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# Effects of 7-week Resistance Training on Handcycle Performance in Able-bodied Males

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## ABSTRACT

The effect of an upper body resistance training program on maximal and submaximal handcycling performance in able-bodied males was explored. Eighteen able-bodied men were randomly assigned to a training group (TG: n = 10) and a control group (CG: n = 8). TG received 7 weeks of upper body resistance training (60 % of 1 repetition maximum (1RM), 3 × 10 repetitions, 6 exercise stations, 2 times per week). CG received no training. Peak values for oxygen uptake ($\dot{V}O_{2peak}$), power output ($PO_{peak}$), heart rate ($HR_{peak}$), minute ventilation ($\dot{V}O_{Epeak}$) and respiratory exchange ratio ($RER_{peak}$), submaximal values (HR, $\dot{V}O_2$, RER, PO, and gross mechanical efficiency (GE)), and time to exhaustion (TTE) were determined in an incremental test pre- and post-training. Maximal isokinetic arm strength and 1RM tests were conducted. Ratings of perceived exertion (RPE) were assessed. A two-way repeated measures ANOVA and post-hoc comparisons were performed to examine the effect of time, group and its interaction ($p < 0.05$). TG improved on $PO_{peak}$ (8.55 %), TTE (10.73 %), and 1RM (12.28–38.98 %). RPE at the same stage during pre- and post-test was lower during the post-test (8.17 %). Despite no improvements in $\dot{V}O_{2peak}$, training improved $PO_{peak}$, muscular strength, and TTE. Upper body resistance training has the potential to improve handcycling performance.

## Introduction

Approximately 10 % of the world's population (650 million people) lives with some form of disability [1] and 10 % of persons with a disability are wheelchair users [2]. Although the majority of wheelchair users rely on hand-rim wheelchair propulsion for daily ambulation [3], hand-rim wheelchair propulsion is highly straining and associated with overuse injuries of the upper body [4–6]. Conversely, handcycling is of particular interest, since handcycling is more efficient, less straining than wheelchair propulsion, and offers more variation with regard to seating position and gears [4, 5, 7]. Consequently, larger distances can be covered and at higher speeds, making handcycling a perfect alternative for outdoor mobility and upper body endurance activity [7, 8]. Handcycling can also be of therapeutic value in early rehabilitation, while evolving into recreational or even elite sports participation [9, 10].

Being largely dependent upon their upper body, wheelchair users have limited muscle mass available for daily functioning and ambulation, which may affect their physical capacity and engagement in an active lifestyle, and consequently present difficulties in coping with the strain of daily activities such as making transfers, upper body lifting, and wheelchair propulsion [1]. To cope adequately with the strain of daily activities and to prevent long-term secondary health problems, adequate upper body training is needed to optimize rehabilitation and increase functional status and participation of wheelchair users [11].

Upper body training programs, both resistance and endurance, can improve physical capacity and optimize mobility and health in wheelchair users [12, 13], and can be an effective means to maintain or elicit improvements in cardiorespiratory fitness and muscular strength in wheelchair users [11, 12]. Resistance training induces different adaptations to the upper body such as increased muscular strength and endurance [14–20]. Enhanced muscular strength could exert a positive influence on handcycling performance, enabling higher levels of cardiorespiratory stress due to delayed local fatigue [14] and is therefore suggested to make activities of daily living less strenuous, as most activities of daily living are performed at a lower percentage of maximal capacity [15].

Resistance training as an intervention with the aim of improving handcycling performance in wheelchair users has not been fully explored [16–19]. In addition, existing literature on upper body resistance training effect on handcycling performance is limited and inconclusive [20–24]. While some reported limited success in increasing both strength and endurance [18], others did not test both components of fitness [20], and others trained only a limited number of upper extremity muscles [21]. In most of these studies, concurrent resistance and endurance training modes were used, making it difficult to establish the specific effect of resistance training.

Conversely, previous upper body programs to improve handcycling performance have focused on endurance training using different training protocols as recommended by the American College of Sports Medicine (ACSM) guidelines as well as low-intensity and high-intensity interval training and concurrent resistance and endurance exercise [16–19, 25]. Although positive results were found for the endurance variables, it is worth noting that the training modes commonly used for training in most training studies [16–19] – arm ergometry, arm cranking, and handcycling – require specialized equipment that is not commonly available in a typical gym setting. Exploring exercise modes that are more commonly available is therefore of paramount importance.

More knowledge on training adaptations to specific modes of upper body resistance training is required to prescribe adequate upper body resistance training regimens, because adaptations that occur in response to exercise training are primarily dependent on the intensity and mode of exercise performed. To our knowledge, only one study has explored the effect of upper body resistance training using standard gym machines [24]. There is a need for further exploratory and interventional studies on the effect of such training modes on handcycling performance to provide insight into the potential use of resistance training to improve handcycling performance and muscle strength, providing knowledge to use in rehabilitation and adapted sports settings.

The aim of the current study was to evaluate the effects of a 7-week ACSM-based [25] resistance training program in a standard gym setting that stressed the primary muscles involved in handcycling using concentric and eccentric contractions of key muscles of the arms and shoulder complex [26, 27] on measures of handcycling performance (as indicated by maximal power output, muscular strength, time to exhaustion, and maximal oxygen uptake) in able-bodied males. Able-bodied participants are inexperienced in wheelchair propulsion and in that respect comparable to some extent to those people with lower-limb impairment early in the initial clinical rehabilitation phase. The study of able-bodied participants in the context of handcycling performance is thus a simulation of possible adaptations that may occur in early rehabilitation of individuals new to a wheelchair, as wheelchair propulsion experience can impact on upper body adaptation and thus may affect handcycling performance. We hypothesized that the resistance training program would improve handcycling performance.

## Materials and Methods

### Participants

Eighteen able-bodied participants volunteered to participate in this study (body mass: 74.4 ± 6.6 kg, height: 1.80 ± 0.074 m, age: 25.5 ± 5.7 years). After screening with the Physical Activity Readiness Questionnaire (PARQ) [28], participants gave written informed consent. On their first visit to the laboratory, participants were familiarized with the experimental set-up using standardized 5-min handcycling familiarization trials on a cycle trainer (20W, 1.39 $ms^{-1}$). Participants were randomly assigned to a training (TG: n = 10) and a control group (CG: n = 8). Criteria for inclusion of this study were 18–40 years of age, inexperience in wheelchair use, no recent experience in upper body sports or training, and no medical contraindications. The study was performed according to the Declaration of Helsinki and was approved by the local ethics committee and meets the ethical standards of the journal [29]. Participants were asked to keep their level of physical activity and diet constant between pre- and post-test.

### Design

This study was designed to determine the effect of resistance training on handcycling performance fitness in able-bodied men. The training group (TG) received a 7-week upper body resistance training program (two times a week, three sets of ten repetitions at six different exercise stations with an initial exercise intensity of 60 % of 1 repetition maximum (1RM); details provided in the next section) [25]. The control group (CG) received no training. Before and after the experimental period, participants performed an incremental handcycling test until exhaustion to determine peak cardiovascular variables ($\dot{V}O_{2peak}$, $HR_{peak}$, $V_{Epeak,}$ and $RER_{peak}$) and handcycling performance ($PO_{peak}$). Preceding the incremental test, a 3-stage submaximal handcycling test on a motor-driven treadmill was conducted to evaluate gross mechanical efficiency (GE) and submaximal parameters ($\dot{V}O_2$, $V_E$, RER, HR, and PO). The measurement of maximal isokinetic strength using an isokinetic dynamometer (Chattanooga Group, Hixson, TN, USA) and isoinertial strength using 1 repetition maximum (1RM) [30] were also performed. Post-tests were conducted at the same time of the day, and on the same day of the week, 7 weeks after the pre-tests were completed. All participants were asked to eat light meals and refrain from smoking and ingesting caffeine and alcohol 24 h before testing, and to maintain their regular daily physical activity pattern and diet during the study period.

## Training

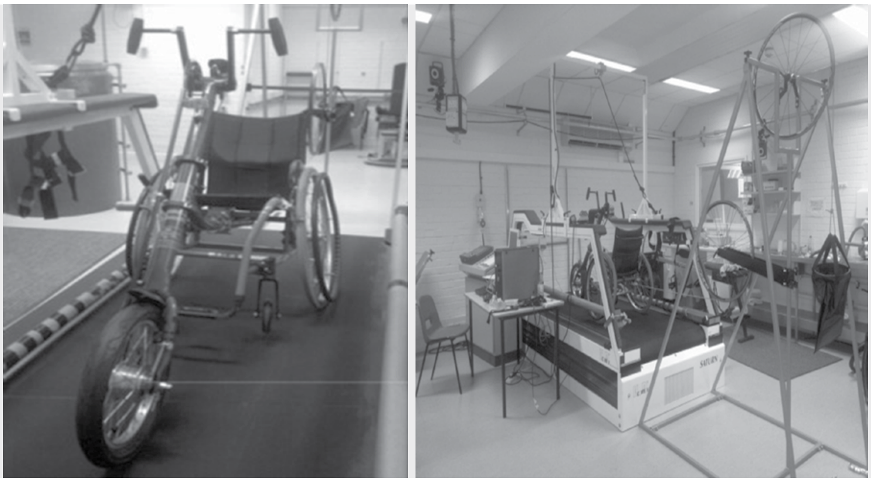
The TG performed resistance training in accordance with ACSM guidelines [25]. They completed 3 sets of 10 repetitions at 6 different exercise stations consisting of exercise on machines (Life Fitness; Franklin Park, IL, USA) for seated chest press, seated row, seated shoulder press, seated lateral pull-down, seated triceps dips, and arm curls twice weekly. Muscles worked were pectorals, deltoids, biceps, triceps, rhomboids, and latissimus dorsi, which are muscles involved in handcycling [27, 31, 32]. Training was performed at the same time of the day on the same days of the week over 7 consecutive weeks. The initial exercise load was 60 % of 1 repetition maximum (1RM). Load increased approximately 5 %, dependent on the limits of the machine used (minimal increase 2.5 kg) when participants performed reps rhythmically, at a moderate to slow controlled speed, through a pain-free range of motion, with a normal breathing pattern during the lifting movements, using good form and technique (no compensatory movements) over two consecutive training sessions. For all lifts, participants used slow and controlled movements and exhaled on exertion. 1RM was determined during initial 1RM strength testing by participants performing one single lift at a certain load, and the load was increased every time a lift was successfully performed until the participant could not successfully lift the load [30, 33]. A 3-min rest was taken between each lift. The last successfully lifted load was considered the 1RM. It was difficult to measure 1RM for seated triceps dips. The exercise was therefore used as supporting and was not analyzed statistically. At the start of each training session, participants performed a 5-min warm-up on a rowing ergometer and 10 repetitions at the lightest load on each exercise machine. After the training session, a 5-min cool-down on a rowing ergometer was performed. A 48-h period was allowed in between training session. During the last training session, 1RM was measured again.

## Incremental exercise testing

Before the training commenced, but after the initial handcycling familiarization sessions, an incremental handcycling test was performed on a motor-driven treadmill (Saturn; HP-Cosmos, Nussdorf, Germany; 1.0 × 2.7 m) using a standard sports wheelchair (Morriën; Morriën BV, Nijkerk, Netherlands) with an attached handcycling unit (Double Performance Tracker 16 tour with a 7-gear system). To measure power output, the cranks of the add-on handcycle unit fixed at the lightest gear and were instrumented with a power sensor SRM system (SRM Powermeter Rotor 3D Compact; Schoberer Rad Messtechnik, Welldorf, Germany; accuracy 0.5 % and sample frequency 1 Hz). Power output was continuously measured by the SRM, and data were recorded on the SRM power controller 7. The SRM system produces a valid and reliable measurement of PO [34]. Tire pressure was fixed at 6.0 bar and was measured before all tests. Gearing was fixed and treadmill velocity was a constant $1.39\,\mathrm{m \cdot s^{-1}}$, which coincided with an rpm of 50. Open circuit spirometry (Oxycon Delta, SBx/CPX; Jaeger, Hoechberg, Germany), calibrated using room air and a calibration gas (16 % $O_2$, 5 % $CO_2$) and a heart rate monitor (Suunto Dual Comfort Belt; Suunto, Vantaa, Finland; sampling frequency 1 Hz, beats per minute) were used to obtain respiratory gas exchange (breath-by-breath) and heart rate, respectively. The incremental exercise tests were performed at the same time of the day. After 7 weeks of training or no training, the incremental tests were repeated at the same time of day on the same day of the week.

The incremental test was preceded by a standard 5-min submaximal steady-state warm-up at 20 W and three submaximal exercise bouts of 4-min duration each at different power outputs (20 W, 30 W, and 40 W). The first bout consisted of 4 min handcycling at 20 W. The second bout consisted of 4 min handcycling at 30 W. The third bout consisted of 4 min handcycling at 40 W. A 5-min rest was taken after the 5-min submaximal steady-state warm-up, before the start of the three 4-min submaximal exercise bouts. A 3-min rest was taken between the 4-min exercise bouts and between the third submaximal bout and the incremental test. Thirty (30) seconds of the last minute (20th to 50th second) were used for calculation of mean maximal and submaximal values. The PO was increased every minute by adding load through a pulley system attached to the rear end of the handcycle (▶ **Fig. 1**) [35] and was determined by the additional force ($F_{add}$), the drag force ($F_{drag}$), and the velocity (v), as described by Eq. (1):

$$\text{Power output (PO)} = (F_{add} + F_{drag})\ ^{*}\ v \qquad \text{Equation 1}$$



▶ **Fig. 1** Experimental setup: Handcycle with attached pulley system.

Drag force was determined by handcycling with no additional force at 1.39 $m \cdot s^{-1}$.

Following the 3-min rest after the last (third) submaximal exercise bout, the 1-min incremental maximal exercise test began. The initial PO of the test was set at 20 W, and increased at 4 W every minute until voluntary exhaustion. The protocol of the handcycling stepwise (1 min) incremental test was based on a handcycling protocol designed for males [36].

Local rate of perceived exertion (RPE) was measured using the Borg 1-10 category ratio scale after every stage whereas measures of central and overall RPE were measured using the Borg 6–20 scale [37, 38] immediately after the end of the submaximal bouts and incremental test. Local RPE corresponds to the exertion of the peripheral working muscles, central RPE corresponds to cardiorespiratory exertion, and overall RPE corresponds to total exertion. During the last 10 s of each submaximal bout and each incremental stage, the experimenter moved his finger along an enlarged, printed RPE list. Participants were informed to nod when the experimenter was pointing to their RPE, so that speech would not interfere with the collected respiratory data.

Power output (PO), heart rate (HR), oxygen uptake ($\dot{V}O_2$), minute ventilation ($\dot{V}O_E$), and respiratory exchange ratio (RER) were measured continuously. Carbon dioxide production was also noted. Average values of the respiratory gas exchange measurements were calculated for the third minute of each submaximal exercise stage. Peak values for PO, HR, $\dot{V}O_{2,}$ and RER were defined as the highest value reached between 20 and 50 sec of every minute during the maximal incremental exercise test.

Gross efficiency (GE), the ratio between external mechanical work performed and the total metabolic production of energy during exercise [39], was calculated for all submaximal steady-state intensities by dividing the measured mechanical PO by the metabolic power input ($P_{met}$):

$$GE = PO/P_{met} * 100\,\%$$

$P_{met}$ was calculated in the last minute (from second 20 to 50) by multiplying oxygen consumption with the oxygen equivalent: $P_{met} = \dot{V}O_2 * ((4940 * RER + 16040)/60)$ [40].

## Maximal strength testing

Maximal strength was determined by a maximal isokinetic strength test using a computer- controlled electromechanical isokinetic dynamometer (Kin-Com; Chattanooga Group, Hixson, TN, USA). The length of the lever arm of the Kin-Com was adjusted to the length of the crank of the handcycle (0.17 m), and the setup was adjusted to the setup of the handcycle (distance from back rest to crank axis: 0.56 m; distance from seat to crank axis: 0.46 m). An isokinetic maximal arm push and an arm pull test were performed. When the lever arm was in the highest vertical position, it was considered to be 0°; whereas the lowest position was 180° (▶ **Fig. 2**). During the push phase, maximal strength was measured between 0 – 90°. The pull phase consisted of a maximal strength measurement between 90–180°. For both the push and pull phase mechanical stops were used, so each participant would pass through the identical total range of motion (ROM). The setup of the Kin-Com was adjusted to

▶ **Fig, 2** In the push phase, the lever start at 0° (**a**: start point) and moved to 90° (**b** end point); and during the pull phase the lever start at 90° (**c** start point) and moved to 180° (**d** end point).

▶ **Table 1** Changes in 1RM measurements from pre- to post-training for TG ($n = 9$).

| Variables | Pre | Post | Mean Difference | Pre-post test |
|---|---|---|---|---|
| Chest press [kg] | 76.4 ± 26.3 | 79.7 ± 23.4 | 3.3 ± 6.5 | $F(1,8) = 2.4$, $p = 0.16$ |
| Seated row [kg] | 73.3 ± 15.9 | 86.1 ± 16.3 * | 12.8 ± 5.9 | $F(1,8) = 41.9$, $p < 0.01$ |
| Shoulder press [kg] | 34.4 ± 13.2 | 39.4 ± 12.8 * | 5.0 ± 5.6 | $F(1,8) = 7.2$, $p = 0.028$ |
| Lateral pull-down [kg] | 72.5 ± 12.6 | 81.4 ± 12.7 * | 8.9 ± 9.2 | $F(1,8) = 89.0$, $p < 0.01$ |
| Arm curls [kg] | 23.6 ± 8.0 | 32.8 ± 6.8 * | 9.2 ± 4.3 | $F(1,8) = 40.3$, $p < 0.01$ |

Values shown are mean ± SD. * Significantly different from pre-test ($p < 0.05$).

the setup of the handcycle. Angular velocity was fixed at the Kin-Com's top speed of $250\,°s^{-1}$ to cover a speed as close as the possible to the cadence used during the incremental handcycle test. Initial force was set at 50 N. For both the push and pull phase, five submaximal exercise trials were performed as a warm = up. The maximal strength test consisted of five maximal isokinetic pushes and five maximal isokinetic pulls of the dominant hand only. The trunk and hip were strapped onto the back of the seat to avoid involuntary movements. Participants were instructed to exert as much force as possible during the test.

### Statistical analyses

Statistical analyses were performed using IBM SPSS Statistics version 20.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics (means and standard deviations) were calculated for all variables. An independent *t*-test was applied to participant characteristics (age, height, and body mass) to detect possible differences between the groups at baseline. A two-way repeated measures analysis of variance and post-hoc comparisons were performed to examine the effect of time, group, and its interaction on peak and submaximal performance ($\dot{V}O_2$, $\dot{V}_E$, HR, RER, PO, and RPE), time to exhaustion (TTE), and muscle strength. The significance level of all tests was set at $p < 0.05$.

## Results

### Participant characteristics

At baseline, there were no statistical differences between the groups with regard to age (TG: 26.1 ± 5.8 years vs. CG: 24.8 ± 6.0 years, $p > 0.05$), height (TG: 1.8 ± 0.1 m vs. CG: 1.8 ± 0.1 m, $p > 0.05$), or body mass (TG: 74.0 ± 6.6 kg vs. CG: 74.9 ± 7.0 kg, $p > 0.05$). Additionally, there were no statistical differences between the groups with regards to physiological and performance parameters.

### Training sessions

Of the 10 participants in the TG, one participant did not complete the resistance training due to personal reasons and was excluded. All other participants completed the training volume and pre- and post-tests successfully. Some participants could not perform the required two training sessions every week and were then allowed to perform an extra session in another week. 1RM values before and after the training are shown in ▶ **Table 1**. Significant increases were found over time for all training exercises ($p < 0.05$) except the chest press.

### Training evaluation

▶ **Table 2** shows the peak physiological and performance parameters of both TG and CG before and after the experimental period. No significant interactions were detected in $\dot{V}O_{2peak}$, $V_{Epeak}$, $RER_{peak}$, $HR_{peak}$, RPE score as well as maximal arm pull and push ($p > 0.05$). However, significant interaction effects were found showing increases in POpeak, ($F = 15.3$, $p < 0.01$), TTE ($F = 22.9$, $p < 0.01$), and a decrease in local RPE ($F = 4.90$, $p = 0.04$) at the lowest maximal stage over time in TG.

▶ **Table 3** shows the submaximal physiological and performance capacity of both TG and CG before and after the experimental period. No significant interactions were detected in $\dot{V}O_2$, $\dot{V}_E$, PO, HR, RER, GE, and RPE scores ($p > 0.05$). However, significant time effects (pre-post test) were found showing an increase in RER ($p < 0.01$) and decreases in local RPE ($p < 0.01$), central RPE ($p < 0.05$), and overall RPE ($p < 0.05$) in TG.

## Discussion

This study is the first study to investigate the effect of a 7-week upper body resistance training program on maximal handcycling performance and muscle strength in able-bodied males using standard gym machines. The most striking outcomes of the present study were improvement in $PO_{peak}$, TTE, and muscular strength (seated row, seated shoulder press, seated lateral pull-down and arm curls) assessed by 1RM and local RPE at the lowest maximal stage after 7 weeks of training. This provides insight into the potential use of resistance training to improve handcycling performance and muscle strength, providing knowledge to use in rehabilitation and adapted sports settings. No improvement in cardiorespiratory parameters ($\dot{V}O_{2peak}$, $\dot{V}E_{peak}$, $RER_{peak}$, $HR_{peak}$, and peak RPE scores) and submaximal metabolic strain ($\dot{V}O_2$, $\dot{V}O_E$, RER, HR, GE, and RPE scores) was found, suggesting no cardiorespiratory adaptations in response to training.

Upper body resistance training is important for persons with spinal cord injury, handcyclists and wheelchair users as it can lead to increased work capacity, muscular strength, and power and as a consequence improved mobility and participation [24]. The current training stressed the major muscles used in handcycling so that improvement could potentially be translational to handcycling. The improvements in $PO_{peak}$, TTE, and muscular strength indicate adaptations in both the central nervous system and the peripheral muscle system in response to resistance [30] and are in accordance with concurrent endurance and resistance studies in persons with spinal cord injury, handcyclists, and wheelchair users [20–23, 41, 42] and are relevant for performance of daily activities. The

▶ **Table 2** Change in maximal strength and peak physiological values for TG and CG.

| Variables | | TG (n = 9) | CG (n = 7) | *p*, pre-post test | Interaction (time × group) |
|---|---|---|---|---|---|
| Maximal arm push [Nm] | Pre | 46.0 ± 10.6 | 51.1 ± 25.7 | 0.35 | F = 1.08, p = 0.32 |
| | Post | 47.6 ± 16.0 | 41.3 ± 14.5 | | |
| Maximal arm pull [Nm] | Pre | 54.1 ± 22.3 | 76.8 ± 38.8 | 0.08 | F = 1.89, p = 0.19 |
| | Post | 47.7 ± 12.7 | 47.2 ± 9.6 * | | |
| $\dot{V}O_{2peak}$ [$ml \cdot min^{-1}$] | Pre | 2068 ± 228 | 2028 ± 321 | 0.55 | F = 0.53, p = 0.23 |
| | Post | 2085 ± 207 | 1962 ± 334 | | |
| $\dot{V}O_{2peak}$ [$ml \cdot kg^{-1} \cdot min^{-1}$] | Pre | 28.1 ± 3.8 | 27.5 ± 5.2 | 0.71 | F = 0.79, p = 0.14 |
| | Post | 28.4 ± 3.9 | 26.3 ± 6.3 | | |
| $\dot{V}O_{Epeak}$ [$l \cdot min^{-1}$] | Pre | 82.9 ± 12.3 | 79.9 ± 12.3 | 0.32 | F = 1.12, p = 0.75 |
| | Post | 82.8 ± 15.8 | 72.3 ± 18.1 | | |
| $RER_{peak}$ | Pre | 1.1 ± 0.1 | 1.1 ± 0.1 | 0.98 | F < 0.01, p = 0.75 |
| | Post | 1.1 ± 0.1 | 1.1 ± 0.0 | | |
| $HR_{peak}$ [bpm] | Pre | 174.5 ± 7.9 | 165.7 ± 17.0 | 0.77 | F = 0.32, p = 0.70 |
| | Post | 167.3 ± 12.3 | 156.0 ± 26.7 | | |
| $PO_{peak}$ [W] | Pre | 97.1 ± 9.7 | 99.2 ± 18.1 | 0.51 | F = 15.3, p < 0.01 |
| | Post | 105.4 ± 10.8 | 95.8 ± 18.4 | | |
| TTE [min] | Pre | 17.7 ± 1.7 | 18.1 ± 3.0 | 0.38 | F = 22.9, p < 0.01 |
| | Post | 19.6 ± 1.9 * | 17.4 ± 3.7 | | |
| $RPE_l$ | Pre | 10.0 ± 0.0 | 9.6 ± 0.7 | 0.64 | F = 0.02, p = 0.35 |
| | Post | 9.9 ± 0.3 | 9.8 ± 0.5 | | |
| $RPE_c$ | Pre | 17.2 ± 1.5 | 17.1 ± 1.8 | 0.92 | F = 0.27, p = 0.85 |
| | Post | 17.1 ± 2.2 | 16.9 ± 2.0 | | |
| $RPE_o$ | Pre | 18.2 ± 1.9 | 18.1 ± 1.6 | 0.72 | F = 0.84, p = 0.74 |
| | Post | 18.0 ± 1.7 | 17.6 ± 1.2 | | |
| $RPE_l$ lowest maximal stage | Pre | 10.0 ± 0.0 | 9.7 ± 0.5 | 0.01# | F = 4.90, p = 0.04 |
| | Post | 9.1 ± 0.8 * | 9.7 ± 0.5 | | |

Values shown are mean ± SD. No significant differences were found in baseline values between groups. * Significantly different from pre-test ($p < 0.05$). #Significant interaction of group * time ($p < 0.05$). RPEl = local rate of perceived exertion; RPEc = central rate of perceived exertion; RPEo = overall rate of perceived exertion.

reduction in local RPE at the lowest maximal lowest power output suggests activities of daily living are likely not to be perceived as strenuous, thus resulting in improved participation in daily activities.

The study finding that $HR_{peak}$ did not improve was comparable to previous upper body resistance training studies [33], and the improvement in TTE is similar to that reported in a comparable study (training mode, intensity and repetitions) by Jacobs et al. [24] exploring longer training duration. Taken together with the improvement in $PO_{peak}$, TTE, and muscular strength, the lack of significant improvement in cardiorespiratory variables found in this study conformed to expectations that resistance training improves anaerobic power through adaptations in both the central nervous system and the peripheral muscle system [30], but is generally considered to provide minimal, if any, improvements in maximal aerobic capacity [24, 30, 43]. The cardiorespiratory benefits of resistance training have been related to resistance intensity, total training volume, and the duration and type of rest/recovery periods [44].

The study by Jacobs et al. [20] exploring longer training duration showed significant improvements in $PO_{peak}$ (+16 %) and $\dot{V}O_{2peak}$ (+15 %) following resistive arm crank exercise. The authors attributed the improvements in $PO_{peak}$ and $\dot{V}O_{2peak}$ to enhanced muscle function, specifically improved trunk control, thereby requiring greater levels of oxygen uptake to supply the needed oxygen delivery to the exercising muscles [18]. Their study samples were individuals with spinal cord injury paraplegia, a population with poor trunk control.

The improvements in $PO_{peak}$ in comparable (training duration) endurance training studies [16–19] were higher (varying from 28.2 % to 47.1 %) compared to this study. Additionally, these studies reported improvement in $\dot{V}O_{2peak}$ (varying from 13.3 % to 22.2 %). It is worth noting that almost all comparable studies examining upper body endurance and concurrent endurance and resistance conditioning [16–24] used continuous resistive arm ergometry and wheelchair ergometry training modes. However, replication of such mode-specific exercises is difficult because arm ergometry and handcycles are specialized equipment and are thus not commonly available in typical gym settings. Alternative modes such as resistance training in a gym to train the upper body in the absence of this specialized equipment is therefore of paramount importance.

The improvement in muscular strength (1RM) can be explained by neuromuscular adaptations in response to the training includ-

▶ **Table 3** Changes in submaximal physiological performance for TG (n = 9) and CG (n = 8).

| | 1st stage | | 2nd stage | | 3rd stage | | ***p*, pre-post test** | ***p*, group × time** |
|---|---|---|---|---|---|---|---|---|
| | **CG** | **TG** | **CG** | **TG** | **CG** | **TG** | | |
| **PO [W]** | | | | | | | 0.93 | 0.13 |
| Pre | 18.5 ± 0.4 | 18.4 ± 0.6 | 29.4 ± 0.9 | 30.3 ± 0.9 | 40.8 ± 1.5 | 41.3 ± 1.1 | | |
| Post | 18.8 ± 1.2 | 18.3 ± 1.1 | 29.8 ± 0.8 | 29.7 ± 1.5 | 41.5 ± 1.1 | 40.7 ± 1.8 | | |
| **$\dot{V}O_2$ [ml/min]** | | | | | | | 0.66 | 0.43 |
| Pre | 685.6 ± 96.4 | 692.5 ± 90.9 | 786.7 ± 76.6 | 837.4 ± 128.7 | 997.2 ± 125.7 | 977.2 ± 118.3 | | |
| Post | 692.0 ± 64.8 | 687.9 ± 74.0 | 825.7 ± 98.9 | 802.0 ± 81.8 | 972.6 ± 88.7 | 943.3 ± 79.1 | | |
| **$\dot{V}_E$ [l/min]** | | | | | | | 0.12 | 0.70 |
| Pre | 17.2 ± 1.7 | 17.8 ± 3.7 | 19.6 ± 1.6 | 21.0 ± 3.8 | 24.8 ± 3.0 | 25.3 ± 3.9 | | |
| Post | 18.4 ± 2.0 | 18.8 ± 2.2 | 21.6 ± 2.0 | 21.7 ± 2.6 | 25.0 ± 2.2 | 25.8 ± 2.3 | | |
| **HR [bpm]** | | | | | | | 0.26 | 0.66 |
| Pre | 86.5 ± 14.2 | 90.2 ± 9.3 | 92.8 ± 13.2 | 94.4 ± 7.8 | 99.2 ± 17.1 | 103.2 ± 9.5 | | |
| Post | 85.7 ± 15.4 | 85.7 ± 9.9 | 89.9 ± 13.2 | 92.5 ± 9.1 | 98.0 ± 12.6 | 99.4 ± 12.0 | | |
| **RER** | | | | | | | 0.001 * | 0.55 |
| Pre | 0.80 ± 0 | 0.78 ± 0 | 0.84 ± 0 | 0.82 ± 0 | 0.88 ± 0 | 0.88 ± 0 | | |
| Post | 0.85 ± 0 | 0.84 ± 0 | 0.87 ± 0 | 0.86 ± 0 | 0.89 ± 0 | 0.90 ± 0 | | |
| **GE [%]** | | | | | | | 0.92 | 0.95 |
| Pre | 8.2 ± 1.1 | 8.2 ± 1.2 | 11.2 ± 1.0 | 11.0 ± 1.5 | 12.2 ± 1.3 | 12.6 ± 1.6 | | |
| Post | 8.1 ± 0.5 | 8.0 ± 1.0 | 10.8 ± 1.3 | 11.0 ± 1.1 | 12.6 ± 1.1 | 12.7 ± 1.4 | | |
| **RPE$_l$** | | | | | | | < 0.01 * | 0.11 |
| Pre | 1.9 ± 0.8 | 1.8 ± 1.1 | 2.9 ± 1.0 | 2.3 ± 0.7 | 3.5 ± 1.6 | 3.9 ± 1.2 | | |
| Post | 1.4 ± 0.5 | 1.3 ± 0.5 | 2.4 ± 0.7 | 2.0 ± 0.7 | 3.5 ± 1.3 | 3.1 ± 1.1 | | |
| **RPEc** | | | | | | | < 0.05 * | 0.42 |
| Pre | 7.9 ± 1.4 | 7.9 ± 1.2 | 9.4 ± 1.6 | 9.0 ± 1.0 | 10.9 ± 2.0 | 11.0 ± 1.4 | | |
| Post | 7.3 ± 0.9 | 7.1 ± 1.1 | 8.6 ± 1.2 | 8.4 ± 1.6 | 10 ± 1.7 | 9.3 ± 1.4 | | |
| **RPEo** | | | | | | | | |
| Pre | 8.0 ± 1.5 | 8.2 ± 2.1 | 9.6 ± 1.9 | 9.3 ± 1.3 | 11.1 ± 1.7 | 11.1 ± 1.9 | < 0.05 * | 0.89 |
| Post | 7.4 ± 1.9 | 7.7 ± 1.0 | 8.5 ± 1.1 | 8.8 ± 1.4 | 10.1 ± 2.0 | 10.0 ± 1.6 | | |

Values shown are mean ± SD. No significant differences were found in baseline values between groups. * Significantly different from pre-test ($p < 0.001$). ^Significant interaction of group * time ($p < 0.001$).

ing increased activity of anaerobic enzymes and intracellular glycogen, improved excitation-contraction coupling and recruitment patterns of the activated motor units, improved firing characteristics and/or enhance shortening cycles of the muscular system [39] as well as shift from type IIx muscle fibers to type IIa muscle fibers, which are less fatigable and have a higher power output [45–47]. The improvement in muscular strength found in this study thus lead to a potentially enhanced anaerobic capacity as evident in the improvement in PO$_{peak}$ and may have induced improvement in movement coordination of the trained muscles, which may in turn have influenced the improvement in TTE. Consequently, larger distances can be covered and at higher speeds [7, 8] owing to improved handcycling performance.

Although there was an improvement in strength based on 1RM, no significant improvement was found for isokinetic strength. The difference in outcome may be accounted for by the differences in the two assessments and physiological adaptations. The physiological adaptations to training are specific to the muscle actions involved, muscles trained, range of motion of the movement, and the energy systems utilized [23, 24, 48]. In this context, 1RM concentrated on those movements similar to those implemented in the training program, whereas the isokinetic test could involve a completely different movement, including different muscle combinations and efforts. Furthermore, whereas a predetermined load and fixed high muscle contraction speed (240–300 s$^{-1}$) were used in the isokinetic strength testing, self-determined exertion force and relatively low controlled self-determined muscle contraction speeds (60–90 s$^{-1}$) were used in 1RM [48]. 1RM is useful for evaluating functional performance, whereas isokinetic tests are useful for evaluating specific muscle function and activation [48]. Since the current study evaluated the effect of resistance training on functional performance in the context of handcycling, the 1RM assessment is considered to be more meaningful [48]. The current study has no control measurement for 1RM, and thus only within-group comparisons were done.

The results of this study are promising for the use of standard gym equipment to improve handcycling performance, particularly for the early phase of rehabilitation in persons who might have difficulty accessing specialized handcycle or arm crank equipment, because the study design improved PO$_{peak,}$ TTE, and muscle strength. Resistance training can provide increased work capacity as a result of greater levels of cardiorespiratory stress as a result of enhanced resistance to local muscle fatigue in addition to the expected enhancements of muscular strength and power [24].

The use of a homogeneous group of able-bodied men to represent individuals who are naive to wheelchair use to simulate the early rehabilitation phase of individuals new to a wheelchair allowed us to compare responses to resistance training in a controlled setting, adding to data available required for establishing training prescriptions for upper body exercise. Additionally, participants in this study had no prior experience in upper body exercise and wheelchair propulsion, which is comparable to wheelchair-dependent persons in early rehabilitation and with relatively short duration wheelchair experience [49]. Based on the results of the current study, it is therefore expected that resistance training can alter the handcycling performance in novice wheelchair dependent persons. However, it is important to evaluate how data collected in able-bodied participants compares with people with different disabilities such as people with spinal cord injury. How these data might influence adaptations to resistance training are to be assessed in future research. Furthermore, overuse injuries and pain at the shoulders, elbows and wrists are common due to demands of wheelchair propulsion and weight-bearing required for transfers in wheelchair users, posing further limitations on their already restricted lifestyle [4, 5, 50]. Development of interventions to prevent as well as treat shoulder pain is therefore of paramount importance. Future studies investigating the safety and effectiveness of resistance training in this context of these overuse injuries assessed as local perceived discomfort or pain are needed to help evaluate the long-term adherence to and adoptability of training.

## Conclusion

This study provides input for the design of evidence-based upper-body resistance training programs that are applicable to people who are interested in improving upper body performance, e. g., novice wheelchair users. In the current intervention, 7 weeks of upper body resistance training improved muscle strength (12.28–38.98 %), peak power output (8.55 %), time to exhaustion (10.73 %), and rate of perceived exertion at the lowest maximal stage (8.17 %). For individuals who are new to wheelchair use, however, the intervention did not translate into improved cardiorespiratory parameters. Although previous handcycling training programs demonstrated greater improvements in handcycling performance, in the absence of the specialized handcycle or arm crank to train, gym-based programs could be of interest. Based on the current findings, resistance training can improve handcycling performance. Rehabilitation professionals should consider resistance training during rehabilitation to improve handcycling performance.

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## Conflict of Interest

The authors declare that they no conflict of interest.

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