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Efficacy of an 8-Week Concurrent Strength and Endurance Training Programme on Hand Cycling Performance

Jonpaul Nevin1, Paul Smith2, Mark Waldron3, Stephen Patterson4, Mike Price5, Alex Hunt6 and Richard Blagrove7

Abstract

Nevin, JP, Smith, P, Waldron, M, Patterson, S, Price, M, Hunt, A, and Blagrove, R. Efficacy of an 8-week concurrent strength and endurance training programme on hand cycling performance. J Strength Cond Res XX(X): 000–000, 2018—The aim of this study was to investigate the effects of an 8-week concurrent strength and endurance training programme in comparison with endurance training only on several key determinants of hand cycling performance. Five H4 and 5 H3 classified hand cyclists with at least 1 year’s hand cycling training history consented to participate in the study. Subjects underwent a battery of tests to establish body mass, body composition, VO2peak, maximum aerobic power, gross mechanical efficiency (GME), maximal upper-body strength, and 30-km time-trial performance. Subjects were matched into pairs based on 30-km time-trial performance and randomly allocated to either a concurrent strength and endurance or endurance training only, intervention group. After an 8-week training programme based on a conjugated block periodization model, subjects completed a second battery of tests. A mixed model, 2-way analysis of variance revealed no significant changes between groups. However, the calculation of effect sizes (ESs) revealed that both groups demonstrated a positive improvement in most physiological and performance measures with subjects in the concurrent group demonstrating a greater magnitude of improvement in body composition (ES = 0.80 vs. −0.22), maximal aerobic power (ES 0.97 vs. 0.28), GME (ES 0.87 vs. 0.63), bench press 1 repetition maximum (1RM) (ES 0.53 vs. 0.33), seated row 1RM (ES 1.42 vs. 0.43), and 30-km time-trial performance (ES = −0.66 vs. −0.30). In comparison with endurance training only, an 8-week concurrent training intervention based on a conjugated block periodization model seems to be a more effective training regime for improving the performance capabilities of hand cyclists.

Key Words: disability sport, arm ergometry, resistance training, conjugated block periodization

Introduction

Hand cycling is a form of paracycling used by individuals who are unable to ride a conventional road bike or tricycle because of either a spinal cord injury (SCI) or physical impairment of the lower extremities. Over the past 2 decades, the popularity of hand cycling as a sport has increased considerably (2,20). Indeed, in 1999, hand cycling was formally recognized as a sport by the International Paralympic Committee (IPC) and has been included in the Paralympic Games since Athens in 2004. Hand cycle races vary in length from 50 to 80 km for a criterium road race and 20–30 km for an individual time trial (22). Hand cycling race tactics are comparable with those of able-bodied cycling and 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 has been shown to place a considerable demand on the aerobic energy system (2). However, it can be speculated that the anaerobic energy system will be repeatedly taxed because of the requirement to generate a relatively high-power output for brief periods during surges in pace, climbing, or sprinting to the finish (1,10,11) (Figure 1).

Despite the increased interest in hand cycling as a sport, there is currently a paucity of research in regard to the typical physiological characteristics of competitive hand cyclists. As with able-bodied cycling, peak oxygen uptake (VO2peak) (1,2,11,22,25,26,30,31,41), maximal aerobic power (MAP)(18,22–24,30,31,38,41), and gross mechanical efficiency (GME)(1,12,18,21,30,41) 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 impact on hand cycling performance (3,10,11).

Relatively few studies have investigated the effects of a structured training intervention on hand cycling performance (2,22,38,39) with all but one (31) using endurance training models.
training only. In comparison with endurance training only, the concurrent integration of both strength (e.g., resistance training) and endurance training (e.g., cycling or running) into a single unified training programme has been demonstrated to significantly enhance body composition, \( \text{Vo}_2 \)-peak, MAP, GME, anaerobic capacity, and subsequent performance potential of individuals in endurance sports such as cycling (5,37,43), running (5,37), and kayaking (15). However, it must be noted that, 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 through a phenomenon commonly known as the interference effect (1,9,13,17,22).

Several physiological adaptations have been proposed, which may explain the observed improvements in endurance performance as a result of concurrent training. These include (a) greater force production capability; (b) enhanced peak power output; (c) improved musculotendinous stiffness; and (d) superior GME because of a reduced relative energy expenditure at a given velocity or power output (17,37). It can be argued that improved GME is of particular importance to endurance athletes because improved efficiency will effectively translate to a reduced work load. This will allow an individual 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).

Given that concurrent training has been demonstrated to enhance body composition, \( \text{Vo}_2 \)-peak, MAP, GME, and maximal strength of able-bodied cyclists (5,37,43), it can be speculated that it may also enhance hand cycling performance. Indeed, Garcia-Pallares et al. (15,16) recently demonstrated that a 12-week concurrent training programme based on a block periodization model significantly improved several neuromuscular, cardiovascular, and performance markers in 11 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 on the theoretical potential of concurrent training to enhance hand cycling performance, this study investigated the effects of an 8-week concurrent training programme compared with endurance training only on several key determinants of hand cycling performance. It was hypothesized that an 8-week concurrent training programme would result in a greater improvement in hand cycling performance than purely endurance training alone.

**Methods**

**Experimental Approach to the Problem**

A repeated measures, pre-test, post-test design, was used to test the hypothesis that concurrent training would result in a greater improvement in hand cycling performance when compared with endurance training alone. Body mass, body composition, \( \text{Vo}_2 \)-peak, MAP, GME, maximal upper-body strength, and 30-km individual time-trial (TT) performance were evaluated in 10 experienced hand cyclists. Based on 30-km TT performance, subjects were matched into pairs before being randomly assigned to either a concurrent (CT) or endurance training only (E) group. Subjects in the CT group were asked to complete an 8-week concurrent...
training intervention designed to develop aerobic capacity and upper-body strength, whereas subjects in the E group were asked to complete an 8-week endurance training only intervention designed to develop aerobic capacity. After an 8-week training intervention, all the aforementioned variables were re-examined to determine which was the more effective training intervention.

**Subjects**

Ten experienced hand cyclists with at least 1 year’s recreational 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 [22]. Three participants were bilateral, above knee amputees (H4); one was a triple amputee (H3); one a single, below knee amputee (H4); 4 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 1072 ± 87 cm; right upper arm girth 33.5 ± 8.7 cm, and relative \( \text{VO}_2\text{peak} \) 31.2 ± 13.5 ml·kg\(^{-1}\)·min\(^{-1}\). No upper-body musculoskeletal injuries that could affect a subject’s participation were reported before 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, England).

**Procedures**

All subjects undertook a series of laboratory and field-based testing protocols before (T1) and immediately on completion (T2) of the 8-week experimental training intervention. Testing was completed over 3 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). After T1, subjects were matched into pairs based on 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 the CT group or E group.

**Anthropometry.** Anthropometric measurements, including body mass, 4-site skinfold thickness summation (chest, triceps, subscapular, and iliac 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 [23]. Body mass was measured to the nearest 0.1 kg using a calibrated scale (Seca 714; Seca, Hamburg, Germany), whereas skinfold thickness and muscle girths were measured to the nearest mm using a pair of skinfold calipers (accurate to 0.2 mm) and a flexible measurement tape (1.0 mm), both from the Harpenden range of anthropometric instruments (Holtain, Ltd, Crymych, Wales).

**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, Madison, Wisconsin, USA). Based on their disability, 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, Madison, Wisconsin, 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 while cycling [6] and was calibrated before testing in accordance with the manufacturer’s instructions.

Throughout the test protocol, heart rate (HR), oxygen uptake (\( \text{VO}_2 \)), carbon dioxide production (\( \text{VCO}_2 \)), and respiratory exchange ratio (RER) were continuously monitored using a HR receiver (Garmin 810; Garmin Ltd, Schaffhausen, Switzerland) and a portable spiroergometry system (Metamax 3B; Cortez Biophysik, Liepzig, 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 first calibrated using a reference calibration gas of known concentration (14.7% oxygen, 4.97% carbon dioxide); the calibration was then verified against ambient air. Second, an air volume calibration was performed using a standardized 3-L syringe. All respiratory parameters were calculated for each breath and averaged over 1-minute durations at rest and over the last 15 seconds 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·L\(^{-1}\) was reached. This metabolic threshold was selected as it represents a consistent, sub-maximal exercise intensity during which energy production is predominantly through aerobic metabolic pathways. Metabolic energy expenditure was calculated from \( \text{VO}_2 \) and RER data according to Garby and Astrup [14]. Gross mechanical efficiency was then defined as \( \text{GME} = \left( \text{external work done} \div \text{energy expenditure} \right) \times 100 \) (%).

After a 10-minute 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 minutes until the required power output could no longer be maintained. Maximal aerobic power and \( \text{VO}_2\text{peak} \) were identified as the average power output at which the subject stopped the test.

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consumption rate achieved during the last fully completed 3-minute stage. Subjects were free to adjust their gear ratio and crank rate as needed to achieve and maintain the required power output. Every 3 minutes and on immediate completion of the test, subjects were asked to indicate their rating of perceived exertion using a 6–20-Borg scale (7).

At the end of each stage, a small sample of capillary blood was collected from each subject’s earlobe to identify fixed blood lactate concentrations of 2 mmol·L⁻¹, 4 mmol·L⁻¹, and the blood lactate concentration at the point of volitional exhaustion. Each whole blood sample was analyzed immediately to determine the concentration of blood lactate using a fully automated analyzer (Biosen C-line; EKF Diagnostics, Barleben, Germany). All capillary blood samples were collected by an experienced phlebotomist and after analysis were disposed of immediately.

Maximal Upper-Body Strength Testing. Upper-body strength was determined through the establishment of each subject’s bench press and seated row 1RM. These exercises were chosen because they closely mimic the synchronistic, push/pull movement pattern observed during hand cycling (40). Bench press 1RM testing (CV 23–25.5%) was conducted on a specifically designed, IPC para–powerlifting bench (Eleiko, Halmstad, Sweden), with a 20-kg Olympic barbell, 450-mm diameter barbell plates (25, 20, 15, and 10 kg), 200-mm diameter barbell plates (5.0, 2.5, 2.0, 1.5, 1.0, and 0.5 kg), and 2 safety locks (Eleiko, Halmstad, Sweden). Seated row 1RM testing (CV 16–19.7%) was performed on a seated row/rear deltoid resistance machine with 1.0-kg body mass increments (Cybex Total Access; Cybex, Medway, Massachusetts, USA).

Both bench press and seated row 1RM testing were conducted in line with the protocols proposed by Haff and Tripplett (19). Subjects were instructed to perform a light warm-up with the bar only for 5–10 repetitions. After a 1-minute recovery period, a second set of 3–5 repetitions was performed with an estimated 60% 1RM load. After a 3-minute 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-minute recovery period before performing a further 1RM attempt with an increased load. Subjects were allowed to perform 3–5 more 1RM attempts with 3-minute recovery between sets until their 1RM had been established within a precision of 1.0 kg.

30-km Individual Time Trial. To assess real-world hand cycling performance, a 30-km individual TT (CV 17.1–18.1%) was conducted at a closed motor racing circuit (Thruxton, England). This location provided a flat 3.75-km circuit. After 2 familiarization laps, participants were required to complete 8 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, Tokyo, Japan).

Training Intervention. Based on a conjugated block periodization model (15–17, 28, 29), the 8-week training intervention for...
both groups was divided into 2 consecutive phases. Phase 1 (P1) focused on the development of upper-body strength and/or aerobic capacity, whereas phase 2 (P2) focused on the development of maximal upper-body 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 CT group were asked to perform 2 strength training and 3 endurance training sessions per week, whereas subjects in the E group were asked to perform 5 endurance training sessions per week.

Strength training loads in the CT group were determined through the use of repetition zones matched with appropriate volume and recovery parameters (33–35) to elicit the required adaptive response (e.g., maximal strength). A detailed description of the strength training variables is given in Table 1. Three hand cycling training zones were identified based on individual MAP established during the incremental ramp test: zone 1 (Z1) light intensity, between 50 and 70% MAP; zone 2 (Z2) moderate intensity, between 70 and 90% MAP; and zone 3 (Z3) high intensity, between 90 and 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, whereas subjects in the CT group completed approximately 80% of the allocated strength training sessions.

**Table 3.** Physiological and performance results in CT and E groups.*

<table>
<thead>
<tr>
<th>Variables</th>
<th>CT group (n = 4)</th>
<th>E group (n = 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-training</td>
<td>Post-training</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>68.8 ± 16.2</td>
<td>69.4 ± 15.4</td>
</tr>
<tr>
<td>4-site skinfold summation (mm)</td>
<td>22.7 ± 2.8</td>
<td>20.4 ± 6.9</td>
</tr>
<tr>
<td>Chest girth (cm)</td>
<td>107.3 ± 6.5</td>
<td>108.5 ± 9.0</td>
</tr>
<tr>
<td>Arm girth (cm)</td>
<td>33.8 ± 6.5</td>
<td>36.7 ± 3.2</td>
</tr>
<tr>
<td>Relative $V_{O2\text{peak}}$ (mL kg$^{-1}$ min$^{-1}$)</td>
<td>32.5 ± 15.7</td>
<td>41.0 ± 16.4</td>
</tr>
<tr>
<td>2 mmol·L$^{-1}$ (W)</td>
<td>65 ± 40.1</td>
<td>102.5 ± 21.4</td>
</tr>
<tr>
<td>GME (%)</td>
<td>9.7 ± 3.8</td>
<td>13.0 ± 4.2</td>
</tr>
<tr>
<td>MAP (W)</td>
<td>135.0 ± 36.1</td>
<td>170.0 ± 28.4</td>
</tr>
<tr>
<td>Bench press 1RM (kg)</td>
<td>83.0 ± 17.8</td>
<td>92.5 ± 17.1</td>
</tr>
<tr>
<td>Seated row 1RM (kg)</td>
<td>80.0 ± 3.8</td>
<td>85.4 ± 5.9</td>
</tr>
<tr>
<td>30-km TT (sec)</td>
<td>4,481 ± 621.2</td>
<td>4,070.5 ± 633</td>
</tr>
</tbody>
</table>

*GME = gross mechanical efficiency; MAP = maximal aerobic power; 1RM = 1 repetition maximum; TT = time trial.

**Figure 2.** Mean (±SD) values of maximal aerobic power (MAP) achieved before and after 8 weeks of either concurrent or endurance only training.
analysis of variance (ANOVA) test was used to evaluate changes in the selected variables, between groups (CT vs. E: independent measures) over the 8-week intervention period (T1–T2: repeated measures). Where statistical significance was noted, a post hoc Bonferroni pairwise comparison was conducted to determine specifically where differences exist. To evaluate the magnitude of change for all parameters, pre/post effect sizes (ESs) were calculated using the following formula: 

\[
\text{ES} = \frac{\text{post-test mean} - \text{pre-test mean}}{\text{pre-test SD}}
\]

Based on the recommendations of Rhea (36), subjects were classed as recreationally trained as such E were classed as either trivial <0.35; small 0.35–0.80; moderate 0.80–1.5; or large >1.50.

RESULTS

Ten subjects started the study; however, 2 withdrew because of personal reasons leaving 4 subjects in the CT group and 4 in the E group. Physiological and performance changes in both intervention groups are displayed in Table 3. Analysis of variance tests revealed no significant changes between the 2 groups in all measures. However, when the data were examined using ES, the CT group was found to have a greater magnitude of change in several measures when compared with the E group.

After the 8-week training intervention, no significant changes were observed in body mass in either the CT group (ES = 0.04) or E group (ES = -0.11, p = 0.163). A moderate change in 4-site skinfold summation was observed in the CT 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 CT group (ES = 0.18) and E group (ES = 0.13, p = 0.639), respectively. Furthermore, a small increase in upper arm girth was observed in the CT group (ES = 0.52), whereas only a trivial increase was noted in the E group (ES = 0.23, p = 0.675).

A trivial improvement in relative \(\text{VO}_2\)peak was noted in the CT group (ES = 0.14), whereas a moderate improvement was seen within the E group (ES = 0.70, p = 0.228). Power output at a fixed blood lactate concentration of 2 mmol L\(^{-1}\) showed a moderate increase in both the CT group (ES = 0.94) and E group (ES = 1.30, p = 0.37). A moderate improvement in GME was noted in the CT 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 CT group (ES = 0.97), whereas 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 CT 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 CT group (ES = 1.42), whereas 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 CT group (ES = -0.66); however, only a trivial change was observed in the E group (ES = -0.30, p = 0.548).

DISCUSSION

The aim of this study was to investigate whether concurrent strength and endurance training would result in a greater improvement in hand cycling performance when compared with endurance training alone. Although not approaching significance using traditional statistical tests (e.g., ANOVA), the use of contemporary statistical testing in the form of ES revealed that both training interventions demonstrated a positive improvement in most physiological and performance measures with the CT group demonstrating a greater magnitude of improvement in body composition, relative \(\text{VO}_2\)peak, MAP, GME, upper-body maximal strength, and 30-km TT performance.

Individuals with SCI or lower limb amputation have a reduced physiological capacity compared with able-bodied persons. Persons with an SCI may also display an even greater reduction because of 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. Despite a reduced physiological capacity, individuals with a physical disability have been demonstrated to...
have a similar adaptive training potential to that of their able-bodied counterparts (3). Fundamentally, physiological adaptations that occur as a result of training are primarily dependent on the frequency, intensity, time, and type of training performed (33–35). Therefore, it would be expected that an appropriate strength and/or endurance training regime would result in similar physiological adaptations to those observed in able-bodied persons.

Most studies investigating the effects of a structured training intervention on hand cycling performance have focused on endurance training only (22,23,38,39). To the best of the authors’ knowledge, only one other study to date has investigated the influence of a concurrent training intervention on hand cycling performance. Jacobs (31) examined the effects of a 12-week concurrent training programme in comparison with endurance training only using a group of untrained paraplegic subjects. Similarly, to this study, the author demonstrated that in comparison with endurance training only, concurrent training resulted in a greater improvement in \( \dot{V}O_2 \text{peak} \) (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 with endurance training only, concurrent training may have the potential to significantly enhance hand cycling performance.

Although both training interventions in this study were effective, it must be noted that subjects in the CT group performed 40% less endurance training than those in the E group, with the reduced volume of endurance training replaced with 2 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 on a conjugated block periodization model may be a more effective, time efficient, and safer approach for improving hand cycling performance, than engaging in purely endurance training alone.

It must be noted that there are several major limitations to this study. Probability values (e.g., \( p \) values) are affected by variance and sample sizes (36). As with many studies of this type, it is extremely difficult to recruit a homogenous group of disabled subjects. As such, the subject group used in this study was relatively heterogeneous in terms of age, performance level, and disability, which resulted in considerable variance within the group. Furthermore, the overall number of subjects was low. Therefore, the use of ANOVA tests in this study may not have identified any significant difference between groups because of the level of between-subject variance and the small sample size. A further limitation of this study was the lack of a control group by which to compare the true effectiveness of either concurrent or endurance only training. In addition, the 30-km TT was a self-paced time trial, which was conducted in variable climatic conditions. Such an approach represents a less-controlled and less-repeatable environment compared with laboratory conditions. However, it does add a degree of ecological validity because it relates more closely to a real-world hand cycling race. Finally, the authors also recognize that 8 weeks represented a relatively short period and that greater gains may have been observed, which had a longer training intervention been used.

**Practical Applications**

In conclusion, the findings of this study demonstrate that both concurrent and endurance training only can result in meaningfully, greater improvements in several key determinants of hand cycling performance. Despite several major limitations, the findings of this study suggest that, over an 8-week training intervention period, concurrent training seems to result in a greater magnitude of improvement in body composition, relative \( \dot{V}O_2 \text{peak} \), MAP, GME, upper-body maximal strength, and 30-km TT performance when compared with endurance training alone. Based on these findings, it is recommended that hand cyclists use a concurrent training programme based on a conjugated block periodization model to optimize hand cycling performance and reduce the likelihood of developing some form of upper limb overuse musculoskeletal injury. 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 to better understand the long-term effects of concurrent training on hand cycling performance.

**References**


