The Efficacy of an Eight-Week Strength and Endurance Training Programme on Hand Cycling Performance

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Abstract

The aim of the present study was to investigate the effects of an 8-week concurrent strength and endurance training programme in comparison to endurance training only on key markers of hand cycling performance. Five H4 and five H3 classified hand cyclists with at least one year's training history consented to participated in the study. Subjects underwent a battery of tests to establish body mass, body composition, VO2peak, maximum aerobic power, gross mechanical efficiency, 30 km time trial performance and maximal upper body strength. Subjects were matched into pairs based upon 30 km time trial performance and randomly allocated to either a concurrent strength and endurance or endurance training only group. Following an 8-week training intervention based upon a conjugated block periodisation model, subjects completed a second battery of tests. A mixed model, 2-way analysis of variance (ANOVA) revealed no significant changes between groups. However, the calculation of effect sizes (ES) revealed that concurrent training resulted in a greater magnitude of change in most measures when compared to endurance training alone. Both groups demonstrated a positive improvement in most physiological and performance measures. However, subjects in the concurrent group demonstrated a greater improvement in body composition (ES 0.80 vs. 0.22), maximal aerobic power (ES 0.97 vs. 0.28), gross mechanical efficiency (ES 0.87 vs. 0.63), 30 km time trial performance (ES 0.73 vs. 0.30), bench press 1 repetition maximum (ES 0.53 vs. 0.33), and seated row 1 repetition maximum (ES 1.42 vs. 0.43). In comparison to endurance training only, an 8-week concurrent training intervention based upon a conjugated block periodisation model appears to be a more effective training regime for improving the performance capabilities of experienced hand cyclists.

Keywords: Disability sport, arm ergometry, resistance training, conjugated block periodisation

Chapter 1 – Introduction

Hand cycling is a form of Paracycling used by individuals who are unable to ride a conventional road bike or tricycle due to either a spinal cord injury and/or physical impairment of the lower extremities. Over the past two decades, the popularity of hand cycling as a sport has increased considerably (3, 20). Indeed, in 1999 hand cycling was formally recognised as a sport by the International Paralympic Committee (IPC) and has been included in the Paralympic Games since Athens in 2004. As a sport, hand cycling is officially administered and governed by the Union Cycliste Internationale (UCI). In addition to being a competitive sport, hand cycling is frequently used in rehabilitation (39) and general health and wellbeing (20) settings.

As a Paralympic sport, hand cycling is open to male and female athletes with a wide range of disabilities. Athletes are functionally classified in one of five classes (H1, H2, H3, H4, and H5) dependent upon the severity of their physical impairment (32). Athletes in H1, H2, H3 and H4 classes compete in a recumbent, arm power (AP) position (Figure 1). In contrast, athletes in the H5 class compete in a kneeling position and, therefore, can use both their arms and trunk (ATP) to generate higher propulsive forces than in a recumbent, AP position (20, 40). For further information on the disability classifications used in hand cycling and the rules and regulations of the sport the reader should refer to the official Paracycling area of the UCI website (http://www.uci.ch/para-cycling/).

Hand cycle races vary in length from 50 – 80 km for a criterium road race and 20 – 30 km for an individual time trial (32). Hand cycling race tactics are comparable to those of able-bodied cycling. These include the use of variable pacing strategies, such as frequent short accelerations to push opponents, taking the lead, or drafting other riders to reduce the overall energy cost by 25 – 40% (3, 11). A typical hand cycling race places a considerable demand upon the aerobic energy system (1). However, it can be speculated that the anaerobic energy system will be repeatedly taxed due to the requirement to generate a relatively high power output for brief periods of time during surges in pace, climbing or sprinting to the finish (1, 10, 11).

Figure 1. Typical competitive H4 AP hand bike set-up

There is a paucity of research associated with the typical physiological characteristics of competitive hand cyclists. As with able-bodied cycling, peak oxygen uptake (VO2peak) (1, 21, 22, 25, 26, 30), maximal aerobic power (MAP) (18, 22, 23, 24, 30, 38), and gross mechanical efficiency (GME) (1, 18, 21, 30) have all been proposed to be significant physiological determinants of hand cycling performance. Furthermore, it can be inferred that other variables such as anaerobic threshold, maximal upper body strength and power-to-weight ratio may also help predict hand cycling performance (3, 10, 11). To date, limited research has been conducted examining the effectiveness of various training approaches to improve key markers of hand cycling performance (2, 22, 30, 38) with all but one (30), utilising endurance training only.

In comparison to endurance training only, the concurrent integration of both strength (i.e., resistance training) and endurance training (i.e., cycling or running) into a single unified training programme has been demonstrated to significantly enhance body composition, VO2peak, MAP, GME, anaerobic capacity, and performance potential of individuals in endurance sports such as cycling (5, 37, 43), running (5, 37) and kayaking (15). Several physiological adaptations have been proposed to occur which may explain the observed improvements in endurance performance as result of concurrent training. These include: (i) greater force production capability; (ii) enhanced maximal power output; (iii) improved musculotendinous stiffness and (iv) superior GME due to a reduced relative energy expenditure at a given velocity or power output (17, 37). Despite enhancing endurance performance, relative to strength training alone, concurrent training has been shown to attenuate gains in muscle hypertrophy, maximal strength, rate of force development and peak power output via a phenomenon commonly known as the interference effect (4, 13, 17, 42).

Given that concurrent training has been demonstrated to enhance body composition, VO2peak, MAP, GME and maximal strength in cyclists (5, 37, 43), it can be speculated that it may also enhance hand cycling performance. Indeed, Garcia-Pallares (15, 16) recently demonstrated that a 12-week concurrent training programme based upon a block periodisation model designed to reduce the impact of the interference effect, significantly improved several neuromuscular, cardiovascular, and performance markers in eleven world-class kayakers. As kayaking demonstrates a similar upper body push/pull movement pattern to that of hand cycling it can be postulated that a comparable training intervention may also improve hand cycling performance.

Based upon the theoretical potential of concurrent training to enhance hand cycling performance, the present study investigated the effects of an 8-week concurrent strength and endurance training programme compared to endurance training only upon several identified markers of hand cycling performance. It was hypothesised that an 8-week concurrent training programme would result in a greater improvement in hand cycling performance than endurance training alone.

Chapter 2 - Methods

2.0 Experimental Approach to the Problem

Body mass, body composition, VO2peak, MAP, GME, maximal upper body strength and 30 km individual time trial (TT) performance was evaluated in ten experienced hand cyclists. Based upon TT performance subjects, were then matched into pairs before being randomly assigned to either a concurrent or endurance only intervention group. Following an 8-week training period, all of the aforementioned variables were re-examined to determine the relative effectiveness of each training intervention.

2.1 Subjects

Ten experienced hand cyclists with at least one year's hand cycling experience provided written informed consent to take part in this study. All subjects were classified as either an H3 or H4 AP hand cyclist in accordance with current UCI Paracycling regulations (32). Three participants were bi-lateral, above knee amputees (H4); one was a triple amputee (H3); one a single, below knee amputee (H4); four were paraplegics (H3) and one had a chronic degenerative condition of the lower limbs (H4). Mean (± SD) characteristics of subjects were as follows: age 32 ± 9 years; body mass 79.8 ± 16.3 kg; 4-site skinfold summation 21.8 ± 3.5 mm; chest circumference 107.2 ± 8.7 cm; right upper arm girth 33.5 ± 8.7 cm. No upper body musculoskeletal injuries that could affect a subject's participation were reported prior to the study. Finally, the study was conducted in accordance with the declaration of Helsinki with approval granted by the Research Ethics Committee of St. Mary's University (Twickenham, United Kingdom).

2.2 Procedures

All subjects undertook a series of laboratory and field based testing protocols prior to (T1) and immediately upon completion (T2) of the 8-week experimental training intervention. Testing was completed over three consecutive days: anthropometry and an incremental, exhaustive hand cycling test (day 1); 1 repetition maximum (1RM) strength testing (day 2); and a 30 km individual TT (day 3). Before testing, all subjects were asked not to engage in any form of strenuous exercise and refrain from the consumption of alcohol for at least 48 hours. All laboratory testing was performed at the same time of day and in stable environmental conditions (18°C, 50 – 60 % relative humidity). Following T1, subjects were matched into pairs based upon TT performance. This was achieved by pairing the fastest TT time with the slowest; this process was then repeated until all subjects had been paired. Subjects from each pair were then randomly assigned into either a concurrent training group (C) or an endurance training only (E) group.

2.3 Anthropometry

Anthropometric measurements including body mass, four-site skinfold thickness summation (chest, triceps, subscapular, and lliac crest) and muscle girths (chest and right upper arm), were performed by the same experienced investigator in accordance with International Society for the Advancement of Kineanthropometry guidelines (27). Body mass was measured to the nearest 0.1 kg using a calibrated scale (Seca 714, Hamburg, Germany); whilst skinfold thickness and muscle girths were measured to the nearest mm using a pair of skinfold callipers (accurate to 0.2 mm) and a flexible measurement tape (1.0 mm), both from the Harpenden range of anthropometric instruments (Holtain, Ltd, UK).

2.4 Incremental Hand Cycling Test

Subjects were asked to complete an incremental, exhaustive hand cycling test using their own hand bike fitted to a standard indoor cycling turbo trainer (Fluid 2, CycleOps, USA). Subjects had been previously custom fitted to their hand bike and were requested not to alter their crank width, crank height, or seat position for the duration of the study. Power output was measured using an instrumented front wheel hub (Powertap, G3, CycleOps. USA, 1.5% accuracy between 0 and 1999 W, sample frequency 0.2 Hz). The Powertap has been shown to be a reliable instrument (CV 0.9 – 2.9%) for the measurement of power whilst cycling (6) and was calibrated prior to testing in accordance with the manufacturer's instructions.

Throughout the test protocol heart rate (HR), oxygen uptake (VO2), carbon dioxide production (VCO2), and respiratory exchange ratio (RER) were continuously monitored using a HR receiver (Garmin 810, Garmin Ltd, USA) and a portable spiroergometry system (Metamax 3B, Cortez Biophysik, Germany), respectively. Gas calibrations were checked before and at the end of each trial to ensure no drift in calibration had occurred. As per the manufacturer's instructions oxygen and carbon dioxide sensors were firstly calibrated using a reference calibration gas of known concentration (14.7% oxygen, 4.97% carbon dioxide), the calibration was then verified against ambient air. Secondly, an air volume calibration was performed using a standardised 3 L syringe.

All respiratory parameters were calculated for each breath and averaged over 1-min durations at rest and over the last 15 s of each exercise stage. Gross mechanical efficiency was calculated as the ratio of external work produced to the amount of energy expended when a fixed blood lactate concentration of 2 $mmol \cdot L^{-1}$ was reached. This metabolic threshold was selected as it represents a consistent, submaximal exercise intensity during which energy production is predominantly via aerobic metabolic pathways. Metabolic energy expenditure was calculated from VO2 and RER data according to Garby and Astrup (14). Gross mechanical efficiency was then defined as; GME = ((external work done/energy expenditure) x 100) (%).

Following a 10-min warm up at a self-selected power output, subjects were requested to start the test protocol at a work rate of 50 W with subsequent 15 W increments every 3-mins until the required power output could no longer be maintained. Maximal aerobic power (MAP) and VO2peak were identified as the average power output and peak oxygen consumption rate achieved during the last fully completed 3-min stage. Riders were free to adjust their gear ratio and/or crank rate as needed in order to achieve and maintain the required power output. Every 3-mins and upon immediate completion of the test subjects were asked to indicate their rating of perceived exertion (RPE) using a 6- to 20- Borg scale (7). At the end of each stage a small sample of capillary blood was collected from each subjects earlobe in order to identify fixed blood lactate concentrations of 2 $mmol \cdot L^{-1}$, 4 $mmol \cdot L^{-1}$ and the blood lactate concentration at the point of volitional exhaustion. Each whole blood sample was analysed immediately to determine the concentration of blood lactate using a fully automated analyser (Biosen C-line, EKF Diagostics, Barleban, Germany). All capillary blood samples were collected by an experienced phlebotomist and following analysis were disposed of immediately.

2.5 Maximal Upper Body Strength Testing

Upper body strength was determined via the establishment of each subject's bench press and seated row 1RM. These exercises were chosen as they closely mimic the synchronistic, push/pull movement pattern observed during hand cycling. Bench press 1RM testing was conducted on a specifically designed, IPC para-powerlifting bench (Eleiko, Sweden), using a 20 kg Olympic barbell, 450 mm diameter barbell plates (25 kg, 20 kg, 15 kg, and 10 kg), 200 mm diameter barbell plates (5.0 kg, 2.5 kg, 2.0 kg, 1.5 kg, 1.0 kg, and 0.5 kg) and two safety locks (Eleiko, Sweden). Seated row 1RM testing was carried out on a fixed seated row/rear deltoid resistance machine with 1.0 kg weight increments (Cybex Total Access, USA).

Both bench press and seated row 1RM testing was conducted in line with the protocols proposed by Haff and Triplett (19). Subjects were instructed to perform a light warm up with the bar only for 5 – 10 repetitions. Following a 1-min recovery period a second set of 3 – 5 repetitions was performed with an estimated 60% 1RM load. After a 3-min recovery period another set of 2 – 3 repetitions, was performed with an estimated 80% 1RM load. Thereafter, an estimated 1RM load was selected and the subject asked to perform a single repetition. If successful, the subject was given a 3-min recovery period prior to performing a further 1RM attempt with an increased load. Subjects were allowed, to perform 3 – 5 more 1RM attempts with 3-min recovery between sets until their 1RM had been established within a precision of 1.0 kg.

2.6 30 km Individual Time Trial

In order to assess real world hand cycling performance, a 30 km individual TT was conducted at a closed motor racing circuit (Thruxton, England). This location provided a flat 3.75 km circuit. Following two familiarisation laps, participants were required to complete eight laps of the 3.75 km circuit. Overall time and lap split times were manually recorded to the nearest second (Seiko S149, Seiko Watch Corporation, Japan).

2.7 Training Intervention

Based upon a conjugated block periodisation model (15, 16, 17, 28, 29), the 8-week training invention for both groups was divided into two consecutive phases. Phase one (P1) focused upon the development of muscle hypertrophy and/or aerobic capacity; whilst phase two (P2) focused upon the development of maximal strength and/or anaerobic threshold. Each phase was 4 weeks in length, split into 3 weeks of accumulated training load, followed by a recovery week in the fourth where the total training volume was reduced by 50%. Subjects in the C group were asked to perform two strength training and three endurance training sessions per week, whilst subjects in the E group were asked to perform five endurance training sessions per week

Table 1. Strength training variables

Phase	Exercises	Repetition Loading Range	Sets	Recovery Between Sets
1	Chest Press, Seated Row,	5 – 7	5	02:00
2	Overhead Press, Lat Pull Down	2 – 4	6	03:00

Strength training loads in the C group were determined via the use of repetition zones matched with appropriate volume and recovery parameters (33, 34, 35) in order to elicit the required adaptive response (e.g., hypertrophy, maximal strength). A detailed description of the strength training variables is given in Table 1. Three hand cycling training zones were identified based upon individual MAP established during the incremental ramp test: zone 1 (Z1) light intensity, between 50 – 70% MAP; zone 2 (Z2) moderate intensity, between 70 – 90% MAP; and zone 3 (Z3) high intensity, between 90 – 110% MAP. A detailed description of hand cycling training variables is given in Table 2. Subjects were asked to complete a weekly online training diary. The adherence rate for hand cycling training sessions was approximately 100% in both groups, whilst subjects in the C group completed approximately 80% of the allocated strength training sessions

Table 2. Endurance Training Variables

Intensity Zone	Sessions Per Week		Time (Mins: Secs)	Work to Recovery Ratio	Recovery Time (Mins:Secs)	Repetitions
	P1	P2				
Z1	2* / 2**	0* / 1**	60 – 110	1:1	n/a	n/a
Z2	1* / 2**	2* / 2**	05:00 – 10:00	2:1	02:30 – 05:00	x 4
Z3	0* / 1**	1* / 2**	00:30 – 01:20	1:2	01:30 – 03:00	x 8

* C group
**E group

2.8 Statistical Analyses

All data are reported as mean (± SD) with an a-priori level of significance for all statistical analyses set at $p < 0.05$. Statistical analyses were performed using SPSS Version 22.00 (SPSS Inc, Chicago). A mixed model, 2-way analysis of variance (ANOVA) test was used to evaluate changes in the selected variables, between groups (E vs. C: independent measures) over the 8-week intervention period (T1 – T2: repeated measures). Prior to running all ANOVA tests, data was checked for sphericity using Mauchly's test. Where sphericity violations were noted a Huynh-Feldt correction was used to modify the degree of freedom employed in the subsequent statistical analysis. Where statistical significance was noted a post-hoc Bonferroni pairwise comparison was conducted to determine specifically where differences exist. In order to evaluate the magnitude of change for all parameters pre/post effect sizes (ES), were calculated using the following formula: [(post-test mean – pre-test mean)/pre-test SD]) (8, 24). Based upon the recommendations of Rhea (36) subjects were classed as recreationally trained as such ES were classed as either trivial <0.35; small 0.35 – 0.80; moderate 0.80 – 1.5; or large >1.50.

Chapter 3 – Results

Ten subjects started the study however; two withdrew due to personal reasons leaving four subjects in the C group and four in the E group. Physiological and performance changes in both intervention groups are displayed in Table 3. ANOVA tests revealed no significant changes between the two groups in all measures. However, when examined using ES, the C group was found to have a greater magnitude of change in most measures when compared to the E group.

After the 8-week training intervention no significant changes were observed in body mass in either the C group (ES = 0.04) or E group (ES = 0.14, p = 0.163). A moderate change in 4-site skin fold summation was observed in the C group (ES = 0.80) however, only a trivial change was noted in the E group (ES = 0.22, p = 0.224). A trivial increase in chest girth was detected in both the C group (ES = 0.31) and E group (ES = 0.13, p = 0.639), respectively. Furthermore, a small increase in upper arm girth was observed in the C group (ES = 0.52) whereas, only a trivial increase was noted in the E group (ES = 0.23, p = 0.675).

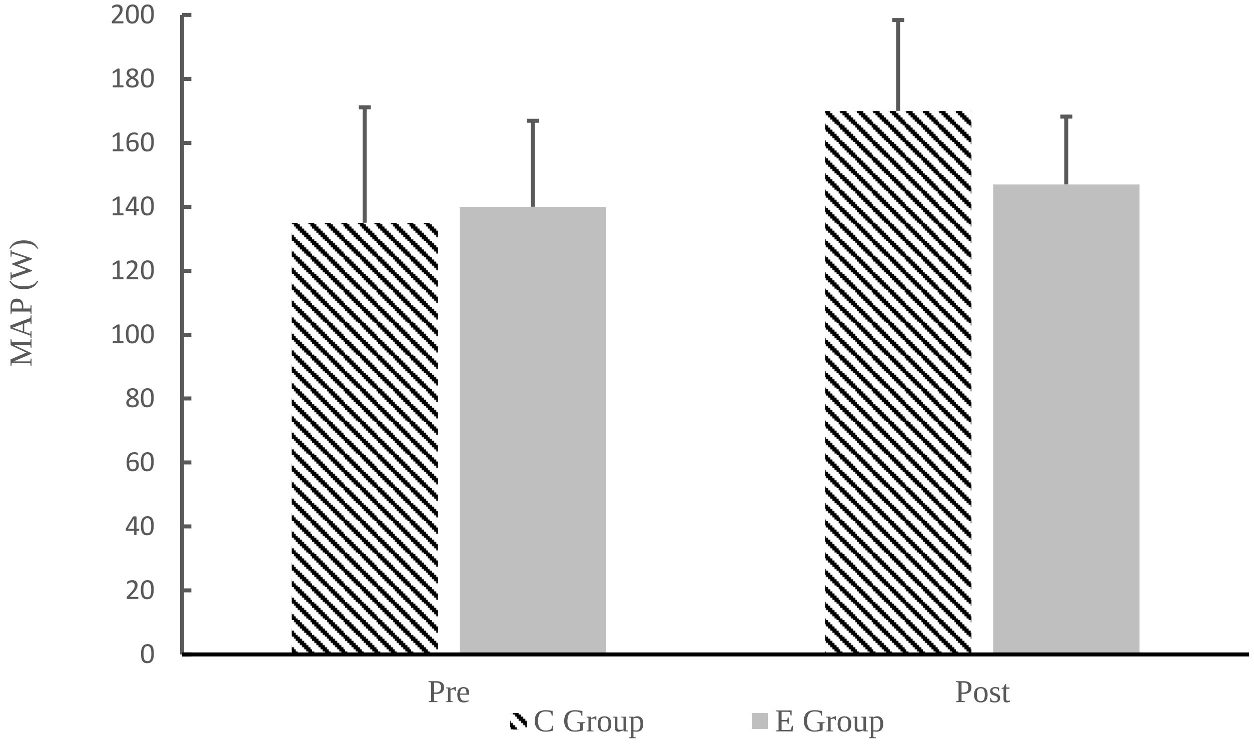

Figure 2. Mean (± *SD*) values of maximal aerobic power (MAP) achieved before and after 8-weeks of either concurrent or endurance only training.

A small improvement in relative VO2peak was detected in both the C group (ES = 0.54) and E group (ES = 0.70, p = 0.228). Power output at a fixed blood lactate concentration of 2 mmol·L-¹ showed a large increase in the C group (ES = 1.75) whilst, only a moderate improvement was observed within the E group (ES = 0.90, p = 0.37). A moderate improvement in GME was noted in the C group (ES = 0.87) however, only a small increase was detected in the E group (ES = 0.63, p = 0.87). In addition, a moderate increase in MAP (Figure 2) was observed in the C group (ES = 0.97) whilst, only a trivial change was noted in the E group (ES = 0.28, p = 0.271).

A small increase in bench press 1RM was detected in the C group (ES = 0.53) whereas, only a trivial increase was observed in the E group (ES = 0.33, p = 0.29). Furthermore, a large increase in seated row 1RM was detected in the C group (ES = 1.42) whilst, only a small increase noted in the E group (ES = 0.43, p = 0.32). Finally, a small improvement in 30 km TT performance (Figure 3) was detected in the C group (ES = 0.73) however, only a trivial change was observed in the E group (ES = 0.30, p = 0.548)..

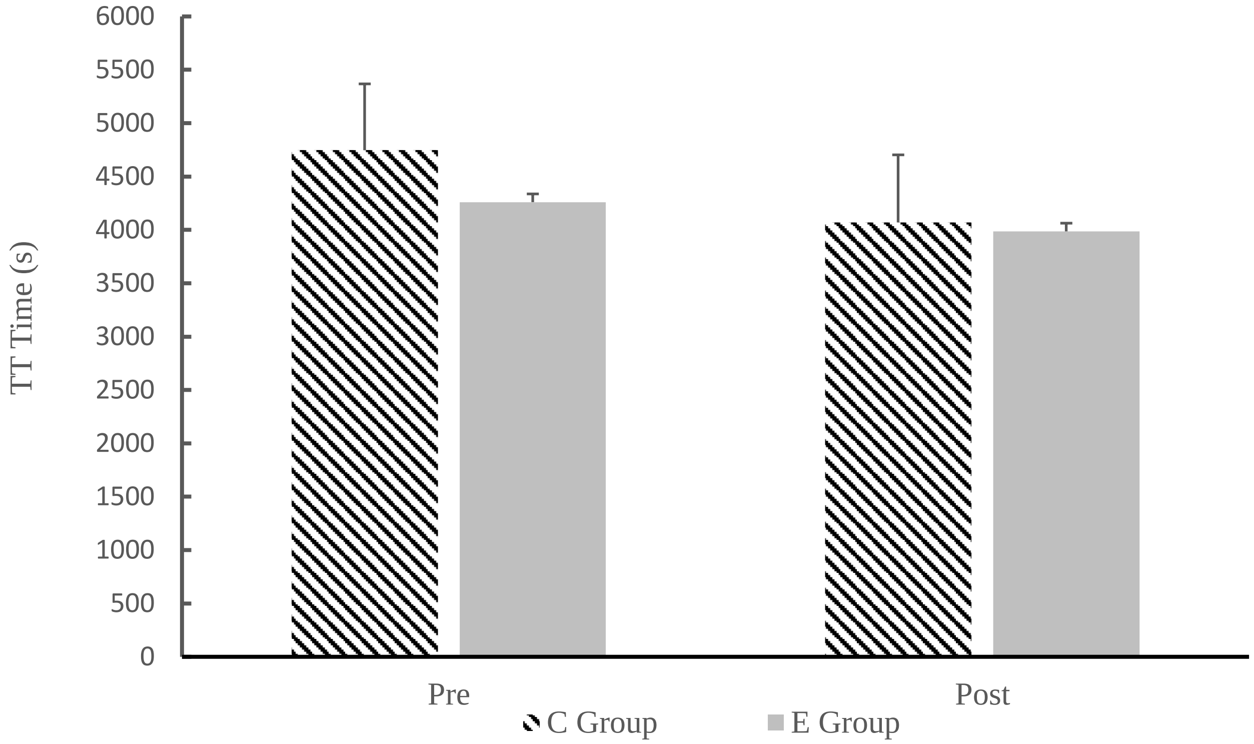

Figure 3. Mean (± *SD*) 30 km time trial (TT) times achieved before and after 8-weeks of either concurrent or endurance only training.

Table 3. Physiological and performance results in C and E groups.

Variables	C Group (C) (*n* = 4)			E Group (E) (*n* =4)		
	Pre-Training	Post-Training	Effect Size	Pre-Training	Post-Training	Effect Size
Body Mass (kg)	68.8 ± 16.2	69.4 ± 15.4	0.04	80.7 ± 19	78.6 ± 19.3	0.14
4- Site Skinfold Summation (mm)	22.7 ± 2.8	20.4 ± 6.9	0.80	35.0 ± 8.8	33.1 ± 9.3	0.22
Chest Girth (cm)	107.3 ± 6.5	108.5 ± 9.0	0.31	107 ± 11.2	108.5 ± 8.9	0.13
Arm Girth (cm)	33.3 ± 6.5	36.7 ± 3.2	0.52	33.5 ±11.2	36.1 ±1.7	0.23
Relative VO_2peak ($mL \cdot kg^{-1} min^{-1}$)	32.5 ± 15.7	41.0 ± 16.4	0.54	28.5 ± 8.0	34.1 ± 8.2	0.70
2 $mmol \cdot L^{-1}$ (W)	65 ± 40.1	102.5 ± 21.4	1.75	55.0 ± 9.6	67.5 ± 14.4	0.90
GME (%)	9.7 ± 3.8	14.0 ± 4.2	0.87	11.5 ± 3.2	13.5 ± 1.4	0.63
MAP (W)	135.0 ± 36.1	170.0 ± 28.4	0.97	140.0 ± 26.9	147.5 ± 21.2	0.28
Bench Press 1RM (kg)	83.0 ± 17.8	92.5 ± 17.1	0.53	71.5 ± 25.9	80.0 ± 20.1	0.33
Seated Row 1RM (kg)	80.0 ± 3.8	85.4 ± 5.9	1.42	75.0 ±23.2	85.0 ± 19.8	0.43
30 km TT (Secs)	4747 ± 621	4070 ± 633	0.73	4260 ± 77	3986 ± 77	0.30

Chapter 4 – Discussion

The present study investigated the effects of an 8-week concurrent strength and endurance training programme compared to endurance training only upon several identified markers of hand cycling performance. Whilst not approaching significance using traditional statistical tests (e.g., ANOVA), the use of contemporary statistical testing in the form of ES (8, 24, 36), revealed that concurrent training resulted in a greater magnitude of change in several key markers of hand cycling performance when compared to endurance training alone. Whilst both training interventions demonstrated a positive improvement in most physiological and performance measures the C group demonstrated greater improvements in relative VO2peak (26.2% vs. 19.6%), MAP (25.9% vs. 5.4%), GME (34% vs. 17.4%) and 30 km TT performance (10.4% vs. 6.4%). Results revealed little change in body mass, chest girth and arm girth. However, the C group displayed a greater improvement in body composition as measured via 4-site skinfold summation (10.1% vs. 5.4%). Surprisingly, the E group displayed a similar improvement in bench press 1 RM (11.9% vs. 11.4%), when compared to C group despite not performing any specific strength training.

Individuals with spinal cord injury (SCI) or lower limb amputation have a reduced physiological capacity compared with able-bodied persons (3, 30). Persons with an SCI may also display an even greater reduction due to reduced trunk muscle function as a result of the direct loss of motor control below the level of the lesion, as well as a lack of sympathetic innervation (21). Despite a reduced physiological capacity, individuals with a physical disability demonstrate a similar adaptive training potential to that of their able bodied counterparts. Fundamentally, physiological adaptations which occur as a result of training are primarily dependent upon the frequency, intensity, time and type of training performed (33, 34, 35). Therefore, is would be expected that an appropriate strength and/or endurance training regime would result in gains comparable to those observed in able-bodied subjects.

To date only a small number of studies have investigated the effects of a structured training intervention upon key markers of hand cycling performance. Valent et al. (39) studied the effects of a 12-week interval training programme upon hand cycling performance in a group of tetraplegics and demonstrated significant improvements in MAP and VO2peak. Abel et al. (2) reported that a structured, 6-month training intervention for an experienced hand cyclist resulted in a significant improvement in power output at lactate threshold and VO2peak. Furthermore, Hettinga et al. (22) established that a 7-week hand cycling specific training programme resulted in a significant increase in VO2peak and MAP in 22 able-bodied female participants. Additionally, Schoenmakers et al. (38) identified that both moderate intensity continuous training and high intensity interval training significantly increased VO2peak and MAP in able-bodied hand cyclists.

From the literature reviewed it is evident that most studies investigating the effects of a structured training intervention upon key markers of hand cycling performance have focused upon endurance training only. To the best of the authors' knowledge only one other study to date has investigated the influence of a concurrent strength and endurance training intervention upon hand cycling performance. Jacobs (30) examined the effects of a 12-week concurrent training programme in comparison to endurance training only using a group of untrained paraplegic subjects. Similarly, to the present study the author demonstrated that in comparison to endurance training only, concurrent training resulted in a greater improvement in VO2peak (15.1% vs. 11.8%), anaerobic capacity (8% vs. 5%), peak power (15.6% vs. 2.6%), and upper body strength (45% vs. -4.2%). These findings demonstrated that individuals with SCI were able to improve their upper body work capacity, strength and power. Furthermore, they suggest that in comparison to endurance training only, concurrent training may have the potential to significantly enhance hand cycling performance.

In agreement with Jacobs (30) the present study demonstrated that in comparison to endurance training alone, concurrent training can result in a greater improvement in relative VO2peak, MAP, GME and 30 km TT hand cycling performance. Improved GME is of particular importance to hand cyclists as improved efficiency will effectively translate in a reduced relative work load. This will allow a rider to produce a higher power output for an equivalent amount of energy (i.e., improved performance capacity) or alternatively result in a longer time to exhaustion at a given rate of work (i.e., improved endurance capacity). Whilst a slight increase in body mass was observed in the C group, a greater improvement in body composition was noted when compared with the E group. However, a similar increase in chest and upper arm girth was observed in both groups. Furthermore, both the C and E groups demonstrated similar increases in upper body strength. These findings appear to refute the training principle of specificity. However, they do suggest that an 8-week hand cycling only training intervention may provide a sufficient stimulus to enhance upper body strength. Moreover, it can also be postulated that the concurrent training intervention may have resulted in an interference effect upon the development of muscle hypertrophy and maximal force generating capacity of subjects in the C group.

In agreement with the findings of the present study concurrent training, relative to strength training alone, has been demonstrated to curtail the development of muscle hypertrophy, maximal strength, rate of force development, and peak power output due to the existence of an interference effect (4, 13, 17, 42). Strength and endurance training represent very divergent modes of exercise which result in very distinct adaptive responses. Strength training has been demonstrated to result in significant increases in muscle force production capability due to several neurological and morphological adaptations. These include, enhanced motor unit recruitment, greater motor neuron rate coding, changes in inter/intra muscular co-ordination, improved cortical and corticospinal excitability, greater muscular cross-sectional area, changes in muscle fibre type, altered muscle architecture and enhanced tendon and connective tissue stiffness (4, 13, 17). Conversely, endurance training has been shown to result in increased cardiac output, greater mitochondrial volume and density, enhanced glycogen storage and enhanced substrate metabolism, all of which culminates in an increase in aerobic capacity (4, 13, 17).

Both acute and chronic hypotheses have been proposed to explain the interference effect. The acute hypothesis contends that residual fatigue resulting from endurance training, results in a reduced ability of muscle to generate force, compromising ones adaptive potential to strength training (9, 42). Conversely, the chronic hypotheses proposes that strength and endurance training regimes result in a complex cascade of divergent molecular signalling events and subsequent gene expression which results in the accumulation of specific proteins and altered muscle phenotypes (9, 42). Strength training adaptations have been proposed to be mediated by the mechanistic mammalian target of rapamycin (mTOR) pathway which stimulates protein synthesis (4, 13). In contrast, endurance training adaptations have been suggested to be controlled by the adenosine monophosphate activated protein kinase (AMPK) pathway which stimulates enhanced mitochondrial mass, improved substrate utilisation, and increased capillary density (4, 13). Recent evidence suggests that activation of AMPK pathway may directly inhibit mTOR activation thus, potentially limiting strength training adaptations (4, 13). Whilst it is likely that both acute and chronic factors contribute to the interference effect. The overall extent may be highly dependent upon the modality, frequency, intensity, duration and sequencing of endurance exercise performed (9, 13, 15, 16 17, 42).

Presently, the sequencing and optimal training load distribution by which to improve key markers of hand cycling performance has not yet been identified. Several authors have proposed conjugated block periodisation to be a more effective training model than the traditional linear approach (16, 17, 28, 29). Conjugated block periodisation places an emphasis upon the highly concentrated development of a specific set of motor attributes during a given training block, whilst simultaneously maintaining other motor attributes albeit, at a reduced training volume. The sequencing of training blocks is intended to build upon the residual training effects of previously developed motor attributes (16, 17, 28, 29). The present study demonstrates that a conjugated block periodisation model based upon the sequenced development of muscular hypertrophy and/or aerobic capacity followed by maximal strength and/or anaerobic threshold can result in a noteworthy improvement in several identified physiological characteristics of hand cycling performance.

Whilst both training interventions were effective it must be noted that the C group demonstrated a greater magnitude of change in several key markers of hand cycling performance when compared to the E group. Furthermore, subjects in the C group performed 40% less endurance training than those in the E group; with the reduced volume of endurance training replaced with two strength sessions per week. An excessive volume of endurance training has been linked with an increased likelihood of upper limb musculoskeletal overuse injury in wheelchair athletes (3). Therefore, a reduction in the total volume of hand cycling training combined with a greater improvement in performance suggests that a concurrent training regime based upon a conjugated block periodisation model may be a more effective, time efficient, and safer approach for improving hand cycling performance than engaging in endurance training alone.

There are several limitations to the present study. Firstly, the subject group used was relatively heterogeneous in terms of age, performance level and disability. Furthermore, the overall number of subjects was low. Probability values (e.g., p values) are affected by sample size and variance (36). Therefore, the use of ANOVA tests in this study may not have identified any significant difference between groups due to the small sample size. Nonetheless the use of ES, demonstrated that concurrent training resulted in a greater magnitude of change in several key markers of hand cycling performance compared to endurance training alone. Another limitation of the present study was the lack of a control group by which to compare the true effectiveness of either concurrent or endurance only training. Additionally, the 30 km TT was a self-paced time trail, which was conducted in variable climactic conditions. Such an approach represents a less controlled and less repeatable environment compared to laboratory conditions. However, it does add a degree of ecological validity as it relates more closely to a real world hand cycling race. In future, and in this regard it would be advisable to measure the average power output during such a TT effort to facilitate a pre vs. post-intervention Finally, the authors also recognise that 8-weeks represents a relatively short period and that greater gains may well have occurred had a longer training intervention been employed.

Chapter 7 – Practical Applications

In conclusion, the findings of this study demonstrate that an 8-week concurrent strength and endurance training programme based upon a conjugated block periodisation model can result in meaningfully, greater improvements in several key markers of hand cycling performance when compared to endurance training alone. Whilst not approaching traditional statistical significance the use of ES revealed that concurrent training resulted in a greater magnitude of change in several key markers of hand cycling performance compared to endurance training alone. In agreement with existing literature (4, 13, 42), findings from the present study raise the possibility of the existence of an interference effect on the development of muscle hypertrophy and maximal force production capability in hand cyclists as a result of a concurrent training regime. However, given observed the improvement in body composition, MAP, GME and 30 km TT performance. It is recommend that hand cyclists and their coaches utilise a concurrent training programme based upon a conjugated block periodisation model in order to optimise hand cycling performance and reduce the likelihood of developing an upper limb overuse musculoskeletal injury. Furthermore, it is recommended that future research in this area should aim to use a larger, more homogenous group of hand cyclists, over a longer training intervention period in order to better understand the long term effects of concurrent training upon hand cycling performance.

Chapter 8 – References

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