeak_{Wingate} (in W and W/kg) for people with a tetraplegia and paraplegia separately, as well as for the total group ($N = 86$).

Discussion

The objectives of this study were to investigate the association between sprint power and POpeak_{GXT} during a GXT, and to

Figure 1. Bland–Altman plots representing the absolute agreement between the predicted POpeak_{GXT} and the measured POpeak_{GXT}. Solid line represents the mean, dotted lines represent mean $\pm$ 2SD (95% LoA). Each circle represents a participant of the validation group. Model 1: The difference in POpeak_{GXT} between predicted and measured value with the theoretical model and POpeak_{Wingate} as independent variable. Model 2: The difference in POpeak_{GXT} between predicted and measured value with the theoretical model and POmean_{Wingate} as independent variable. Model 3: The difference in POpeak_{GXT} between predicted and measured value with the statistical model and POpeak_{Wingate} as independent variable. Model 4: The difference in POpeak_{GXT} between predicted and measured value with the statistical model and POmean_{Wingate} as independent variable.

validate the prediction models of POpeak_{GXT} based on sprint power and personal and lesion characteristics. Although a large part of POpeak_{GXT} was explained in the regression models (mainly by the sprint power and lesion level) and the relative agreement was excellent, absolute agreement was low as shown by the high 95% limits of agreement. Therefore, the model can only be used with caution for setting the GXT protocol.

Association

From all personal and lesion characteristics, lesion level was the only characteristic that showed a significant association with POpeak_{GXT}. This was in contrast to the studies of Simmons et al. [21] and Kouwijzer et al. [6], who also found a significant

association between sex and POpeak_{GXT} measured during an arm ergometry test, next to lesion level, in people with SCI. The difference between the present study and the studies by Simmons et al. [21] and Kouwijzer et al. [6] is the addition of sprint power to the regression model to predict POpeak_{GXT}. It might be that the effect of sex on POpeak_{GXT} is already included in sprint power and, therefore, does not remain in the present statistical models. Adding mean sprint power to the model led to higher explained variances ($R^2 > 70\%$) compared to the models including only personal and lesion characteristics ($R^2 = 42\%$ [6] and $R^2 = 57\%$ [21]). This result was expected due to previously found strong associations between sprint power and peak power output of a GXT during wheelchair ergometry in people with SCI [7] and cycling ergometry in people with cerebral palsy [8].

Figure 2. Scatter plots representing the absolute agreement between the predicted $PO_{peakGXT}$ and the measured $PO_{peakGXT}$. The solid line is the line of identity, when a marker lies on this line it means that the predicted value is exactly the same as the measured value. The dashed lines indicate 20% deviation boundaries. Each circle represents a participant of the validation group. (A) The difference in $PO_{peakGXT}$ between predicted and measured value with the theoretical model and $PO_{peakWingate}$ as independent variable. (B) The difference in $PO_{peakGXT}$ between predicted and measured value with the theoretical model and $PO_{meanWingate}$ as independent variable. (C) The difference in $PO_{peakGXT}$ between predicted and measured value with the statistical model and $PO_{peakWingate}$ as independent variable. (D) The difference in $PO_{peakGXT}$ between predicted and measured value with the statistical model and $PO_{meanWingate}$ as independent variable.

Table 3. Reference values for PO_{peak} and PO_{mean} during asynchronous Wingate test (both in W and W/kg) for participants with a tetraplegia (TP) and paraplegia (PP).

Variable	Level	N	Median	Poor	Fair	Average	Good	Excellent
PO_{peak} (W)	TP	32	94	<30	30–80	80–127	127–168	>168
	PP	54	243	<160	160–208	208–270	270–297	>297
	Total	86	184	<85	85–155	155–203	203–277	>277
$PO_{peak/kg}$ (W/kg)	TP	32	1.25	<0.40	0.40–0.98	0.98–1.89	1.89–2.30	>2.30
	PP	54	3.08	<2.23	2.23–2.57	2.57–3.31	3.31–3.84	>3.84
	Total	86	2.35	<1.22	1.22–2.05	2.05–2.59	2.59–3.60	>3.60
PO_{mean} (W)	TP	30	64	<18	18–55	55–71	71–117	>117
	PP	54	152	<100	100–143	143–162	162–196	>196
	Total	84	123	<59	59–103	103–144	144–172	>172
PO_{mean} (W/kg)	TP	30	0.90	<0.24	0.24–0.59	0.59–1.15	1.15–1.70	>1.70
	PP	54	2.00	<1.25	1.25–1.92	1.92–2.03	2.03–2.42	>2.42
	Total	84	1.73	<0.80	0.80–1.43	1.43–1.92	1.92–2.10	>2.10

Quintiles were defined based on percentiles: Poor (<20%), Fair (20–40%), Average (40–60%), Good (60–80%) and Excellent (>80%).

A possible explanation for the strong correlation between sprint power and peak aerobic power output might be that the same muscle mass is used during a sprint and GXT while different physiological systems (anaerobic vs. aerobic) are recruited. It might also be that the different energy systems are equally well trained in wheelchair users with SCI. In non-disabled participants much weaker relationships ($R^2 = 0.36$) between sprint power and $PO_{peak_{GXT}}$ were found compared to people with a disability ($R^2 = 0.94$) [8]. The larger variability in the group with a disability might be an explanation for this, i.e. the magnitude of the correlation coefficient will be higher in a more heterogeneous group.

The strong relationship between sprint power and $PO_{peak_{GXT}}$ might also indicate that sprint power training programs could enhance peak aerobic power output, as was previously suggested by Janssen et al. [7]. The effect of specific sprint training on $PO_{peak_{GXT}}$ has, as far as known, not yet been studied in arm exercise. However, evaluation of a 7-weeks high intensity interval training (HIIT) with handcycling, compared to a moderately intensity continuous training, showed that HIIT was significantly more effective to improve GXT outcomes of PO_{peak} and VO_{2peak} [22]. Since the performance of a Wingate test costs less time than a GXT, and because of the strong association among the test outcomes, it might be a good test to monitor a person with SCI more frequent during a training period.

Adding lesion level and sprint power to the model to predict $PO_{peak_{GXT}}$ led to a higher explained variance than the models with either of these determinants. Although lesion level and sprint power are associated, i.e. people with tetraplegia show lower sprint power than people with paraplegia [21], adding both determinants leads to the strongest model. Sprint power gives information about talent, skill, training status, which are also important for $PO_{peak_{GXT}}$, while lesion level gives information about the functional capabilities of the participant.

Validation

Although previous studies have looked at predictions of $PO_{peak_{GXT}}$ with Wingate test outcomes and/or personal and lesion characteristics [7,8,21], validation of these models was only done by Kouwijzer et al. [6]. Our validation study showed higher predictive strength than those of Kouwijzer et al. [6] with $PO_{peak_{GXT}}$ predictions based on handcycling training hours and personal and lesion characteristics. The explained variances of our models, including sprint power, were higher ($R^2 = 0.70$ vs. $R^2 = 0.42$) and subsequently the ICCs were higher (ICC = 0.89 vs. ICC = 0.43) and 95% limits of agreement were smaller (−30 to 31 W vs. −69–54 W). Although the validity results are much more promising than in the study of Kouwijzer et al. [6], the 95% limits of agreement in the present study are still quite wide, and 5 of the 21 participants (i.e. 24%) showed a predicted value that deviated more than 20% from the measured value. This implies that when using the predicted value to set the GXT resistance protocol, the test duration will be shorter than 8 min or longer than 12 min. A test duration of 8–12 min is suggested to be optimal for achieving peak physiological responses during a GXT [5,23]. The validation results might also be dependent on the sample size, which is rather small in our study. It has been suggested that about 50 participants are needed for a reliability study to have, among others, a reasonable number of dots in a Bland Altman plot to estimate the limits of agreement [24]. Although we had 93 participants in this study, by combining two previously published studies, we needed the largest part of the sample for developing the models, leaving us with a sample size of about 25 participants

for the validation study. In the future, it would be interesting to standardize the arm-crank ergometer protocols for the Wingate test and GXT so that results from different SCI studies, and if possible different labs, can be combined into one large database that can be used for these kind of prediction and validation studies.

Reference values

This is the first study that gives reference values for the outcomes of the Wingate test performed on an asynchronous arm-crank ergometer by people with SCI. These reference data were set-up identically to the reference data of GXT outcomes during a wheelchair GXT [20] and during a synchronous [6] and asynchronous [21] arm ergometry GXT.

Although Wingate reference values for people with SCI were not previously published, average results of the Wingate outcomes have been shown before. Our mean $PO_{peak_{Wingate}}$ values (tetraplegia: 103 ± 67 W; paraplegia: 237 ± 105 W) were quite similar to the mean values found by Simmons et al. [21] (tetraplegia: 96 ± 61 W ($N = 25$); paraplegia: 251 ± 85 W ($N = 56$)), which might be explained by including some of the same study participants. In contrast, the values found by Morgulec et al. [11] for active (150 ± 55 W ($N = 19$)) and sedentary (112 ± 82 W ($N = 12$)) people with a tetraplegia were higher, while Jacobs et al. [10] found much higher values for people with paraplegia (312 ± 97 W, $N = 43$) and a wide range in people with tetraplegia (C5: 54 W to C7: 203 W, $N = 45$) [9]. For the $PO_{mean_{Wingate}}$ similar results were found, i.e., our mean values (tetraplegia: 68 ± 47 W; paraplegia: 152 ± 64 W) were almost the same as those of Simmons et al. [21] (tetraplegia: 65 ± 46 W; paraplegia: 163 ± 61 W) but lower than Morgulec et al. [11] (active tetraplegia: 113 ± 30 W; sedentary tetraplegia 74 ± 54 W) and Jacobs et al. [10] (paraplegia: 221 ± 72 W) and somewhere in the range of outcomes of persons with tetraplegia (C5: 32 W to C7: 134 W) [9]. Differences in outcomes between studies can, of course, be due to the different personal and SCI characteristics of the studied groups. However, the Wingate test protocol has also an effect on the PO outcomes, i.e. different resistance settings lead to lower or higher peak or mean PO values [17].

Limitation & recommendation

There are some limitations of this study. As noted previously, the sample size for the model and validation group is relatively small, which may have an effect on the outcomes. Furthermore, the model is only applicable for the specific GXT and Wingate test protocols described in the methods section. Although some studies did not find differences in peak physiological responses with different GXT protocols [25,26], others did [27]. The GXT was performed on different systems (Monark or Lode) and with slightly different cadences (60 vs. 55 rpm), which might be another limitation of our study. However, according to previous studies no difference was found in PO_{peak} between an electromechanically braked vs. mechanically braked leg cycle ergometer [28] and although the cadence was found to be a possible confounder for VO_{2peak} , it did not have an effect on PO_{peak} in arm crank GXT [29].

Lastly, the prediction model is applicable for asynchronous arm-cranking only. Peak and mean Wingate power during synchronous arm-cranking appeared to be significantly lower than during asynchronous arm-cranking [30]. Furthermore, physiological responses during a GXT also seem to indicate more positive results for asynchronous arm-cranking [31].

Conclusions

Strong associations were found between $PO_{meanWingate}$ and $PO_{peakGXT}$. Although a large part of $PO_{peakGXT}$ was explained in the regression model and the relative agreement was excellent, absolute agreement was low. Therefore, the model can only be used with caution for setting the GXT protocol.

Disclosure statement

The authors report no conflicts of interest.

References

- [1] Dallmeijer AJ, Zentgraaff ID, Zijp NJ, et al. Submaximal physical strain and peak performance in handcycling versus handrim wheelchair propulsion. *Spinal Cord*. 2004;42:91–98.
- [2] Arnet U, Drongelen S, Scheel-Sailer A, et al. Shoulder load during synchronous handcycling and handrim wheelchair propulsion in persons with paraplegia. *J Rehabil Med*. 2012;44:222–228.
- [3] Valent LJ, Dallmeijer AJ, Houdijk H, et al. Effects of hand cycle training on physical capacity in individuals with tetraplegia: a clinical trial. *Phys Ther*. 2009;89:1051–1060.
- [4] de Groot S, Postma K, van Vliet L, et al. Mountain time trial in handcycling: exercise intensity and predictors of race time in people with spinal cord injury. *Spinal Cord*. 2014; 52:455–461.
- [5] Buchfuhrer MJ, Hansen JE, Robinson TE, et al. Optimizing the exercise protocol for cardiopulmonary assessment. *J Appl Physiol Respir Environ Exerc Physiol*. 1983;55: 1558–1564.
- [6] Kouwijzer I, Valent LJ, Osterthun R, et al. Peak power output in handcycling of individuals with a chronic spinal cord injury: predictive modeling, validation and reference values. *Disabil Rehabil*. 2018;1–10. Accepted.
- [7] Janssen TW, van Oers CA, Hollander AP, et al. Isometric strength, sprint power, and aerobic power in individuals with a spinal cord injury. *Med Sci Sports Exerc*. 1993;25: 863–870.
- [8] De Groot S, Janssen TW, Evers M, et al. Feasibility and reliability of measuring strength, sprint power, and aerobic capacity in athletes and non-athletes with cerebral palsy. *Dev Med Child Neurol*. 2012;54:647–653.
- [9] Jacobs PL, Johnson B, Somarriba GA, et al. Reliability of upper extremity anaerobic power assessment in persons with tetraplegia. *J Spinal Cord Med*. 2005;28:109–113.
- [10] Jacobs PL, Mahoney ET, Johnson B. Reliability of arm Wingate Anaerobic Testing in persons with complete paraplegia. *J Spinal Cord Med*. 2003;26:141–144.
- [11] Morgulec N, Kosmol A, Vanlandewijck Y, et al. Anaerobic performance of active and sedentary individuals with quadriplegia. *APAQ* 2005;22:253–264.
- [12] Nash MS, van de Ven I, van Elk N, et al. Effects of circuit resistance training on fitness attributes and upper-extremity pain in middle-aged men with paraplegia. *Arch Phys Med Rehabil*. 2007;88:70–75.
- [13] von Elm E, Altman DG, Egger M, et al. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *Lancet*. 2007;370:1453–1457.
- [14] Callahan MK, Cowan RE. Relationship of fitness and wheelchair mobility with encounters, avoidances, and perception of environmental barriers among manual wheelchair users with Spinal Cord Injury. *Arch Phys Med Rehabil*. 2018;99: 2007–2014.
- [15] Cowan RE, Callahan MK, Nash MS. The 6-min push test is reliable and predicts low fitness in spinal cord injury. *Med Sci Sports Exerc*. 2012;44:1993–2000.
- [16] Cowan RE, Nash MS, de Groot S, et al. Adapted manual wheelchair circuit: test-retest reliability and discriminative validity in persons with spinal cord injury. *Arch Phys Med Rehabil*. 2011;92:1270–1280.
- [17] Jacobs PL, Johnson BM, Mahoney ET, et al. Effect of variable loading in the determination of upper-limb anaerobic power in persons with tetraplegia. *J Rehabil Res Dev*. 2004; 41:9–14.
- [18] American College of Sports Medicine's Guidelines for Exercise Testing and Prescription. Philadelphia, USA: Lippincott Williams & Wilkins; 2009.
- [19] Cicchetti DV. Guidelines, criteria, and rules of thumb for evaluating normed and standardized assessment instruments in psychology. *Psychol Assess*. 1994;6:284–290.
- [20] Janssen TW, Dallmeijer AJ, Veeger DJ, et al. Normative values and determinants of physical capacity in individuals with spinal cord injury. *J Rehabil Res Dev*. 2002;39:29–39.
- [21] Simmons OL, Kressler J, Nash MS. Reference fitness values in the untrained spinal cord injury population. *Arch Phys Med Rehabil*. 2014;95:2272–2278.
- [22] Schoenmakers P, Reed K, Van Der Woude L, et al. High intensity interval training in handcycling: the effects of a 7 week training intervention in able-bodied men. *Front Physiol*. 2016;7:638.
- [23] Myers J, Bellin D. Ramp exercise protocols for clinical and cardiopulmonary exercise testing. *Sports Med*. 2000;30: 23–29.
- [24] de Vet HCW, Terwee CB, Mokkink LB, et al. Measurement in medicine. Cambridge, UK: Cambridge University Press; 2011.
- [25] Maher JL, Cowan RE. Comparison of 1- versus 3-minute stage duration during arm ergometry in individuals with spinal cord injury. *Arch Phys Med Rehabil*. 2016;97: 1895–1900.
- [26] Smith PM, Doherty M, Drake D, et al. The influence of step and ramp type protocols on the attainment of peak physiological responses during arm crank ergometry. *Int J Sports Med*. 2004;25:616–621.
- [27] Smith PM, Amaral I, Doherty M, et al. The influence of ramp rate on VO_{2peak} and "excess" VO_2 during arm crank ergometry. *Int J Sports Med*. 2006;27:610–616.
- [28] Ozkol M. Electromagnetically braked versus mechanically braked cycle ergometers: effects of aerobic power and total physical workloads. *Isokinetics Exerc Sci*. 2014;22:165–173.
- [29] Smith PM, Doherty M, Price MJ. The effect of crank rate strategy on peak aerobic power and peak physiological responses during arm crank ergometry. *J Sports Sci*. 2007; 25:711–718.
- [30] Lovell DI, Mason D, Delphinus E, et al. A comparison of asynchronous and synchronous arm cranking during the Wingate test. *Int J Sports Physiol Perform*. 2011;6:419–426.
- [31] Mossberg K, Willman C, Topor MA, et al. Comparison of asynchronous versus synchronous arm crank ergometry. *Spinal Cord*. 1999;37:569–574.