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Effects of Inspiratory Muscle Training Upon Recovery Time During High Intensity, Repetitive Sprint Activity

Abstract

The present study examined the influence of specific inspiratory muscle training (IMT) upon recovery time during repetitive sprint activity, as well as the physiological and perceptual responses to fixed intensity shuttle running. Using a double-blind placebo-controlled design, 24 male repetitive sprint athletes were assigned randomly to either an IMT (n = 12) or placebo (n = 12) group. The self-selected recovery time during a repetitive sprint test and the physiological response to submaximal endurance exercise were determined. Following completion of baseline and pre-intervention measures, the IMT group performed 30 inspiratory efforts twice daily against a resistance equivalent to 50% maximum inspiratory mouth pressure (MIP) for 6 wk. The placebo group performed 60 breaths once daily, for 6 wk, at a resistance equivalent to 15% MIP, a load known to elicit negligible changes in respiratory muscle function. The IMT group improved total recovery time during the repetitive sprint test by 6.2 ± 1.1% (mean ± SEM) above the changes noted for the placebo group ($p = 0.006$). Blood lactate and perceptual responses to submaximal exercise were also significantly attenuated following IMT ($p \leq 0.01$). These data support existing evidence that specific IMT attenuates the blood lactate and perceptual responses to submaximal endurance exercise. In addition, the present study provides new evidence that IMT improves recovery time during high intensity, intermittent exercise in repetitive sprint athletes.

Key words
Dyspnoea · lactate · ergogenic · multi-sprint · respiratory muscle

Introduction

Repetitive sprint sports are characterized by repeated short bouts of high-intensity exercise interspersed with periods of active or passive recovery. Although repetitive sprint sport players may only perform high intensity exercise for a small percentage of a total game on average, such periods are often instrumental in determining the eventual outcome. Consistent performance in repetitive sprint activity requires adequate recovery between sprints. The lactic acidosis incurred from repetitive sprint activity inevitably drives pulmonary ventilation higher and increases the intensity of perceptual effort sensations, including breathlessness. The intense breathlessness that follows sprint activity may provide a strong cue to athletes about their readiness to sprint again and may therefore determine their contribution to team performance.

Specific respiratory muscle training (RMT) reduces the intensity of breathlessness in patients with lung disease [1], healthy sedentary [10,11,29,32] and endurance trained individuals [5,34]. The mechanism(s) by which RMT ameliorates exertional breathlessness remains speculative, but is probably linked, in part, to the improved force generating capacity of the respiratory muscles after training. Killian et al. [22] has argued that breathlessness is a function of respiratory effort. Thus, it is reasonable to suggest that enhancing respiratory muscle function may reduce the effort sensation associated with a given level of ventilation, thereby reducing the perception of breathlessness.

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An ergogenic effect of RMT has also been demonstrated in both endurance trained and untrained individuals [3–5,9,15,23,17,34]. These previous studies have, without exception, focussed upon endurance exercise and none have considered the potential role of RMT in recovery following intense whole body and respiratory work. Thus, the question of whether RMT improves performance in repetitive sprint activity remains unanswered.

We hypothesized that, by its action on inspiratory effort sensation, specific inspiratory muscle training (IMT) would hasten recovery time between successive sprints, but would have no influence upon sprint performance *per se*. Thus, the aims of the present study were: 1) to evaluate a new field test designed specifically to assess recovery time during repeated sprint activity, 2) to examine the influence of specific IMT upon recovery time during the repetitive sprint test, and 3) to determine the physiological and perceptual responses to fixed intensity shuttle running.

Materials and Methods

Participants

Following local ethics committee approval and written informed consent, 24 male repetitive sprint sport players participated in the study. The sports represented in the study were soccer (n = 17), rugby (n = 4), field hockey (n = 2) and basketball (n = 1). The playing standard of individuals was at least amateur club level, although the majority of individuals also played county level or above. All participants were non-smokers (self-report) with normal lung function. Descriptive characteristics of the participant group pre-IMT are presented in Table **1**.

Table **1** Descriptive and physical characteristics of the participants (mean ± SEM)

	IMT[a]	*Placebo*[a]
Age (y)	21.3 ± 1.1	20.2 ± 0.7
Stature (m)	1.74 ± 0.02	1.77 ± 0.01
Body mass (kg)	72.2 ± 1.7	75.0 ± 2.2
Sum of 4 skinfolds (mm)	32.6 ± 1.5	32.9 ± 2.8
Estimated body fat (%)	13.4 ± 0.8	12.8 ± 0.9
Estimated $\dot{V}O_2$max ($ml \cdot kg^{-1} \cdot min^{-1}$)	56.3 ± 0.9	55.8 ± 1.7

Note: [a] n = 12. $\dot{V}O_2$max, maximal oxygen uptake. Body density was estimated from the sum of four skin-fold sites based on the procedures of Durnin and Womersley [8], and estimated percentage body fat was calculated using the equation of Siri [22]

General design

A double-blind, placebo-controlled design was utilized whereby participants were randomly assigned to either an experimental (IMT) or placebo (sham-IMT) group. Pre-intervention trials (requiring 2 visits) were repeated within a 2 wk period. Post-IMT trials (also requiring 2 visits) were conducted 6 wk later and all visits were separated by at least 48 h. All procedures were conducted in accordance with ethical standards of the Committee on Human Experimentation at the host institution and with the Helsinki Declaration of 1975.

Procedure

Participant preparation and testing environment

Testing took place during a maintenance phase of normal training so that the confounding influence of whole-body training-induced changes would be minimized. Each test was scheduled at the same time of day in order to minimize the effect of diurnal fluctuation. Participants were advised not to engage in strenuous activity two days before an exercise test and not to exercise on the day of a test. Individuals were requested to maintain their normal diet in the few days preceding an exercise test, to refrain from alcohol two days before a testing session, and to avoid caffeinated beverages on a test day. Subjects recorded food intake and exercise for 48 h before the first trial, then used the records to replicate these activities before subsequent trials.

Pulmonary function

Forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), peak expiratory flow (PEF), peak inspiratory flow (PIF) and maximum voluntary ventilation measured over 15 s (MVV) were determined using a portable pneumotachograph spirometer (Vitalograph 2120, Buckingham, U.K.). Measurements were made according to European Respiratory Society recommendations [26].

Respiratory muscle strength

Respiratory muscle strength was assessed using a portable handheld mouth pressure meter (Precision Medical Ltd., Pickering, North Yorks, U.K.) for the determination of maximum static inspiratory (MIP) and expiratory (MEP) pressures. Subjects performed 10 maximal efforts at 30 s intervals from residual volume for MIP [25], or total lung capacity for MEP, and the highest value for each was retained.

Repetitive sprint performance

The repetitive sprint test consisted of fifteen 20 m sprints with a maximum of 30 s passive recovery between each sprint. Following a standardised warm-up and prior to the start of the actual test, a representative best sprint performance was determined from the best of 3 sprints performed 30 s apart. The test was performed in an indoor gymnasium and only one subject was tested at a time. Prior to the test, participants were presented with standard written instructions advising them to maintain maximal sprint performance whilst taking as little rest as possible between sprints and it was impressed upon them that one of the performance criteria was the total duration of rest taken. Subjects were told that failure to maintain sprint time within 10% of the initial best sprint time would result in failure of the test. In reality, the time was merely recorded and the individual was encouraged to do better if sprint performance was dropping. Although subjects were not verbally encouraged during the actual test, they were given a countdown of the duration of recovery every 5 s up to 30 s when the instruction to start the next sprint was given. Sprints were automatically timed to the nearest 0.01 s by two infrared photoelectric cells interfaced to a timing system (Eleiko Sport AB, Sweden) and were initiated one meter behind electronic timing gates. Total test time was manually recorded to the nearest 0.01 s with a stopwatch. Performance was assessed by calculating a total sprint time (i.e., "sprint time 1" plus "sprint time 2", etc.) and a total recovery time ("total test time" minus "total sprint time") for all 15 sprints and each set of 5 sprints.

Physiological demands of the repetitive sprint test

The physiological demands of the repetitive sprint test were assessed using a separate group of individuals (n = 3) familiar with performing the test and with similar physical and performance characteristics as the experimental group. Minute ventilation ($\dot{V}_E$) was measured breath-by-breath during the repetitive sprint test and a multistage shuttle run test (see below) with a portable respiratory system (Cortex MetaMax 3B, Leipzig, Germany) and analysed using dedicated software (Cortex MetaSoft 1.2, Leipzig, Germany). Heart rate (f_c) was recorded throughout the tests via telemetry (Vantage NV, Polar Electro Oy, Finland). Upon completion of the repetitive sprint test capillary blood was sampled from an earlobe every 1.5 min up to 15 min post-exercise for subsequent determination of peak $[La^-]_B$ (YSI 1500 Sport, Ohio, USA). Ratings of respiratory and peripheral exertion were recorded immediately after completion of the final sprint using Borg's modified CR10 scale [2].

Physiological response to fixed intensity shuttle running

Following a standardised warm-up, subjects completed 20 min of shuttle running over a 20 m course. The test was performed at 80% of the speed attained upon termination of a maximum multistage shuttle run test [24]. The speed was calculated by interpolation from the total number of shuttles completed in the final stage of the multistage shuttle run test. Pacing was provided by audible cues emitted every 20 m at pre-programmed intervals by a microcomputer. The criterion for stopping subjects was if they were unable to keep within 2 m of the end lines on 3 consecutive occasions. After every 5 min and upon test termination, subjects stopped briefly (< 30 s) for blood sampling from an earlobe for subsequent determination of whole blood lactate concentration (YSI 1500 Sport, Ohio, USA). A modified version of the CR10 scale [2] was used to produce a symptom profile of perceived exertion every 5 min when subjects stopped for blood drawing. Subjects were instructed to give a differentiated response relative to sensations of breathing and peripheral (i. e., legs) effort. Heart rate (f_c) was recorded every 5 s by telemetry (Polar Vantage NV, Polar Electro Oy, Finland) and mean f_c for the final minute of each 5 min period was derived using dedicated software (Polar Precision Performance 2.0, Finland). The post-IMT trial was conducted at the same absolute intensity as the pre-IMT trial.

Inspiratory muscle training

Participants were ranked according to inspiratory muscle strength (MIP) and subsequently divided into matched pairs. One individual of each pair was randomly assigned to the experimental group by an independent observer and the remaining individual was assigned to the control condition. The principle investigators were therefore blinded to the training condition. The IMT group performed 30 dynamic inspiratory efforts twice daily for 6 wk against a pressure-threshold load equivalent to 50% MIP, a protocol known to be effective in eliciting an adaptive response [6]. The placebo group trained using 60 slow protracted breaths once daily for 6 wk at 15% MIP, a protocol known to induce minimal changes in inspiratory muscle function [5]. Loading characteristics of the IMT device (POWERbreathe®, IMT Technologies Limited, U.K.) have been documented [7]. Following the initial setting of training loads, subjects in the experimental group were instructed by an independent observer to periodically increase the load to a level that would permit them to only just complete 30 manoeuvres; the placebo group subjects were not given these instructions. Subjects were told they were participating in a study to compare the influence of strength (IMT group) versus endurance (placebo group) protocols and, as a consequence, were blinded to the true purpose of the study and the expected outcomes. Subjects were instructed to cease training 48 h prior to post-IMT trials. All subjects completed IMT and physical activity diaries throughout the study. The intensity of participants' physical activity was assessed using self-rated dyspnoea and sweating responses, which were reported on a 5 point Likert-scale.

Data analyses

Mixed factorial ANOVA was used to test for between group effects due to "treatment" (IMT or placebo) and within group effects due to "time" (pre- and post-treatment) and "set" time during fixed intensity shuttle running (1 to 4) on each of the dependent variables. Planned pairwise comparisons were made with repeated measures *t*-tests and the Bonferroni adjustment was used to modify the *per family type* I error rate per comparison. Pearson product moment correlation coefficients were computed to assess the degree of relationship between the relative changes in selected physiological variables following IMT. Reliability of test measures between the two pre-intervention trials for all 24 subjects was assessed using the coefficient of variation (CV), intraclass correlation and 95% ratio limits of agreement. A post-hoc power analysis on the within-between interaction effect was computed using dedicated software (GPOWER Version 2, Bonn, Germany). Unless stated otherwise, results are expressed as mean ± standard error of the mean (SEM). An alpha level of 0.05 was chosen *a priori* to represent statistical significance. Statistical analyses were performed using the 8.0 release version of SPSS for Windows (SPSS Inc., Chicago IL, USA).

Results

Physiological demands of the repetitive sprint test

A marked physiological response was observed in the separate group of individuals examined (n = 3). For example, median (range) values for peak $[La^-]_B$, and ratings of perceived respiratory and peripheral effort were 8.6 (8.0 – 9.1) $mmol \cdot L^{-1}$, 10.0 (9.0 – 10.0) and 10.0 (9.0 – 10.0), respectively. Values for $\dot{V}_E$ and f_c represented a significant proportion of the maximum physiological response elicited during the multistage shuttle run test (median 81 and 90%, respectively). As expected, $\dot{V}_E$ and f_c were driven higher with each successive sprint (see Table **2**).

Table **2** Physiological demands of the repetitive sprint test (n = 3)

Sprint No.	$\dot{V}_E$ *(%$\dot{V}_E$max)*	f_c *(%$f_c$max)*
1 – 5	63 (36 – 74)	84 (74 – 97)
6 – 10	87 (86 – 88)	95 (91 – 98)
11 – 15	93 (84 – 100)	96 (92 – 100)
Mean	81 (74 – 82)	90 (89 – 95)

Note: $\dot{V}_E$, minute ventilation; f_c, heart rate.
Values are median (range).

Reproducibility of the repetitive sprint test

The within subject coefficient of variation and intraclass correlation coefficient for total recovery time was 4.5% (95% CI = 3.5 to 6.8%) and 0.95 (95% CI = 0.87 to 0.98), respectively. The systematic bias ratio (i.e., general learning effects) for the 95% ratio limits of agreement was 1.02, multiplied or divided by the random error ratio (i.e., biological or mechanical variation) of × / ÷ 1.07 – that is, 95% of the ratios (measurement 1 divided by measurement 2) should be contained between 0.95 and 1.09. As an example, if a subject's total recovery time was 371 s on the first test (the slowest time for the group studied), it is possible (worst case scenario) that the same subject could obtain a result as low as 353 s, or as high as 404 s, on the second test. For a subject with a higher performance on the first test at 163 s (the fastest time for the group studied), the re-test would be as low as 155 s or as high as 178 s. Standard errors for the bias and random error components of the ratio limits of agreement were 0.01 (95% CI = 0.01 to 0.04) and 0.01 (95% CI = 0.93 to 0.98 and 1.07 to 1.12 for lower and upper limits, respectively).

Habitual physical exercise and IMT compliance

The intensity, frequency and duration of participants' physical activity did not vary between or within groups ($p > 0.05$). Based on self-report, the experimental group completed 69 ± 4 of the 84 training sessions (82% adherence) whilst the control group completed 37 ± 3 of the 42 sessions (88% adherence). Dose-response relationships were observed for the experimental group between the number of completed training sessions and the relative changes in MIP ($r = 0.83$, $p \leq 0.01$) and PIF ($r = 0.62$, $p \leq 0.05$).

Pulmonary and respiratory muscle function

All pulmonary function values were within predicted normal limits for healthy adults based on sex, age and stature (see Table **3**). Pre-IMT measures did not differ significantly between the experimental and control groups ($p > 0.05$). For the placebo group, none of the pulmonary or respiratory muscle function measures were significantly different following the 6 wk of sham training (pre-IMT 2 vs. post-IMT). In contrast, significant improvements in MIP (30.5 ± 2.2%) and PIF (20.3 ± 2.3%) were observed in the IMT group. No other measures changed significantly post-IMT. Significant positive relationships were observed between the relative change in MIP and PIF ($r = 0.74$; $p \leq 0.05$) and total recovery time ($r = 0.84$; $p \leq 0.01$). Although IMT failed to improve MVV, a significant relationship was noted for the relative change in PIF and MVV ($r = 0.59$; $p \leq 0.05$). Furthermore, a positive relationship was observed for the relative change in PIF and respiratory RPE ($r = 0.74$; $p \leq 0.01$).

Repetitive sprint performance

The IMT and placebo groups did not improve total sprint time following intervention (47.7 vs. 47.7 s and 47.8 vs. 47.9 s for pre- vs. post-IMT and -control; $p > 0.05$). In contrast, total recovery time was reduced by a mean of 6.9 ± 1.3% in the IMT group (243.9 ± 9.2 vs. 227.2 ± 9.0 s for pre- and post-IMT, respectively; range = –0.9 to 14.5%; $p \leq 0.01$). Corresponding values for the placebo group were 0.7 ± 1.3% (249.4 ± 16.5 vs. 246.6 ± 14.7 s for pre- and post-placebo, respectively; $p > 0.05$). The improvement in total recovery time was 6.2 ± 1.1% greater for the IMT group compared to the placebo group ($P = 0.006$). Post-hoc analysis on the within-between subject interaction (assuming a moderate effect size of 0.25) revealed adequate statistical power ($1-\beta = 0.91$). Improvements in total recovery time for repetitions 1 – 5 (3.8%), 6 – 10 (6.4%) and 11 – 15 (7.5%) were most pronounced in the IMT group although only repetitions 6 – 10 and 11 – 15 reached statistical significance ($P = 0.004$ and 0.001, respectively) (see Fig. **1**).

Table **3** Pulmonary and respiratory muscle function for experimental and control groups (mean ± SEM)

	IMT[a]		*Placebo*[a]	
	Pre-IMT	***Post-IMT***	***Pre-IMT***	***Post-IMT***
FVC(L)	5.63 ± 0.09 (109 ± 1)	5.72 ± 0.09 (111 ± 1)	5.91 ± 0.15 (110 ± 2)	5.87 ± 0.15 (109 ± 2)
FEV_1 (L)	4.81 ± 0.10 (109 ± 1)	4.81 ± 0.11 (109 ± 2)	4.98 ± 0.13 (109 ± 2)	4.93 ± 0.12 (108 ± 2)
FEV_1/FVC (%)	85.4 ± 1.2 (100 ± 1)	84.1 ± 1.4 (98 ± 2)	84.2 ± 0.7 (99 ± 1)	84.1 ± 0.7 (99 ± 1)
PEF ($L \cdot min^{-1}$)	631.1 ± 14.1 (105 ± 2)	621.2 ± 12.3 (104 ± 2)	660.1 ± 17.6 (108 ± 3)	653.5 ± 16.7 (107 ± 2)
PIF ($L \cdot min^{-1}$)	512.2 ± 8.7 (95 ± 2)	614.4 ± 10.4** (114 ± 4)	526.4 ± 22.5 (96 ± 4)	529.2 ± 22.8 (96 ± 4)
MVV ($L \cdot min^{-1}$)	186.3 ± 4.0 (101 ± 2)	191.0 ± 4.2 (103 ± 2)	190.3 ± 3.9 (101 ± 1)	189.7 ± 3.7 (101 ± 1)
MIP ($-cmH_2O$)	130.3 ± 3.7	173.8 ± 6.0**	133.4 ± 3.6	134.3 ± 3.8
MEP (cmH_2O)	171.8 ± 3.9	173.6 ± 4.3	174.1 ± 3.2	173.3 ± 2.9

Note: [a] n = 12; FVC, forced vital capacity; FEV_1, forced expiratory volume in one second; PEF, peak expiratory flow; PIF, peak inspiratory flow; MVV, maximum voluntary ventilation; MIP, maximum inspiratory mouth pressure; MEP, maximum expiratory mouth pressure. Values in parentheses represent predicted values based on age, stature and gender (Quanjer et al., 1993). **significantly different from pre-IMT values ($p \leq 0.01$).

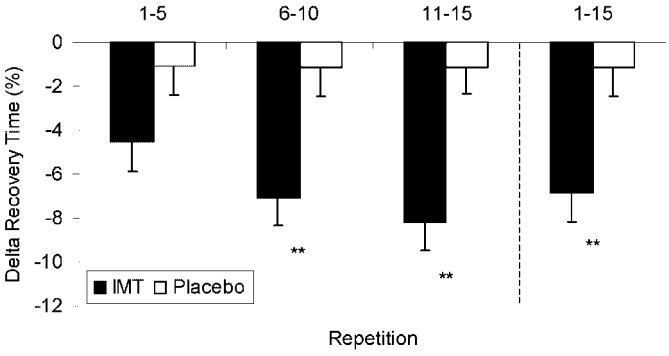

Fig. **1** Relative changes in cumulative recovery time during repetitive sprint test for IMT and placebo groups (Mean ± SEM). Note: **$p \leq 0.01$.

Maximal incremental running

Maximum speed attained during the multistage shuttle run test post-IMT was not different from pre-IMT values for either placebo (3.83 ± 0.06 vs. 3.84 ± 0.07 $m \cdot s^{-1}$; $p > 0.05$) or IMT groups (3.89 ± 0.04 vs. 3.86 ± 0.13 $m \cdot s^{-1}$; $p > 0.05$). Consequently, post-IMT values for estimated $\dot{V}O_2max$ were not different from pre-IMT values for either placebo (55.7 ± 1.6 vs. 55.8 ± 1.7 $ml \cdot kg^{-1} \cdot min^{-1}$; $p > 0.05$) or IMT groups (57.1 ± 1.0 vs. 56.3 ± 0.9 $ml \cdot kg^{-1} \cdot min^{-1}$; $p > 0.05$). Similarly, maximum heart rate post-IMT was not different from pre-IMT for either placebo (195 ± 1 vs. 195 ± 1 beats $\cdot min^{-1}$) or IMT groups (197 ± 2 vs. 196 ± 2 beats $\cdot min^{-1}$).

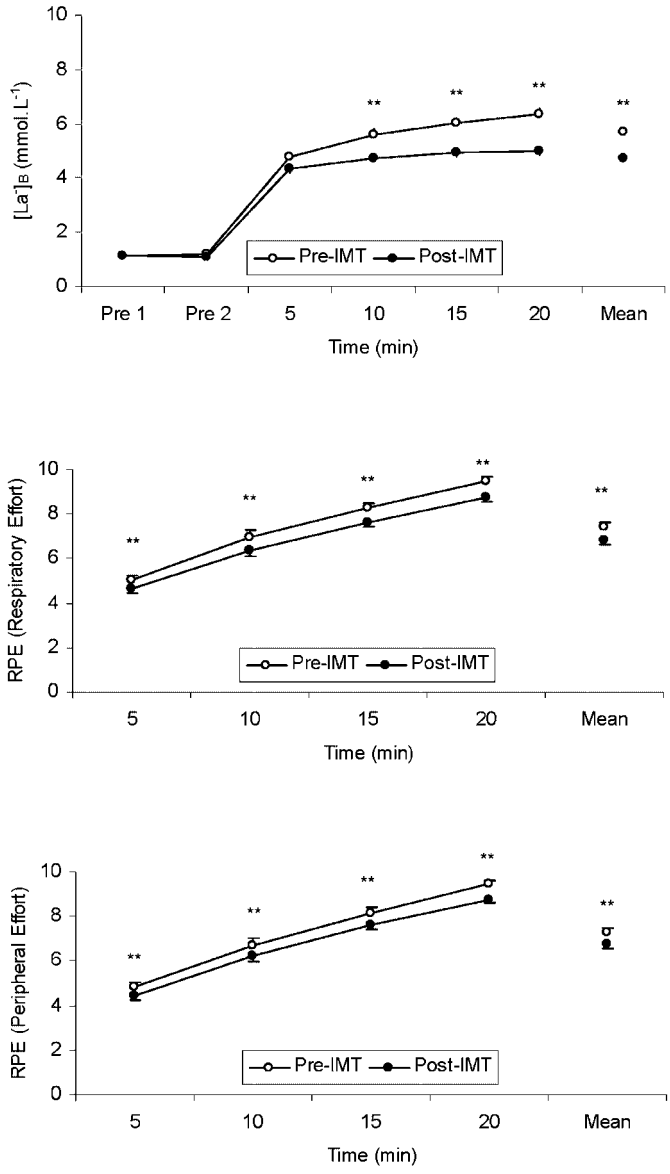

Fig. **2** Changes in blood lactate (top panel), respiratory effort (middle panel) and peripheral effort (bottom panel) during shuttle run test for IMT group (Mean ± SEM). Note: **p ≤ 0.01.

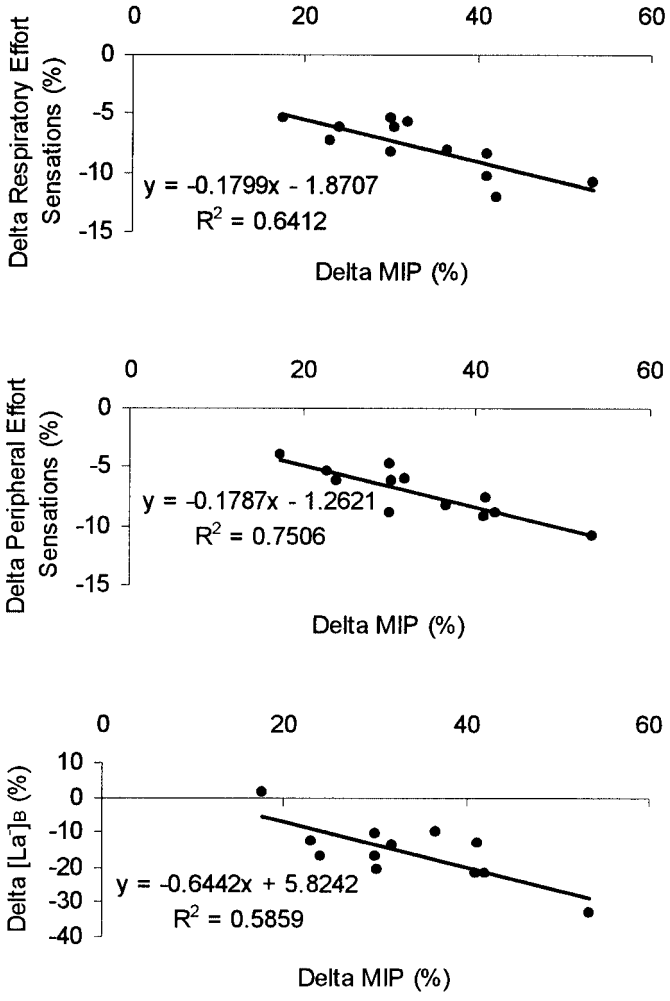

Fig. **3** Change in maximum inspiratory pressure (MIP) versus respiratory effort (top panel), peripheral effort (middle panel) and blood lactate concentration (bottom panel). Note: all correlation coefficients significant ($p \leq 0.05$).

Physiological response to fixed intensity shuttle running

All subjects were able to complete the 20 min of exercise. There were no significant changes in the placebo group. In contrast, perceptual and $[La^-]_B$ responses to submaximal exercise were attenuated post-intervention in the IMT group (see Fig. **2**). Respiratory RPE and peripheral RPE were reduced by 7.9 ± 0.6 ($p \leq 0.01$) and 7.2 ± 0.6% ($p \leq 0.01$), respectively, compared to pre-IMT. Mean $[La^-]_B$ was 15.7 ± 2.9% lower compared to pre-IMT ($p \leq 0.01$). There were significant correlation coefficients between the relative change in MIP and respiratory RPE ($r = -0.80$, ≤ 0.01), peripheral RPE ($r = -0.87$, $p \leq 0.01$) and $[La^-]_B$ ($r = -0.77$, $p \leq 0.01$) (Fig. **3**). Furthermore, the relative change in the sprint test total recovery time was significantly correlated with respiratory RPE ($r = 0.64$, $p \leq 0.05$), peripheral RPE ($r = 0.75$, $p \leq 0.01$) and $[La^-]_B$ ($r = 0.72$, $p \leq 0.01$) (Fig. **4**).

Discussion

Main findings

The purpose of the present study was to determine the influence of specific IMT upon recovery during high intensity, repetitive sprint activity. The main findings suggest that IMT improved high intensity, intermittent exercise performance (manifest as a reduction in recovery time between repeated sprints) and attenuated the blood lactate and perceptual responses to submaximal endurance exercise. To the authors' knowledge, this is the first study to assess the influence of IMT upon any aspect of high intensity, repetitive sprint exercise. The finding of an attenuated physiological response to submaximal shuttle running supports previous laboratory-based studies investigating the influence of RMT upon time to exhaustion during constant load cycling [3–5,9,15,17,30,32] and maximal rowing [39].

Relevance and reliability of the repetitive sprint test

Direct assessment of the physiological responses to our repetitive sprint test in three subjects confirmed that it induced large changes in $\dot{V}_E$, f_c and $[La^-]_B$, as well as breathing and peripheral perceptual ratings. Thus, it provides a significant physiological

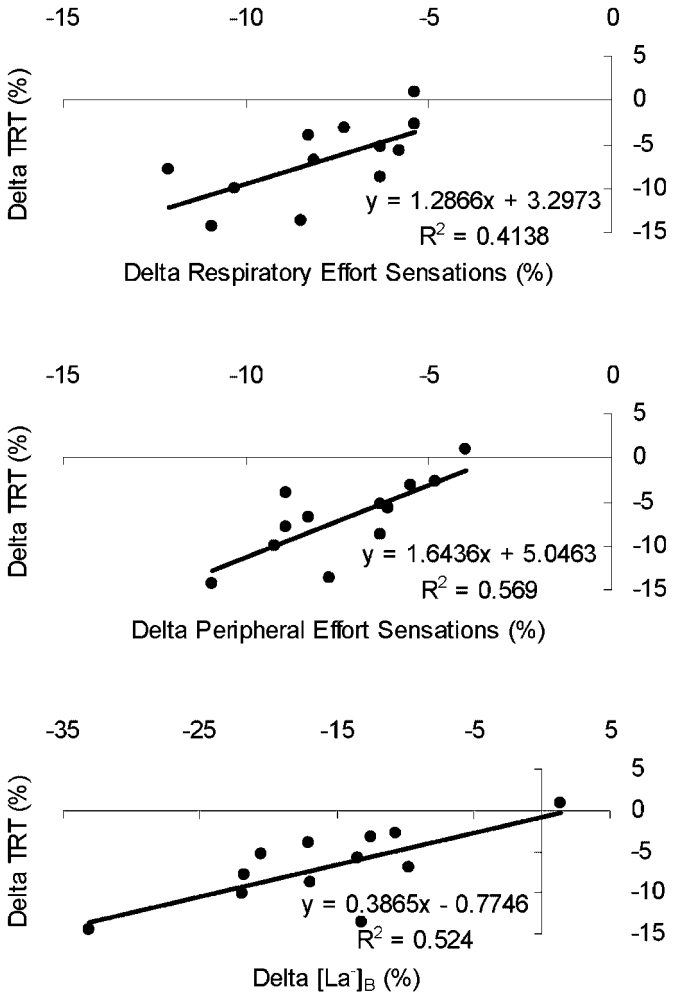

Fig. **4** Change in total recovery time (TRT) versus respiratory effort (top panel), peripheral effort (middle panel) and blood lactate concentration (bottom panel). Note: all correlation coefficients significant ($p \leq 0.05$).

challenge and its design (20 m sprints followed by self-selected rest) makes it relevant to repetitive sprint sports. However, it remains one step removed from actual match play or game situations and the data must be viewed accordingly.

Several studies have failed to demonstrate an ergogenic effect with IMT in healthy individuals and this may be partly explained by large inter-individual variances in exercise performance coupled with small sample sizes. The small relative variability of the participant group over its distribution on total recovery time (CV = 3.5 – 6.8 %) suggests that our repetitive sprint test can be used reliably to detect small differences in exercise performance. Whilst there is a dearth of data regarding test-retest reliability of repetitive sprint performance measures, the reliability coefficients for mean total recovery time determined in the present study do compare favourably with the results of previous investigations [8,14].

Changes in respiratory muscle function

The significant increases in MIP and PIF, but not MEP or PEF in the IMT group, suggest that the improvements represent a genuine training response. The magnitude of improvement in MIP for the IMT group (31 %) is consistent with previous studies in healthy subjects using pressure-threshold IMT, ranging from 23 to 45 % [5,6,19]. Furthermore, the finding of a dose-response relationship for the IMT group (number of completed training sessions) is in agreement with research in patients [35].

The manoeuvre utilized by subjects undertaking the current IMT intervention was characterized by a combination of inspiratory pressure and flow. Thus, the finding of a significant increase in MIP and PIF is in accordance with the pressure-flow specificity of IMT [33] and confirms the results from previous investigations utilizing pressure-threshold IMT [5]. That change in MIP should account for ~ 55 % of the variance in PIF is perhaps not surprising given the functional crossover between maximum force generation and maximum shortening velocity.

Changes in exercise performance

We did not anticipate any alteration in actual sprint performance in response to IMT, and this was confirmed by our data. Repeated sprint performance over 20 m is determined by a variety of factors, but predominantly those related to the phosphocreatine and anaerobic glycolytic systems. Previous studies of IMT have identified reductions in blood lactate concentration during post-IMT exercise trials [5,15,30]. However, our subjects showed no deterioration in sprint performance as the sprints progressed. Thus, for IMT to influence actual sprint performance it would have been necessary for post-IMT sprints to have been faster at all repetitions, including the first, and there are no physiological reasons to suppose that this should be the case.

Our finding that IMT shortened recovery time during a repeated sprint test is new, but consistent with our original hypothesis. We are confident that the observed improvement was a genuine response since post-hoc analysis on the within-between subject interaction (assuming a moderate effect size of 0.25) revealed adequate power ($1\text{-}\beta = 0.91$). Since the level of the subjects' habitual physical activity did not change throughout the study and $\dot{V}O_2$max estimated from the multistage shuttle run test remained unchanged, it is unlikely that either the improvements in inspiratory muscle function or physiological response to exercise can be ascribed to whole-body training-induced changes. The mechanism(s) by which IMT improves the recovery time during repetitive sprint activity is, as yet, unclear. There are a number of possible mechanisms and it is perhaps relevant to speculate upon these in light of our present data.

Attenuated respiratory and peripheral effort sensations

The significant relationships observed between relative changes in inspiratory muscle function, perceived exertion and total recovery time suggest that respiratory and/or peripheral effort sensations played a major role in improving repetitive sprint performance. Indeed, changes in inspiratory muscle strength, respiratory RPE and peripheral RPE accounted for ~71, 41 and 52 % of the total variance for the relative change in total recovery time, respectively.

There is preliminary evidence that RMT leads to overall dyspnoea abatement in clinical populations [1], healthy sedentary [10,11,29,32] and endurance trained individuals [5,34]. Thus, it is reasonable to suggest that a reduction in the intensity of dyspnoea and/or acceleration in the decay of its intensity following IMT may have had a positive influence upon total recovery time

between successive sprints. This suggestion is supported by the significant correlation between the change in total recovery time and the change in respiratory RPE.

Inspiratory muscles are functionally weakened during exercise due to the direct result of the larger tidal volume and flow rate required to meet an increased ventilatory drive [20]. As muscles weaken, a given level of tension represents a relatively greater percentage of the maximum tension that can be developed and the respiratory effort required to generate a given level of inspiratory muscle tension is correspondingly increased [27]. Studies that have specifically trained the inspiratory muscles of healthy individuals have observed significant increases in inspiratory muscle strength, such that a smaller fraction of maximum tension is generated with each breath [21]. Moreover, concomitant reductions in the motor output to the respiratory muscles and the perceived sense of respiratory effort were observed [21]. In the present study, both the force (MIP) and velocity (PIF) of inspiratory muscle contraction increased significantly. Thus, it is likely that the relative demands placed on the ventilatory system, assuming a similar level of ventilation [30,34], were reduced post-IMT. Consequently, the magnitude of perceived respiratory effort for a given submaximal contraction velocity would correspondingly be reduced [13]. Inspiratory muscle fatigue also results in an increase in the perceived magnitude of respiratory effort [11]. Thus, it is possible that subjects in the present study improved recovery time as a result of concomitant reductions in inspiratory muscle fatigue and respiratory effort sensations. Indeed, recent evidence from our laboratory suggests that pressure threshold IMT attenuates inspiratory muscle fatigue following short-term high intensity exercise in healthy individuals [34].

In addition to the effects of specific IMT upon respiratory effort sensations during whole body exercise, it is possible that IMT mediated its influence upon the intensity of exertional perceptions via peripheral mechanisms. The fixed intensity run was performed at the same speed pre- and post-intervention, and blood lactate concentration was significantly reduced at all time points following IMT. This finding concurs with the results from previous investigations into the effects of specific RMT upon the physiological response to constant load submaximal exercise [5,15,30]. That changes in MIP should account for ~59% of the variance in blood lactate suggests that changes in inspiratory muscle function following IMT were linked with the attenuated metabolic response. It is important to note, however, that the correlation between the changes in inspiratory muscle strength (MIP) and blood lactate concentration was primarily the result of two "extreme" values which suggests that this mechanism may only come into effect when large changes are experienced in inspiratory muscle function (see Fig. **3**). It is generally accepted that exercise performance is impaired when lactate removal is surpassed by its rate of production. Accordingly, it is reasonable to speculate that reduced blood lactate concentration to a magnitude commensurate with "steady state" conditions might improve exercise capacity. A significant relationship was observed between the relative change in total recovery time and mean blood lactate concentration during the fixed intensity run, although this relationship also seemed to be the result of two "extreme" values in the data series. Nevertheless, the significant relationship between the relative change in blood lactate and peripheral RPE is consistent with investigations which support blood pH as a potent mediator of exertional perceptions, especially at exercise intensities that equal or exceed the lactate threshold [23]. Taken together these findings suggest that specific IMT may be associated with a reduction in the intensity of peripheral effort sensations via favourable changes in acid base balance.

Blood flow to exercising muscle determines the availability of energy substrates for exercise metabolism. Inadequate perfusion of tissue limits metabolism, inducing fatigue and intensifying the peripheral perceptual signal [31]. Conversely, improvements in blood flow to exercising muscle would be expected to reduce the intensity of peripheral effort sensations. Experimental evidence suggests that unloading the inspiratory muscles during high intensity exercise (>85% $\dot{V}O_2$max) improves endurance capacity [18]. Those authors proposed that a redistribution of blood flow from respiratory muscles to locomotor muscles was responsible for the improvement in exercise capacity. If IMT's effect is to delay the recruitment of accessory muscles and/or improve accessory muscle function, this might lead to reduced chest wall distortion and improved efficiency of breathing, which in turn might translate into a lower work of breathing and a reduced metabolic and blood flow demand by the inspiratory muscles. The consequence of a lower inspiratory muscle blood flow demand may be improved locomotor perfusion and a correspondingly lowered circulating blood lactate concentration.

Conclusion

In conclusion, we have assessed the reproducibility and sensitivity of a new repetitive sprint test and found it to have utility for repetitive sprint athletes. Our data support existing evidence that specific IMT attenuates the blood lactate and perceptual responses to submaximal endurance exercise. Furthermore, the data provide new evidence that IMT improves recovery time during high intensity, intermittent exercise in repetitive sprint athletes.

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