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Training for the HandbikeBattle: an explorative analysis of training load and handcycling physical capacity in recreationally active wheelchair users

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ABSTRACT

Purpose: (1) to analyze training characteristics of recreationally active wheelchair users during handcycle training, and (2) to examine the associations between training load and change in physical capacity.

Methods: Former rehabilitation patients ($N = 60$) with health conditions such as spinal cord injury or amputation were included. Participants trained for five months. A handcycling/arm crank graded exercise test was performed before and after the training period. Outcomes: peak power output per kg (POpeak/kg) and peak oxygen uptake per kg (VO_2peak/kg). Training load was defined as Training Impulse (TRIMP), which is rating of perceived exertion (sRPE) multiplied by duration of the session, in arbitrary units (AU). Training intensity distribution (TID) was also determined (time in zone 1, RPE ≤ 4; zone 2, RPE 5–6; zone 3, RPE ≥ 7).

Results: Multilevel regression analyses showed that $TRIMP_{sRPE}$ was not significantly associated with change in physical capacity. Time in zone 2 (RPE 5–6) was significantly associated with ΔVO_2peak, $\%\Delta VO_2$peak, ΔVO_2peak/kg and $\%\Delta VO_2$peak/kg.

Conclusion: Training at RPE 5–6 was the only determinant that was significantly associated with improvement in physical capacity. Additional controlled studies are necessary to demonstrate causality and gather more information about its usefulness, and optimal handcycle training regimes for recreationally active wheelchair users.

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sRPE; training intensity distribution; monotony; strain; upper-body exercise

➤ IMPLICATIONS FOR REHABILITATION

- Monitoring of handcycle training load is important to structure the training effort and intensity over time and to eventually optimize performance capacity. This is especially important for relatively untrained wheelchair users, who have a low physical capacity and a high risk of overuse injuries and shoulder pain.
- Training load can be easily calculated by multiplying the intensity of the training (RPE 0–10) with the duration of the training in minutes.
- Results on handcycle training at RPE 5–6 intensity in recreationally active wheelchair users suggests to be promising and should be further investigated with controlled studies.

Introduction

Physical capacity is generally reduced in manual wheelchair users [1]. A low physical capacity is associated with a high prevalence of cardiometabolic disease [2]. Therefore, exercise interventions to increase physical capacity in wheelchair users are important. An interesting goal to train for is the HandbikeBattle [3]. The HandbikeBattle is organized as an annual event in the mountains of Austria and is an uphill handcycling mountain race among

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teams of Dutch rehabilitation centers. The teams consist of former patients with, among others, a spinal cord injury (SCI) or amputation. The event was created to initiate an active lifestyle by means of free-living handcycle training.

Handcycling is a common exercise mode for manual wheelchair users during and after rehabilitation [4,5]. It is shown that handcycle training results in improvement in physical capacity during and after rehabilitation even in the most vulnerable patients with a tetraplegia [5]. Furthermore, handcycling has a higher efficiency than wheelchair propulsion and leads to lower shoulder loads [6,7]. This is important as 30–73% of wheelchair users with a SCI experience musculoskeletal pain in the shoulder [8,9]. Handcycle training studies during or after rehabilitation are, unfortunately, scarce. In addition, studies related to upper-body training often have a small heterogeneous sample size or do not take training load into consideration.

Elite athletes commonly monitor their training load, yet it is less common in rehabilitation interventions. Monitoring of training load is important to structure the training effort and intensity over time and to eventually optimize performance capacity. In turn, critical assessment of training load helps to prevent under-training or overtraining [10]. Indices of training load relate to form, frequency, duration and intensity. Training load can be divided in external and internal training load [10]. In (hand)cycling, external training load is often represented by the training stress score (TSS) based on power output (PO (W)) [11]. This is an objective measure of external training load, but it is costly, and only applicable to handcycling and not to other forms of exercise (therapy) in rehabilitation. Internal training load measures are, among others, the training impulse (TRIMP) based on heart rate reserve (HRR) [12] or the session rating of perceived exertion (sRPE) [13]. TRIMP based on sRPE ($\text{TRIMP}_{\text{sRPE}}$) is calculated by multiplying the overall RPE of the session by the duration of the session in minutes [13]. $\text{TRIMP}_{\text{sRPE}}$ is an easy to use and cheap method to monitor internal training load, is applicable to different training modes, and gives an overall representation of the individual's perception of training, potentially taking into account physical, psychological and environmental factors [14]. These subjective factors are very important to the individual's training response, in addition to the imposed objective external training load [15]. An additional advantage of $\text{TRIMP}_{\text{sRPE}}$ as internal training load measure is that for individuals with tetraplegia training intensity based on heart rate (HR) is often not applicable due to the altered sympathetic response to exercise, which makes heart rate difficult to interpret [16]. It would, therefore, be an ideal method to monitor training sessions in rehabilitation. Previous studies showed large to nearly perfect correlations $(0.5-0.97)$ among $\text{TRIMP}_{\text{sRPE}}$ and HR-based TRIMP methods in sprint kayak, wheelchair basketball, soccer, cycling and recreational handcycling [15,17–20]. Whereas very large to nearly perfect correlations $(0.81-0.95)$ were found between $\text{TRIMP}_{\text{sRPE}}$ and TSS in cycling and recreational handcycling [19,20].

Although training load measures generally correlate well and training monitoring based on training load seems to be useful during the training process [14,21], dose-response relationships with improvements in physical capacity remain controversial [21]. Foster et al. found a correlation of 0.029 between increase in $\text{TRIMP}_{\text{sRPE}}$ and improvement in time trial performance [22]. In addition, $\text{TRIMP}_{\text{sRPE}}$ explained only 12% of the variance of change in VO_2max in rugby players [23], and small to moderate correlations were found between $\text{TRIMP}_{\text{sRPE}}$ and change in performance in hurling [24]. A recent study, in which elite cyclists underwent a laboratory incremental cycling test until exhaustion before and after the training period, concluded that different training load measures ($\text{TRIMP}_{\text{sRPE}}$, HR-based TRIMP and TSS) were only correlated to submaximal outcome measures (PO at 2 mmol/L and 4 mmol/L blood lactate), and not to changes in POmax or VO_2max [25]. In recreational cyclists, no relationships were found among different HR-based TRIMP methods and change in POmax (determined with a laboratory incremental cycling test until exhaustion) [26]. In addition to training load itself, it was proposed that training time in each intensity zone (training intensity distribution, TID) [26,27], lack of day-to-day variability in training load (monotony) and training strain could all play a role in adaptations to training [13,28,29].

Taken together, knowledge on training adaptations is rapidly increasing but far from complete or consistent. Especially in adaptive sports and upper-body training in wheelchair users during rehabilitation there is a lack of knowledge about suitable training regimes, loads and dose-response relationships. Previously it has been shown that training for the HandbikeBattle leads to improvements in physical capacity and health [4]. It is, however, unknown what training regimes led to these improvements. In an attempt to unravel more details on training regimes and dose-response relationships of handcycle training, the purpose of this explorative prospective cohort study was (1) to analyze training characteristics, and (2) to examine the associations between training load and the change in physical capacity.

Materials & methods

Participants

Inclusion criteria for the HandbikeBattle event were: being a former rehabilitation patient from one of the twelve rehabilitation centers; impairment of the lower extremities due to e.g. SCI, amputation, cerebral palsy or spina bifida; and commitment to the HandbikeBattle challenge. Exclusion criterion: contra-indications to participate in the HandbikeBattle as diagnosed during the medical screening before the training period. There were no specific inclusion/exclusion criteria for training status. The included group was heterogeneous and ranged from untrained to recreationally active participants at the start of the training period. In the present study, data were used from participants of the HandbikeBattle 2013 and 2015–2019 cohorts. In total 227 individuals were recruited to start monitoring their training sessions in this period. Twenty-six individuals dropped out during the training period for the HandbikeBattle due to motivational problems ($N=4$), medical reasons ($N=16$), family matters ($N=1$), not being able to combine training with activities of daily living ($N=4$), or financial reasons ($N=1$). No individuals dropped out due to overuse injuries. Twenty-one individuals did not complete the GXT before or after the training period. Another 120 individuals did not have complete training data. Training data were considered complete if more than 80% of training sessions had a filled out RPE. Hence, data from 60 participants were used in the present study, whereas data from 167 individuals could not be used. For non-response analyses, data of these 167 individuals were used as a comparator group of non-participants. All participants provided written informed consent. The study was approved by the Local Ethics Committee of the Center for Human Movement Sciences, University Medical Center Groningen, the Netherlands (ECB/2012_12.04_I_rev/Ml).

Procedures

Design

The HandbikeBattle event is a serious challenge (20.2-km length and 863 m elevation gain) each year in June. At the start of the 5-month training period, most participants are relatively untrained handcyclists. Connected to, but not part of, the HandbikeBattle event is a prospective observational cohort study that was initiated to monitor effects of participation in the training period and the event. Measurements were performed at the start of the training period (January, T1), during the training period, and after the training period prior to the event (June, T2). At T1 a medical screening was performed by a rehabilitation physician or sports physician at the rehabilitation center. The screening comprised a medical anamnesis, physical examination and a handcycling/arm crank graded exercise test (GXT). At T2 the GXT was repeated with the same protocol and equipment. At T1 participants were asked to fill out a questionnaire about musculoskeletal shoulder pain. Guidance during the training period was provided by therapists from the respective rehabilitation centers, for example with a joint training session each month and information about uphill handcycling. The training period was free-living, i.e. no specific training program was provided by the researchers. After the GXT at T1, participants started to train indoors and outdoors. The main part of the training was done individually or together with HandbikeBattle participants from the same rehabilitation center. All participants were asked to monitor all their sporting activity with an online app (Strava) or a training diary on paper.

Physical capacity

Physical capacity was measured during an incremental handcycling/arm crank GXT to volitional exhaustion at T1 and T2, organized in and conducted by the staff of each of the participating rehabilitation centers. All tests were performed in synchronous mode of cranking. Dependent on the rehabilitation center, the GXTs were performed with the use of an arm ergometer (Lode Angio, Groningen, the Netherlands) or a recumbent sport handcycle attached to the Cyclus 2 ergometer (RBM elektronik-automation GmbH, Leipzig, Germany). Either a 1-min step protocol, 3-min step protocol or continuous ramp protocol was used, and was individualized for each participant. The set-up and protocol choice were consistent within participants over time. Criteria to stop the test were volitional exhaustion or failure in keeping a constant cadence above the preset value. After termination of the test, participants were asked to score their perceived exertion (i.e. RPE) during the final stage on a scale from 0 to 10 (Modified CR-10 scale) [13]. PO (W), HR (bpm) and gas exchange were measured during the test. For the 1-min step protocol, POpeak was defined as the highest PO that was maintained for at least 30 s. For the 3-min step protocol POpeak was determined as the highest PO maintained over 3 min, plus 1/6× step size in Watts for every additional 30 s in the next step [30]. For the ramp protocol, the highest PO achieved during the test was considered POpeak. Peak oxygen uptake (VO_2peak, L/min) was defined as the highest 30-s average for VO_2. Outcome parameters in the analyses were the absolute and relative changes in POpeak/kg and VO_2peak/kg between T1 and T2 (ΔPOpeak/kg, %ΔPOpeak/kg, and ΔVO_2peak/kg, and %ΔVO_2peak/kg). Data of the GXT were assessed with the following criteria: HRpeak $\geq$95% $\times$ (200-age), RPE $\geq$7, peak respiratory exchange ratio (RERpeak) $\geq$1.10 [31].

Training load calculation

Participants were asked to fill out after each training session: the type of training, duration of the training (minutes) and the overall sRPE score on a scale from 0 to 10 (Modified CR-10 scale) [13]. If the sRPE score was missing for a session, the average sRPE score of the same type of training was used for the analysis to calculate the $TRIMP_{sRPE}$ for that session [23]. $TRIMP_{sRPE}$ was calculated by multiplying the overall RPE of the session by the duration of the session in minutes [13]. Total $TRIMP_{sRPE}$ in arbitrary units (AU) was calculated as the sum of $TRIMP_{sRPE}$ of all training sessions during the training period for each participant. Average monotony per week (AU) was calculated per participant per week as the average daily $TRIMP_{sRPE}$ (AU) divided by the SD of the daily $TRIMP_{sRPE}$ of that week [29]. Total monotony (AU) was calculated for each participant as the sum of the weekly monotony for all weeks during the training period. Average strain per week (AU) was calculated per participant per week as the average $TRIMP_{sRPE}$ per week multiplied by average monotony per week [29]. Total strain (AU) was calculated for each participant as the sum of the weekly strain for all weeks during the training period. TID was calculated as the relative and absolute time and number of sessions spent in low intensity (zone 1, RPE $\leq$4), moderate intensity (zone 2, RPE 5–6) and high intensity (zone 3, RPE $\geq$7) [27].

Possible confounding variables

Possible confounding variables were musculoskeletal shoulder pain at T1, and handcycling classification. Age and sex were not considered as their influence on training adaptations is less clear [32].

Musculoskeletal shoulder pain comprised two locations (shoulder (L/R)) with range 1 = no pain, 6 = very severe pain. Two groups were created: no-mild pain = 0, moderate-severe pain = 1. Having moderate-severe pain was defined as $\geq$4 (moderate pain) at one or both locations.

Handcycling classification was used as a proxy for severity of impairment and determined by an UCI certified Paracycling classifier, following the UCI Para-cycling Regulations: resulting in five classes, ranging from H1 (most impaired) to H5 (least impaired) [33]. H1 and H2 handcyclists have limitations in arm-hand function, whereas H3, H4 and H5 handcyclists have intact arm-hand function and limitations in trunk and/or lower extremities only. For the analyses in the present study, participants were divided in two large groups: (1) H1–H3 and (2) H4–H5.

Statistical analyses

The analyses were performed using SPSS (IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp.) and MLwiN Version 3.02 [34]. Descriptive statistics were calculated for outcome measures and determinants. Data were tested for normality with the Kolmogorov–Smirnov test with Lilliefors significance correction and the Shapiro–Wilk test, combined with z-scores for skewness and kurtosis. To ascertain possible response bias, characteristics of included participants in the present study ($N = 60$) were compared with non-participants ($N = 167$) using independent-samples t-tests, Mann-Whitney U tests and chi-squared tests.

Changes in physical capacity were tested with paired-samples t-tests. Cohen's *d* effect sizes were calculated and were evaluated according to Hopkins as trivial (0–0.19), small (0.20–0.59), moderate (0.60–1.19), large (1.20–1.99), or very large ($\geq$2.00) [35]. The Pearson product-moment correlation (r) was used to examine the associations among the training load determinants and changes in physical capacity, with a Spearman's rank correlation (ρ) in case of non-normality. The strength of the correlation coefficients was evaluated according to Hopkins as trivial (0–0.09), small (0.10–0.29), moderate (0.30–0.49), large (0.50–0.69), or very large

(≥0.70) [35]. In addition, multilevel regression analyses were used to examine specific multivariate associations. Two-level models were created with participant as first level and rehabilitation center as second level to be able to make adjustments for the dependency of participants within centers. The first set of regression analyses comprised the association between change in physical capacity (ΔPOpeak/kg, %ΔPOpeak/kg, ΔVO$_2$peak/kg, and %ΔVO$_2$peak/kg) and Total TRIMP$_{sRPE}$ (basic models). Each regression analysis was corrected for baseline value of the outcome measure (POpeak/kg or VO$_2$peak/kg at T1) and duration of the training period (weeks). Thereafter, shoulder pain and handcycling classification were added as possible confounders (final models). A variable was included as confounder in the final model if its inclusion changed the beta of training load with more than 10% [36]. The second set of multilevel regression analyses comprised the association between change in physical capacity (ΔPOpeak/kg, %ΔPOpeak/kg, ΔVO$_2$peak/kg, and %ΔVO$_2$peak/kg), and separate determinants for frequency, duration and intensity: duration of the training period (weeks), number of training sessions per week (N), average training volume per training session (min), and average sRPE per training session. Additional explorative analyses were performed with TID, total monotony, total strain and high intensity training sessions only (RPE > 5) as determinants [22]; and with ΔPOpeak and ΔVO$_2$peak as outcome parameters. Significance was set at $p < 0.05$ for all statistical analyses.

Results

Participants had more often a high classification (H4–H5) than non-participants (Table 1). Within the non-participants group, POpeak and POpeak/kg at T1 were lower for dropouts compared with individuals who completed the training period but had incomplete training data (Table 1). Eighty-six percent of GXTs met ≥ 2 of above criteria for a peak GXT. All outcome measures were normally distributed. A total of 4617 training sessions were analyzed for this study. The most common training sessions comprised: handcycling ($N = 3269$), strength and conditioning ($N = 895$), swimming ($N = 60$), wheelchair basketball ($N = 50$), and wheelchair rugby ($N = 45$). Handcycling was the main sport for all participants. Twenty-one participants had a filled out sRPE in all training sessions. Thirty-nine participants had missing sRPE with an average of 6.1% missing data (SD: 4.6, range: 1−17%). Participants trained for 21 ± 6 weeks with an average of 3.6 ± 1.4 training sessions per week (Table 2). Mean weekly TRIMP$_{sRPE}$ was 1654 ± 579 AU (Table 2). Physical capacity showed a significant increase between T1 (before training period) and T2 (after training period) (Table 3). Figure 1 shows two typical examples of training characteristics of participants training for the event.

Correlations between training characteristics and outcome parameters were trivial to small (Table 2). Total TRIMP$_{sRPE}$ was not significantly associated with change in physical capacity (Table 4). After adding confounders to the models, associations remained non-significant (Table 4). Separate determinants for frequency, duration and intensity showed no significant associations except for a negative association between duration of the training period and ΔVO$_2$peak/kg (Table 5).

Additional explorative regression analyses with high intensity training sessions only (RPE > 5), total monotony or total strain as determinants; or ΔPOpeak and ΔVO$_2$peak as outcome parameters, showed no significant results. Multilevel multivariate regression analyses with TID showed a significant association between ΔVO$_2$peak as well as %ΔVO$_2$peak and absolute number of training sessions and time in moderate intensity (RPE 5–6). In addition, significant associations were found between ΔVO$_2$peak/kg as well as %ΔVO$_2$peak/kg and absolute time in moderate intensity (RPE 5–6) (Table 6). None of the TID parameters were associated with change in POpeak or POpeak/kg, nor relative time or training sessions were associated with the change of any of the physical capacity outcome measures.

Discussion

Physical capacity improved with 17−22% during 21 ± 6 weeks of training. Correlations between training characteristics and outcome parameters were not significant and total TRIMP$_{sRPE}$ was not significantly associated with change in physical capacity. In addition, the separate components of frequency, duration and intensity were not unequivocally associated with change in

Table 1. Characteristics and outcomes at the start of the training period for participants ($N = 60$) and non-participants ($N = 167$).

	Participants			Non-participants								
Characteristics	*N*			*N*	Total		N	Incomplete data		*N*	Drop-outs	
Sex (male/female)	60	39/21	(65/35)	167	115/52	(69/31)	141	99/42	(70/30)	26	16/10	(62/38)
Age (years)	60	40	(12)	166	41	(14)	141	41	(14)	25	41	(13)
Impairment type	60			166			141			25		
Spinal cord injury		26	(43)		95	(57)		80	(57)		15	(60)
Tetraplegia		5	(8)		16	(10)		14	(10)		2	(8)
Paraplegia		21	(35)		79	(47)		66	(47)		13	(52)
Amputation		8	(13)		19	(11)		15	(11)		4	(16)
Multi trauma		1	(2)		6	(4)		6	(4)		0	(0)
Spina bifida		7	(12)		12	(7)		10	(7)		2	(8)
Other		18	(30)		34	(21)		30	(21)		4	(16)
POpeak (W)	59	118	(39)	155	109	(41)	134	112**	(42)	21	90**	(24)
ΔPOpeak (W)	59	22	(18)	122	19	(17)	122	19	(17)	0	–	–
POpeak/kg (W/kg)	59	1.51	(0.51)	147	1.44	(0.52)	127	1.48**	(0.54)	20	1.18**	(0.30)
ΔPOpeak/kg (W/kg)	59	0.30	(0.24)	113	0.27	(0.25)	113	0.27	(0.25)	0	–	–
VO$_2$peak (L/min)	59	1.91	(0.57)	154	1.76	(0.54)	134	1.79	(0.55)	20	1.57	(0.45)
ΔVO$_2$peak (L/min)	59	0.30	(0.27)	118	0.24	(0.27)	118	0.24	(0.27)	0	–	–
VO$_2$peak/kg (ml/kg/min)	59	24.75	(7.88)	146	23.49	(6.82)	127	23.89	(6.95)	19	20.82	(5.35)
ΔVO$_2$peak/kg (ml/kg/min)	59	4.13	(3.37)	110	3.31	(3.82)	110	3.31	(3.82)	0	–	–
Shoulder pain (no-mild/moderate-severe)	54	44/10	(81/19)	123	101/22	(82/18)	109	90/19	(83/17)	14	11/3	(79/21)
Handcycling classification (H1–H3/H4–H5)	60	22/38*	(37/63)	153	85/68*	(56/44)	141	79/62	(56/44)	12	6/6	(50/50)

Data represent *N* (%) or mean (SD). POpeak: peak power output; VO$_2$peak: peak oxygen uptake. Shoulder pain: two categories: (1) no-mild pain and (2) moderate-severe pain. Handcycling classification: two categories: (1) H1–H3 and (2) H4–H5. * Significant difference with $p < 0.05$ between participants and non-participants. **Significant difference with $p < 0.05$ between non-participants with incomplete training data and non-participants who dropped-out.

Table 2. Overview of training characteristics (*N* = 60) and correlations with outcome parameters.

	Mean ± SD	Range (min–max)	ΔPOpeak/kg *r* (*p*-value)	%ΔPOpeak/kg *r* (*p*-value)	ΔVO$_2$peak/kg *r* (*p*-value)	%ΔVO$_2$peak/kg *r* (*p*-value)
Duration of training period (weeks)	21 ± 6	8–33	–0.01 (0.92)	0.10 (0.44)	–0.14 (0.31)	–0.04 (0.76)
Number of training sessions	77 ± 40	23–183	–0.00 (0.99)	0.14 (0.29)	0.01 (0.95)	0.08 (0.55)
Number of training sessions per week	3.6 ± 1.4	1–8	0.00 (0.99)	0.11 (0.40)	0.10 (0.45)	0.13 (0.34)
Total training volume (min)	6174 ± 2841	1635–13728	–0.03 (0.83)	0.06 (0.65)	–0.08 (0.57)	–0.01 (0.92)
Average training volume per week (min)	299 ± 102	112–572	–0.07 (0.62)	–0.06 (0.68)	–0.03 (0.82)	–0.03 (0.85)
Average training volume per training session (min)	86 ± 20	47–136	–0.07 (0.58)	–0.24 (0.07)	–0.16 (0.23)	–0.19 (0.16)
Total TRIMP$_{sRPE}$ (AU)	33892 ± 14746	9293–69440	–0.03 (0.84)	0.09 (0.50)	–0.09 (0.51)	–0.04 (0.77)
Average TRIMP$_{sRPE}$ per week (AU)	1654 ± 579	622–3350	–0.05 (0.72)	–0.01 (0.94)	–0.02 (0.90)	–0.03 (0.81)
Average TRIMP$_{sRPE}$ per training session (AU)	484 ± 154	199–919	–0.10 (0.44)	–0.19 (0.16)	–0.14 (0.28)	–0.18 (0.18)
Average sRPE per training session	5.4 ± 1.3	3–8	0.03 (0.83)	0.07 (0.60)	–0.02 (0.88)	–0.02 (0.86)
Total monotony (AU)	15.9 ± 7.3	4.5–36.0	–0.01 (0.95)	0.13 (0.34)	–0.06 (0.64)	0.01 (0.95)
Average monotony per week (AU)	0.8 ± 0.2	0.3–1.4	–0.03 (0.82)	0.06 (0.65)	–0.00 (0.98)	0.01 (0.93)
Total strain (AU)*	29879 ± 19465	5615–99140	0.07 (0.58)	0.10 (0.44)	0.06 (0.68)	0.07 (0.62)
Average strain per week (AU)*	1483 ± 835	429–4131	0.05 (0.72)	0.06 (0.68)	0.04 (0.78)	0.01 (0.97)
Training intensity distribution						
Sessions						
RPE 1–4 (*N*)*	28.7 ± 30.5	0–130	0.03 (0.85)	–0.01 (0.94)	–0.03 (0.84)	–0.05 (0.69)
RPE 5–6 (*N*)*	24.2 ± 21.6	1–117	–0.06 (0.63)	0.04 (0.78)	0.15 (0.27)	0.19 (0.16)
RPE 7–10 (*N*)*	23.9 ± 22.1	0–105	0.09 (0.50)	0.18 (0.17)	0.00 (0.99)	0.05 (0.70)
RPE 1–4 (%)	35.3 ± 29.0	0–94	0.00 (0.99)	–0.07 (0.59)	–0.03 (0.81)	–0.04 (0.76)
RPE 5–6 (%)	30.9 ± 18.0	2–75	–0.05 (0.72)	–0.01 (0.96)	0.20 (0.13)	0.22 (0.10)
RPE 7–10 (%)	33.7 ± 28.2	0–98	0.03 (0.84)	0.07 (0.58)	–0.10 (0.46)	–0.10 (0.44)
Time						
RPE 1–4 (min)*	2129 ± 2425	0–11998	0.04 (0.79)	–0.04 (0.75)	–0.03 (0.85)	–0.07 (0.59)
RPE 5–6 (min)*	1878 ± 1437	30–7458	–0.11 (0.41)	–0.04 (0.75)	0.19 (0.14)	0.22 (0.10)
RPE 7–10 (min)*	2155 ± 1826	0–7304	0.01 (0.94)	0.09 (0.51)	–0.10 (0.45)	–0.06 (0.63)
RPE 1–4 (%)	31.5 ± 27.8	0–96	0.01 (0.97)	–0.08 (0.56)	–0.07 (0.63)	–0.06 (0.63)
RPE 5–6 (%)	30.8 ± 18.1	1–80	–0.09 (0.52)	–0.06 (0.68)	0.24 (0.07)	0.26 (0.05)
RPE 7–10 (%)	37.6 ± 28.4	0–99	0.05 (0.73)	0.11 (0.43)	–0.10 (0.47)	–0.11 (0.40)

Data represent % or mean (SD). sRPE: session rating of perceived exertion; TRIMP: Training Impulse; POpeak: peak power output; VO$_2$peak: peak oxygen uptake. *A Spearman's ρ instead of Pearson's *r*.

Table 3. Physical capacity before (T1) and after (T2) the training period.

	N	T1 (pre-training)	T2 (post-training)	Mean difference Δ (%)	*p*-value	Effect size	Qualitative outcome
POpeak (W)	59	118 ± 39	138 ± 45	22 ± 18 (20%)	<0.001	0.52	Small effect
POpeak/kg (W/kg)	59	1.51 ± 0.51	1.80 ± 0.57	0.30 ± 0.24 (22%)	<0.001	0.56	Small effect
VO$_2$peak (L/min)	59	1.91 ± 0.57	2.23 ± 0.66	0.30 ± 0.27 (17%)	<0.001	0.48	Small effect
VO$_2$peak/kg (ml/min/kg)	59	24.76 ± 7.88	29.00 ± 8.03	4.12 ± 3.36 (18%)	<0.001	0.52	Small effect

Data represent mean ± SD. POpeak: peak power output; VO$_2$peak: peak oxygen uptake. *N* = 60, however, 1 participant did not have POpeak and did have VO$_2$peak, whereas 1 other participant did not have VO$_2$peak and did have a POpeak.

physical capacity. Explorative analyses showed that absolute time and number of training sessions spent in moderate intensity (zone 2) were associated with an increase in physical capacity.

Physical capacity of the participants in the present study was comparable to other HandbikeBattle studies (Table 1) [4,37] and other recreational handcyclists [7]. The changes in physical capacity were comparable to changes as described in a systematic review (10 – 30% for POpeak and VO$_2$peak) on upper-body exercise in people with an SCI [38]. An 8-week training intervention for experienced handcyclists resulted in 20 – 26% improvement in VO$_2$peak/kg [39], whereas a 6-week home-based arm crank exercise intervention with four sessions per week at moderate intensity showed 19% improvement in VO$_2$peak/kg in untrained individuals with SCI [40].

Compared with previous studies on training load in able-bodied athletes, the duration of the training period was longer (21 ± 6 weeks in present study, versus 6 – 12 weeks in previous studies) [23–26,28,41]. The mean weekly TRIMP$_{sRPE}$ was lower than for able-bodied elite cyclists (1654 ± 579 AU in present study versus 4086 ± 1460 AU) [25], but higher than or comparable to weekly loads in studies on rugby, hurling and soccer [23,24,28,41].

In the present study there were no significant dose-response relationships between TRIMP$_{sRPE}$ and changes in physical capacity. This is in agreement with several previous studies with able-bodied athletes. Previous studies in team sports have shown correlations of 0.22–0.70 between TRIMP$_{sRPE}$ and change in maximum velocity [41,42] and correlations of 0.20 – 0.24 between TRIMP$_{sRPE}$ and change in VO$_2$max [24,28]. In rugby, a curvilinear relationship between TRIMP$_{sRPE}$ and VO$_2$max was found with an explained variance of 12% [23]. One could argue that other training load parameters such as HR-based TRIMP or TSS might have a better association with changes in physical capacity in handcycling. Two recent studies in cycling showed, however, no conclusive results. In elite cyclists, there were no significant associations among different training load parameters (TRIMP$_{sRPE}$, different HR-based TRIMP methods and TSS) and change in POmax or VO$_2$max [25]. In recreational cyclists, there were no significant associations among different HR-based TRIMP methods and change in POmax [26]. Although the TSS is an objective parameter of external load, it is only applicable to (hand)cycling training sessions and not to other sporting activity, which is a disadvantage. In addition, HR-based TRIMP methods cannot be used for individuals with tetraplegia due to the altered sympathetic response to exercise [16]. In contrast, the TRIMP$_{sRPE}$ is a robust measure and can be used irrespective of mode or location [14]. An interesting focus for future handcycling research would be a combination of several (objective and subjective) internal and external training load methods. That approach would make it possible to account for variability of

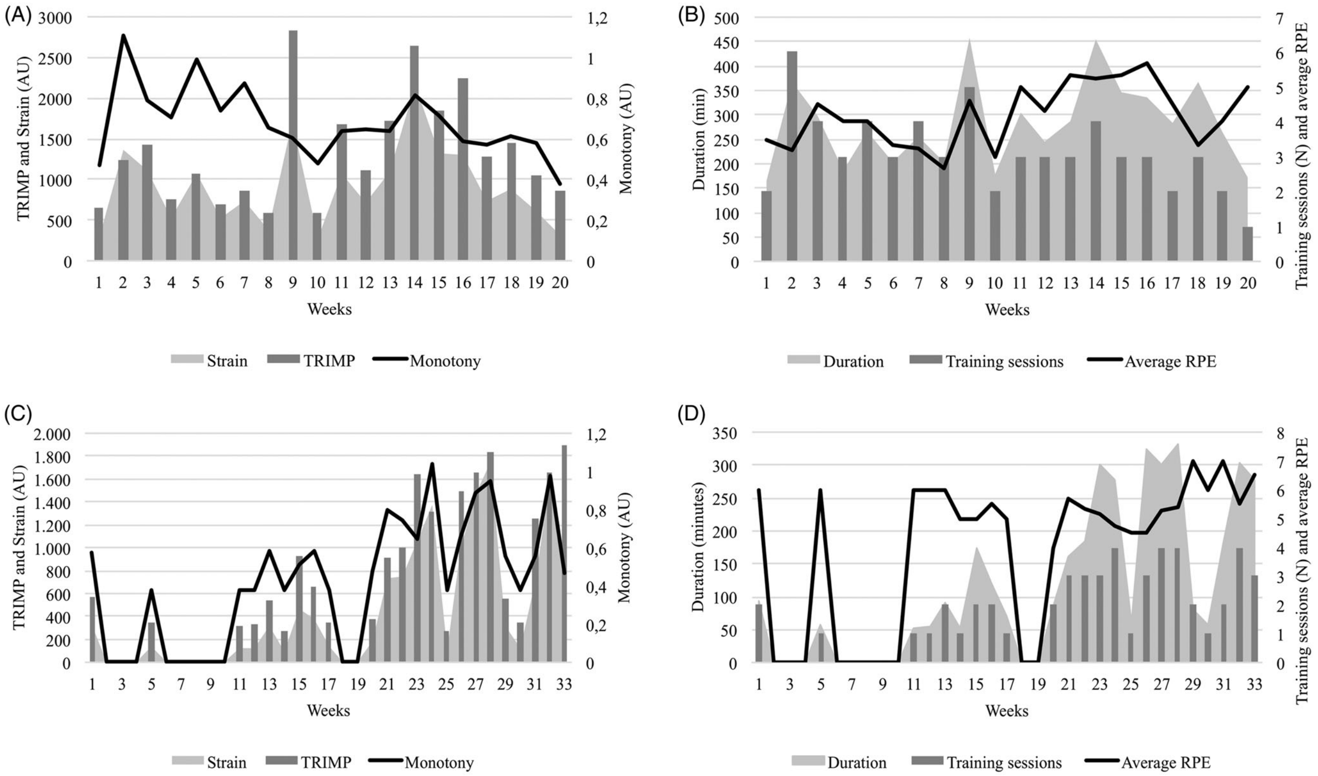

Figure 1. (A and B) Typical example of a participant who showed a relatively consistent training period. H5 handcyclist with a paraplegia. At T1: VO_2peak 2.38 L/min, POpeak 115 W. Relative change in VO2peak/kg: 4%, relative change in POpeak/kg: 11%. Training period was 20 weeks, with 3 training sessions per week on average, and average TRIMP per week of 1330 AU. Training volume per training: 90 min, average RPE per session: 4.2. (C and D) Typical example of a participant who showed a relatively long but inconsistent training period. H4 handcyclist with a paraplegia. At T1: VO2peak 1.10 L/min, POpeak 78 W. Relative change in VO_2peak/kg: 6%, relative change in POpeak/kg: 15%. Training period was 33 weeks, with 2 training sessions per week on average, and average TRIMP per week of 622 AU. Training volume per training: 71 min, average RPE per session: 5.5. At the start of the training period this participant had a lot of pain complaints related to the spinal cord injury, not related to training. In week 18 there was a surgery on the urinary tract.

Table 4. Basic and final models. Associations between absolute/relative change in physical capacity and total $TRIMP_{sRPE}$.

	ΔPOpeak/kg (×1000)			%ΔPOpeak/kg (×1000)			ΔVO_2peak/kg (×1000)			$\%\Delta VO_2$peak/kg (×1000)		
	Beta	SE	*p*-value	Beta	SE	*p*-value	Beta	SE	*p*-value	Beta	SE	*p*-value
Basic models												
Constant	322.795	174.474		41040.014	12216.585		8677.781	2373.900		43232.485	9857.727	
Total $TRIMP_{sRPE}$ (AU)	−0.000	0.003	0.85	0.021	0.180	0.91	0.000	0.035	1.00	0.003	0.146	0.98
Training period (weeks)	0.013	6.542	1.00	−46.652	458.077	0.92	−110.808	91.556	0.23	−366.253	380.192	0.34
Outcome at T1	−6.211	63.648	0.92	−12568.108	4456.565	0.005	−92.209	56.100	0.10	−710.645	232.958	0.002
Final models												
Constant	145.037	194.411		29628.436	13596.147		7442.817	2733.174		34979.079	11245.838	
Total $TRIMP_{sRPE}$ (AU)	0.001	0.003	0.73	0.118	0.195	0.55	0.027	0.039	0.49	0.122	0.161	0.90
Training period (weeks)	−2.321	7.206	0.75	−213.232	503.975	0.67	−163.174	102.917	0.11	−580.116	423.459	0.17
Outcome at T1	31.277	71.575	0.66	−10512.696	5005.644	0.04	−99.125	62.052	0.11	−658.526	255.318	0.01
Confounders												
Shoulder pain	142.326	89.764	0.47	11183.739	6277.665	0.07	966.735	1253.308	0.44	6850.936	5156.824	0.18
Classification	164.083	70.598	0.02	10943.692	4937.260	0.03	2134.731	980.212	0.03	9649.970	4033.152	0.02

Corrected for duration of training period (weeks) and value of the outcome parameter at T1. Shoulder pain: two categories: (1) no-mild pain and (2) moderate-severe pain (reference: no-mild). Handcycling classification: two categories: (1) H1–H3 and (2) H4–H5 (reference: H1–H3). A variable was included as confounder if the regression coefficient of total $TRIMP_{sRPE}$ changed more than 10%. Physical capacity outcome parameters are multiplied by 1000 to visualize the details in the beta. The determinant of interest is highlighted in greyscale.

the intensity within the training sessions and the quality of the training (e.g. a continuous training might have an overall RPE 6, whereas an interval training might also have an overall RPE 6). In addition, the combination of monitoring tools would be preferable as, for example, an increase in RPE in combination with a decrease in HR may be indicative of overreaching [43,44].

Another interesting focus for future research would be the associations among training load and changes in submaximal responses in handcycling. In the study by Sanders et al. significant associations were found between $TRIMP_{sRPE}$ and change in PO at the first lactate threshold (LT1, $r = 0.54$), and change in PO at the second lactate threshold (LT2, $r = 0.60$) in elite cycling [25]. HR-based TRIMP methods and TSS were strongly associated with change in PO at the lactate thresholds as well ($r = 0.52-0.81$ and $r = 0.75-0.79$, respectively) [25].

In previous literature in elite athletes, a low day-to-day variability in training load, that is, a high weekly monotony, was associated with a decline in performance and risk of overtraining and

Table 5. Associations between absolute/relative change in physical capacity and frequency (training sessions per week), duration (volume per training) and intensity (sRPE per training).

	ΔPOpeak/kg (×1000) Beta	SE	*p*-value	%ΔPOpeak/kg (×1000) Beta	SE	*p*-value	ΔVO_2peak/kg (×1000) Beta	SE	*p*-value	%ΔVO_2peak/kg (×1000) Beta	SE	*p*-value
Constant	440.869	354.203		44393.485	20744.201		10339.873	3888.866		56269.609	19515.935	
Training period (weeks)	−1.861	5.844	0.75	−111.711	406.651	0.78	−155.332	78.520	0.048*	−502.000	326.457	0.12
Training sessions per week (N)	−5.657	26.569	0.83	−301.639	1799.464	0.87	147.580	350.198	0.67	904.359	1479.801	0.54
Volume per training (min)	−1.387	1.974	0.48	−93.830	136.853	0.49	−27.957	27.021	0.30	−57.834	111.346	0.60
sRPE per training	3.100	25.660	0.90	4335.796	4928.621	0.38	481.676	981.019	0.62	−1416.477	1495.303	0.34
Outcome at T1	11.267	68.024	0.87	−11583.516	4682.740	0.01	−76.373	59.844	0.20	−742.301	253.707	0.003

Corrected for value of the outcome measure at T1. *Significant association with $p < 0.05$. Physical capacity outcome parameters are multiplied by 1000 to visualize the details in the beta. The determinants of interest are highlighted in greyscale.

Table 6. Associations between absolute/relative change in physical capacity and absolute training intensity distribution.

	ΔVO_2peak (×1000) Beta	SE	*p*-value	%ΔVO_2peak (×1000) Beta	SE	*p*-value	ΔVO_2peak/kg (×1000) Beta	SE	*p*-value	%ΔVO_2peak/kg (×1000) Beta	SE	*p*-value
Constant	462.526	206.001		45431.036	10275.538		9793.533	2393.556		48844.377	9848.711	
(RPE 1–4) (N sessions)	1.414	1.359	0.30	58.541	67.769	0.39	9.037	16.621	0.59	52.135	68.392	0.45
(RPE 5–6) (N sessions)	4.242	1.918	0.03*	231.431	95.658	0.02*	42.902	23.722	0.07	188.965	97.608	0.05
(RPE 7–10) (N sessions)	−0.042	1.788	0.98	−66.335	89.166	0.46	−2.563	22.261	0.91	−26.922	91.597	0.77
Training period (weeks)	−15.157	8.184	0.06	−882.131	408.223	0.03	−216.074	100.870	0.03	−836.225	415.046	0.04
Outcome at T1	1.499	64.946	0.98	−8581.190	3239.586	0.008	−100.012	55.863	0.07	−762.783	229.859	<0.001
Constant	435.294	207.101		45274.884	10158.960		10032.444	2402.470		50176.226	9925.690	
(RPE 1–4) time (min)	0.001	0.018	0.96	0.309	0.865	0.72	−0.060	0.212	0.78	0.181	0.874	0.84
(RPE 5–6) time (min)	0.067	0.030	0.03*	4.072	1.450	0.005*	0.738	0.365	0.04*	3.123	1.506	0.04*
(RPE 7–10) time (min)	−0.006	0.022	0.79	−0.726	1.063	0.49	−0.121	0.266	0.65	−0.591	1.098	0.59
Training period (weeks)	−13.154	8.086	0.10	−930.988	396.665	0.02	−208.867	99.388	0.04	−825.270	410.615	0.04
Outcome at T1	7.169	65.771	0.91	−8548.169	3226.254	0.008	−106.726	56.189	0.06	−809.064	232.141	<0.001

Corrected for duration of training period (weeks) and value of the outcome parameter at T1. *Significant association with $p < 0.05$. Physical capacity outcome parameters are multiplied by 1000 to visualize the details in the beta. The determinants of interest are highlighted in greyscale.

illness, especially when combined with a high training load, resulting in a high strain [29]. Although the monotony threshold is different for each individual, in previous research a weekly monotony above 2.0 AU was mentioned to be associated with a decline in performance and risk of overtraining [28,29], whereas a weekly monotony around 1.0 AU indicates large day-to-day variability [45]. In the present study the weekly monotony was low for most participants, with only 3.6 ± 1.4 training sessions per week. Overtraining is, therefore, unlikely in the present study, whereas undertraining cannot be excluded. Especially considering the heterogeneity of the population, undertraining is likely in participants that were not able to maintain continuity in their training regime (Figure 1(C and D)).

As training load consists of a combination of form, frequency, duration and intensity, different combinations may result in the same training load, but in a different response. In this view, TID and its effect on performance is widely studied. The threshold-training model, that is training in moderate intensity close to the second ventilatory threshold (VT2), has shown to be a guideline for training intensity in untrained participants [46,47]. In contrast, the polarized-training model is shown to be associated with improvements in performance in elite endurance athletes. In the polarized-training model, athletes train the majority of time (e.g. 75%) in the low intensity zone below the first ventilatory threshold (VT1) and the remaining time clearly above the VT2 in the high intensity zone [26,27]. The present study suggests that the threshold-training model could also be applicable to recreationally active wheelchair users during handcycle training, as only training at moderate intensity was associated with increase in physical capacity. However, it should be kept in mind that the associations between VTs and RPE in wheelchair users are not yet sufficiently studied. Ideally, the association between RPE and the occurrence of VTs should be determined during a GXT with long stage duration for each individual participant.

A limitation of the present study is that the time between the first and second (evaluation) GXT was relatively long. In future studies it would be advised to perform additional measurements, such as a GXT, time trial, strength testing or body composition, after every 4 − 6 weeks of training. In this way the associations between training load and the outcome parameters could become clearer and lack of consistency in training could be accounted for. In addition, this could aid in the adherence of training monitoring. It should be noted that given the large number of participants and logistics, this set up was not possible in the current study. Monitoring training load in a large group of non-elite participants was a challenge, which becomes clear from the 120 individuals with incomplete training data.

In addition, as the researchers were not present during the training sessions, the timing of obtaining the sRPE scores was not controlled. Therefore, it is possible that the sRPE was obtained before or later than the recommended 30 min after exercise. Although a previous study suggests that the sRPE is temporally robust up to 24 h after training [48], in follow-up research it would be advised to collect information about the variability of intensity during the training session (with for example HR) to see whether there is high intensity effort or a cool down period at the end of a training session, and to control the timing of sRPE rating.

As a result of the exploratory character of the current study, conclusive results about an optimal training regime for recreational handcyclists could not be provided. Additional controlled studies are necessary to compare different training regimes.

Training based on an intensity of RPE 5–6 seems promising and should be further investigated in future research.

That said, the population of the present study was heterogeneous and several (unmeasurable) factors could play a role in the interaction between training load and training adaptations. Figure 1(C and D) illustrates the inconsistency of training, due to all sorts of factors, not necessarily related to the training itself. Wheelchair users are a more vulnerable population than elite able-bodied athletes. However, even in a homogeneous group of able-bodied athletes, complex (temporal, fluctuating) inter-relationships exist among load, the ability to tolerate load (i.e. load capacity), performance and health [49]. Several components that influence these inter-relationships are for example fatigue, emotional disturbances, illness or training history [14,15]. An individualized approach is necessary, as the individual's psychophysiological response (internal training load) will determine training adaptation [50]. To get a grip on all these components, an integrated approach is proposed with monitoring of objective physiological measures, RPE, stress, coping, nutrition and sleep [14,49].

Conclusions

The present explorative study showed no significant associations between total $\text{TRIMP}_{\text{sRPE}}$ and changes in physical capacity during handcycle training. In addition, the separate components of frequency, duration and intensity were not unequivocally associated with change in physical capacity. However, analyses with TID showed that training at RPE 5–6 was significantly associated with an increase in physical capacity. TID might, therefore, be a promising focus for future handcycle training research. Additional controlled studies are necessary to gather more information about optimal handcycle training regimes for recreationally active wheelchair users.

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