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ORIGINAL ARTICLE

Inspiratory muscle training improves 100 and 200 m swimming performance

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Abstract Inspiratory muscle training (IMT) has been shown to improve time trial performance in competitive athletes across a range of sports. Surprisingly, however, the effect of specific IMT on surface swimming performance remains un-investigated. Similarly, it is not known whether any ergogenic influence of IMT upon swimming performance is confined to specific race distances. To determine the influence of IMT upon swimming performance over 3 competitive distances, 16 competitive club-level swimmers were assigned at random to either an experimental (pressure threshold IMT) or sham IMT placebo control group. Participants performed a series of physiological and performance tests, before and following 6 weeks of IMT, including (1) an incremental swim test to the limit of tolerance to determine lactate, heart rate and perceived exertion responses; (2) standard measures of lung function (forced vital capacity, forced expiratory volume in 1 s, peak expiratory flow) and maximal inspiratory pressure (MIP); and (3) 100, 200 and 400 m swim time trials. Training utilised a hand-held pressure threshold device and consisted of 30 repetitions, twice per day. Relative to control, the IMT group showed the following percentage changes in swim times: 100 m, −1.70% (90% confidence limits, ±1.4%), 200 m, −1.5% (±1.0), and 400 m, 0.6% (±1.2). Large effects were observed for MIP and rates of perceived exertion. In conclusion, 6 weeks of IMT has a small positive effect on swimming performance in club-level trained swimmers in events shorter than 400 m.

Keywords Respiratory muscles · Performance · Breathing

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Introduction

Competitive surface swimming requires the ability to tightly regulate breathing pattern at volumes and flow rates that are much higher than during terrestrial exercise. Accordingly, well-conditioned inspiratory and expiratory musculature is a pre-requisite for maintenance of efficient stroke mechanics. As previously highlighted by Wells et al. (2005), the demands upon the respiratory muscles include (1) a reduced duty cycle due to controlled frequency breathing (Town and Vanness 1990), (2) the need to expand the chest wall against the additional pressure incurred as a result of submersion in water (Hong et al. 1969), (3) increased flow resistive load due to the high flow rates during inspiration and expiration (Courteix et al. 1997; Kohl et al. 1997), and (4) increased respiratory muscle contraction velocity and increased tidal volume (Dicker et al. 1980) and (5) potential dual use of the accessory respiratory muscles to aid the swimming stroke. Indeed, evidence suggests that swimming is a uniquely demanding sport for the inspiratory muscles. Lomax and McConnell (2003) reported that that a single 200 m front-crawl swim, corresponding to 90–95% of race pace, was sufficient to induce profound inspiratory muscle fatigue [~29% decrement in post-exercise maximal inspiratory pressure, (MIP)] in less than 2.7 min. This is the largest magnitude of exercise-induced inspiratory muscle fatigue so far documented, as well as occurring in the shortest time so far assessed. Furthermore, swim training has also been shown to induce improvements in inspiratory muscle function (Mickleborough et al. 2008), which supports the notion that there are uniquely demanding challenges imposed by swimming upon the inspiratory muscles.

It is now well documented that specific inspiratory muscle training (IMT) enhances exercise performance in untrained (Edwards and Cooke 2004; Gething et al. 2004; Sheel 2002) and trained individuals across a range of endurance sports (Edwards et al. 2008; Griffiths and McConnell 2007; Johnson et al. 2007; Romer et al. 2002a; Volianitis et al. 2001), as well as during repeated sprinting (Romer et al. 2002b; Tong et al. 2008). Given the uniquely challenging nature of swimming, it is therefore surprising that there have been no studies to date examining the influence of specific IMT upon swimming performance. The only study to examine respiratory muscle training did so by implementing concurrent, simultaneous inspiratory and expiratory muscle training, but the study failed to generate significant improvements in swim performance in the group as a whole (males and females) (Wells et al. 2005). Hence, the aim of this study was to determine the effect of specific IMT upon swimming time trial performance over a range of standard competitive swimming distances.

Table 1 Descriptive baseline (pre-intervention) characteristics of participants (mean ± SD)

	EXP (N = 8, 5 M, 3 F)	CON (N = 8, 5 M, 3 F)
Anthropometry		
Age (years)	19.1 ± 2.6	19.0 ± 2.1
Height (cm)	176.5 ± 4.0	180.5 ± 6.5
Body mass (kg)	71.1 ± 3.2	73.4 ± 8.1
Training history (years)	7.8 ± 3.1	8.1 ± 2.9
Pulmonary function		
FVC (L)	5.2 ± 0.7	5.4 ± 1.2
FEV_1 (L)	4.3 ± 0.5	4.5 ± 0.9
PEF (L s^{-1})	5.5 ± 0.8	5.3 ± 1.0
MIP (cm H_2O)	115 ± 26	117 ± 30
Incremental step test		
V_{LT} (m s^{-1})	1.37 ± 0.14	1.38 ± 0.15
V_{max} (m s^{-1})	1.47 ± 0.13	1.51 ± 0.14
HR_{LT} (b min^{-1})	161 ± 9	163 ± 11
HR_{max} (b min^{-1})	191 ± 11	190 ± 11
Stroke parameter		
SR_{100} (strokes min^{-1})	47.4 ± 4.2	48.2 ± 5.4
SR_{200} (strokes min^{-1})	43.7 ± 5.1	44.0 ± 4.1
SR_{400} (strokes min^{-1})	41.3 ± 5.5	41.9 ± 5.9

FVC forced vital capacity, FEV_1 forced expiratory volume in 1 s, *PEF* peak expiratory flow, *MIP* maximal inspiratory pressure, V_{LT} velocity at lactate threshold, V_{max} maximal incremental velocity, *SR* stroke rate

Methods

Subjects

Sixteen club-level competitive swimmers (ten males, six females) participated. Participant characteristics are presented in Table 1. The athletes' swim specialities were 50/100 m (n = 5), 200/400 m (n = 9) and 800/1,500 m (n = 2) events. All procedures were approved by the institutional ethics committee. All participants were non-asthmatics with no evidence of respiratory restriction or obstruction upon examination of pre-intervention maximum flow-volume loops. All participants consented to the requirements of the study in writing.

Experimental design

The study was conducted during the early competitive season. Participants were divided into matched-pairs based on their pre-intervention incremental step test performance, and subsequently assigned randomly to an experimental (EXP) group or placebo control (CON) group. The EXP group performed IMT twice daily for 6 weeks while the CON group performed sham IMT. Before the IMT intervention participants preformed a range of physiological tests and performance trials. During sessions one to three, participants completed familiarisation tests for measures of dynamic lung function, maximal inspiratory pressure as well as performing three practice swimming performance time trials (TT) on separate days. These initial performance trials were not used for analysis. Session four involved an incremental swimming step test to the limit of tolerance. Sessions five to seven involved three swimming performance TT (baseline measures), in random order, each separated by 48 h. After the 6 weeks IMT intervention, participants repeated all tests and swimming performance TT. Prior to all tests and performance trials, participants were requested to abstain from heavy physical exercise and ingestion of caffeine for at least 24 h and prepare in their usual way for competition.

Procedures

Dynamic lung function measures

Pulmonary function (forced flow-volume loops) was assessed using an on-line turbine spirometer (Microlab, MicroMedical, Kent, UK). Measurements were made according to the American Thoracic Society and European Respiratory Society recommendations (Miller et al. 2005). The forced vital capacity (FVC), forced expiratory volume in 1 s (FEV_1) and peak expiratory flow rate (PEF) were determined for all subjects before and after IMT.

Maximal inspiratory pressure

Maximal inspiratory mouth pressure (MIP) was measured at residual volume using a portable hand-held mouth pressure metre (MicroRPM, MicroMedical Ltd, Kent, UK) with participants standing upright in water. To standardise the water depth, participants immersed themselves until the water was at the level of their clavicle. All subjects were well habituated with the procedure during three separate familiarisation sessions. Participants received visual feedback of pressure achieved during each effort by viewing the digital display on the hand-held device, in order to maximise their inspiratory effort. At all times, participants were instructed to make maximal inspiratory efforts as rapidly as possible. Repeat MIP measurements were taken before each TT, and before any warm-up, until a stable baseline MIP was achieved. The criteria for determining MIP stability was successive efforts within 5%. The highest MIP recorded was included in the subsequent analysis.

Incremental swim step test

Participants performed an incremental swim step test in a 25-m indoor swimming pool during which cardiovascular, metabolic, mechanical and perceptual responses to increasing speeds of swimming were quantified. In accordance with the swimming specific protocol of Pyne et al. (Pyne et al. 2001), participants completed 7 × 200 m even-paced swims progressing in intensity based on each participant's personal best 200 m time. At the end of each stage, blood lactate concentration (B[La]) was measured at the earlobe using a portable analyser (Lactate Pro, Akray, Japan). Measures of interest obtained from the incremental test were velocity at the lactate threshold (V_{LT}) and maximal swim velocity (V_{max}). To determine V_{LT}, blood lactate values for each test were plotted against swimming velocity (average velocity over each 200-m stage in m s^{-1}) and V_{LT} was calculated as a function of the slope and y-intercept of the lactate–velocity curve according to the following equation:

$$V_{LT}\left(\mathrm{m\ s^{-1}}\right) = 0.03 \times (\mathrm{intercept/slope})\ \text{of the blood lactate} - \text{velocity curve.} \quad (1)$$

In addition, heart rate (HR), rates of perceived exertion (RPE, Borg 6–20 scale) and stroke rate were also measured for each 200 m stage.

Swimming time trial performance

Swimming performance was evaluated as the time taken to complete 100, 200 and 400 m TT in a 25-m indoor swimming pool, the order of which was randomised and counterbalanced. Participants performed each time trial in matched-pairs to introduce competition and to encourage maximal effort. Each TT was preceded by the participants' self-chosen pre-competition warm-up routine. Participants were requested to perform the same warm-up pre- and post-IMT.

Inspiratory muscle training

Participants were ranked according to their baseline MIP measures and divided into matched-pairs. One individual of each pair was assigned at random to the IMT group by an independent observer and the other to the placebo group. A POWERbreathe (HaB International Ltd., UK) pressure threshold device was used for all IMT. The IMT group performed 30 dynamic inspiratory efforts twice daily for 6 weeks (84 sessions) against a pressure threshold load equivalent to 50% MIP. The control group (CON) trained using an identical training device, but with a sham protocol involving 60 slow protracted breaths once daily for 6 weeks at 15% MIP (Romer et al. 2002a). After the initial setting of training loads, the participants in the IMT group were instructed by an independent observer to increase periodically the load to a value that would permit them to only just complete 30 repetitions (Romer et al. 2002a); the control group was not given these instructions. The participants were told they were participating in a study to compare the effect of strength (EXP) versus endurance (CON) IMT protocols and, as a consequence, were blinded to the true purpose of the study and the expected outcomes.

The first IMT session for all subjects was supervised. Once per week, subjects in both groups were observed performing IMT throughout the intervention period to ensure technique and load were appropriate. All other IMT sessions were performed in the subjects' own time. Participants were requested to complete a daily training diary (frequency and duration) both for pool-based training and IMT training throughout the study. Participants in both groups were instructed to cease IMT 48 h before the post-intervention TT.

Statistical analysis

Data were entered into a customised Microsoft® Office Excel spreadsheet, designed for statistical analysis by Hopkins (2006), and log-transformed. To make inferences about true (population) values of the effect of IMT on swimming performance, the uncertainty in the effect was expressed as 90% confidence limits (CL) and as likelihoods that the true value of the effect represents substantial change (Batterham and Hopkins 2005). An effect was deemed unclear if its confidence interval overlapped the thresholds for substantiveness, that is, if the effect could be substantially positive or negative. An estimate of the smallest substantial change was required to make these inferences. We therefore assumed a smallest worthwhile effect of 1.0%, which was also applied to physiological measures directly related to performance. For all other measures we used 0.2 of baseline between-subject SD (Hopkins 2006). Effect size (ES) for each measure were calculated using Cohen's *d* statistic and interpreted using Hopkins' categorisation criteria where 0.2, 0.6 and >1.2 were considered small, medium and large, respectively. Traditional significance statistics were also performed on log-transformed data. Repeated measures ANOVA was used to determine a main effect and if interactions existed. Unpaired (unequal variance) *t* tests were used to compare the mean of the differences in performance, and all other measures, between groups.

Results

The EXP group completed 74 ± 4 of the 84 prescribed IMT sessions (88% adherence), whereas the CON group completed 36 ± 3 sessions (86% adherence). Pool-based training during the intervention period was similar between groups, with no apparent differences in training frequency (EXP: 9 ± 2; CON: 9 ± 1 session week^{-1}), volume (EXP: 31.4 ± 8.4; CON: 29.8 ± 6.8 km week^{-1}) or intensity (expressed as a percent of V_{max}).

Swimming time trial performance

When compared to changes in CON, IMT resulted in a substantial reduction in swim times (Fig. 1) for both 100 m (−1.7 ± 1.4%; ES: 0.18 ± 0.14; benefit likely) and 200 m TTs (−1.5 ± 1.0%; ES: 0.25 ± 0.16; benefit likely) (Table 2), but not 400 m TT (0.6 ± 1.2%; ES: 0.11 ± 0.20; unclear). In support, unpaired *t* tests revealed significant differences when comparing the mean change in performance between groups for 100 and 200 m TTs, but not 400 m TT ($P = 0.04$, 0.02 and 0.35, respectively, Table 2). Repeated measures ANOVA for each TT revealed a main effect of time for both 100 and 200 m TTs ($P < 0.05$), and a group × time interaction for 100 m ($P = 0.032$) and 200 m TTs ($P = 0.018$), but not 400 m TT ($P = 0.363$).

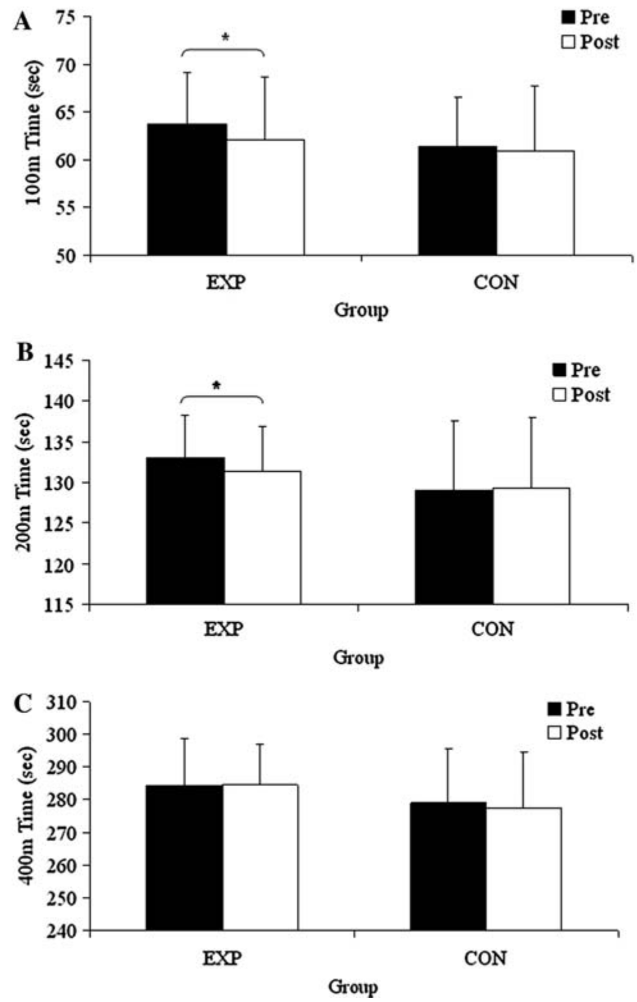

Fig. 1 Pre- and post-performance times for three competitive swimming distances: **a** 100 m; **b** 200 m; and **c** 400 m for both experimental and control groups. *Pre–post comparison, $P \leq 0.05$

Respiratory measures

There was a substantial (8.9 ± 3.6%; ES: 0.41 ± 0.15; Benefit very likely; $P < 0.01$) increase in MIP in EXP, compared to CON (Table 2). No other changes in respiratory measures were observed. There was no significant correlation between the individual changes in MIP and any swimming performance measure (TT or V_{max}) between baseline and post-intervention.

Physiological and perceptual measures during incremental exercise

There was no substantial change in V_{LT} in either group. The RPE-intensity relationship for both groups is shown in Fig. 2a, b. In the EXP group, the RPE was substantially lower after IMT across a range of intensities (Fig. 2a). No changes in RPE were observed in the CON group (Fig. 2b).

Table 2 Mean percent (±SD) change in performance and physiological measures post-IMT and control and chances that the true difference in the changes is substantial

	EXP ($N = 8$)	CON ($N = 8$)	Difference ±90% CL	Cohen's ES ±90% CL	Practical inference descriptive[a]	P value
Incremental						
V_{max}	0.4 ± 1.1	0.3 ± 1.3	0.1 ± 1.1	0.02 ± 0.11	Unclear	0.81
V_{LT}	0.2 ± 0.9	-0.1 ± 1.4	0.3 ± 1.2	0.08 ± 0.19	Unclear	0.12
Time trial						
100 m	−2.7 ± 1.9	−1.0 ± 1.1	−1.7 ± 1.4	−0.18 ± 0.14	Benefit likely	0.04
200 m	−1.2 ± 1.1	0.2 ± 1.1	−1.5 ± 1.0	−0.25 ± 0.16	Benefit likely	0.02
400 m	0.1 ± 1.6	−0.5 ± 0.8	0.6 ± 1.2	0.11 ± 0.20	Unclear	0.35
Respiratory						
FVC	2.7 ± 4.6	4.0 ± 5.2	1.3 ± 4.4	−0.07 ± 0.23	Unclear	0.60
FEV_1	1.7 ± 4.2	2.6 ± 8.1	−0.9 ± 5.8	−0.05 ± 0.31	Unclear	0.77
PEF	1.6 ± 5.1	−0.1 ± 4.9	1.7 ± 5.1	−0.08 ± 0.21	Unclear	0.51
MIP	9.1 ± 4.2	0.3 ± 3.9	8.9 ± 3.6	0.41 ± 0.15	Benefit very likely	<0.01

±90% CL: add and subtract this number to the difference to obtain the 90% confidence limits for the true difference

[a] Based on a smallest beneficial or harmful change in performance of 1%

P value represents a comparison of the mean of the pre-post differences between groups

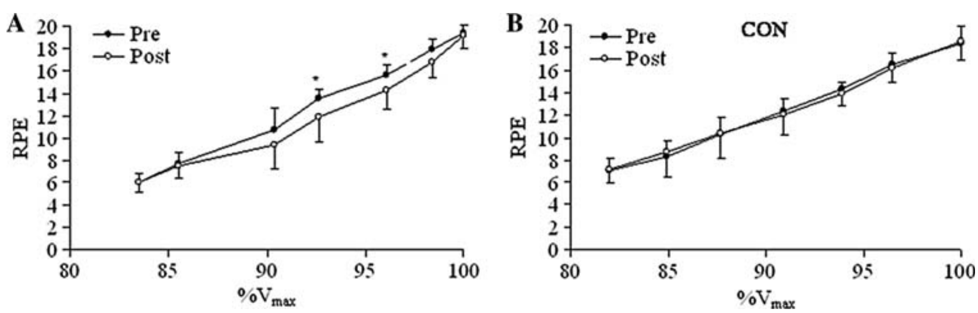

Fig. 2 Ratings of perceived exertion (RPE) during incremental step test exercise for EXP and CON groups pre- (*filled circle*) and post- (*open circle*) intervention (mean ± SD). *Pre–post comparison, $P \leq 0.05$

There was no significant correlation between the individual changes in RPE and any swimming performance measure (TT and V_{max}) between baseline and post-intervention.

Discussion

To our knowledge this is the first study to determine the effect of specific IMT upon surface swimming performance, and over a range of standard competitive distances. We observed small, but worthwhile changes both in 100 and 200 m TT performance, but not 400 m (Table 2). We also used peak incremental swim speed as a performance outcome. However, in contrast to improvements in 100 and 200 m TT performance, we observed no change in V_{max} after 6 weeks of IMT. This finding differs from that of a previous study of IMT in rowing (Volianitis et al. 2001), but is consistent with that observed in cycling (Romer et al. 2002a).

When compared to previous IMT studies involving terrestrial sports, the 1.7 and 1.5% improvement in 100 and 200 m TT, respectively, are lower than the twofold greater improvements observed for 20-km [3.8–4.6%; (Romer et al. 2002a)], 25-km [2.66 ± 2.51%; (Johnson et al. 2007)] and 40-km cycling TT [3.8–4.6%; (Romer et al. 2002a)] as well as 6-min 'all-out' rowing (~3%) (Griffiths and McConnell 2007; Volianitis et al. 2001) in well-trained athletes following IMT. It is difficult to identify precisely why our performance effect size was smaller, but it is noteworthy that the magnitude of the increase in MIP in the present study was also smaller, as was the duration of the swim TTs, compared to those of the cycling (30–60 min) and rowing (6 min) IMT studies. In addition, the difference in effect size may simply be due to subtle difference in study design or swimming-specific factors. For example, the respiratory demands of swim training alone have been shown to substantially increase MIP (Clanton et al. 1987; Mickleborough et al. 2008), which may diminish the potency of the effect of IMT on swimming performance (also see discussion on MIP below).

In the present study, the difference between the magnitude of change in 100 and 200 m TT was small (Table 2). The lack of observed difference for 400 m TT (and V_{max}), despite an improvement in MIP, countered our expectation.

This finding might indicate that there is a threshold for the efficacy of IMT that is related to the intensity/duration of the TT, at least for swimming. For terrestrial sports, a previous study reporting the performance from two cycling trials to the limit of tolerance (tlim) at different fixed intensities found slightly larger, though non-significant, improvements in time to the limit of tolerance at a higher power outputs (18.3 ± 15.1%; 333 ± 74 W, tlim ~ 6 min) compared to a lower power-output (15.3 ± 19.1%; 281 ± 62 W, tlim ~ 26 min) after IMT (Johnson et al. 2007). Conversely, Romer et al. (2002a) showed the opposite in their study finding that a longer trial was associated with slightly greater gains (3.8 ± 1.7 and 4.6 ± 1.9% for 20 and 40 km TT, respectively). It is important to note the difference between TTs and tlim tests, which have widely differing effect sizes; TTs are normally less than 5%, whilst tlim tests can be as high as 50%. From the limited evidence relating to the influence of exercise duration upon effect size, it remains unclear whether the efficacy of IMT is in any way proportional to the intensity of the performance measure for terrestrial events.

Based on findings of studies showing performance enhancement with large changes in MIP (Romer et al. 2002a; Volianitis et al. 2001), it has been suggested that improvement in performance following IMT requires an MIP effect size of >25% (Griffiths and McConnell 2007), at least in terrestrial athletes. In contrast, however, our changes in MIP, relative to the control group, were much smaller than that observed previously in terrestrial athletes following an identical IMT intervention (25–45%) (Griffiths and McConnell 2007; Romer et al. 2002a, b; Volianitis et al. 2001). The reason for this is unclear, but is not due to superior baseline MIP, since this was no greater in our group of swimmers than in previous terrestrial sport IMT studies (Griffiths and McConnell 2007; Romer et al. 2002a, b; Volianitis et al. 2001). However, our findings of clear differences in MIP between EXP (swim + IMT) and CON (swim training only, sham IMT) after IMT are somewhat different to those reported recently by Mickleborough et al. (2008) in elite swimmers, and we believe this is probably due to different study design. Specifically, Mickleborough et al. (2008) studied swimmers with exceptional pre-intervention baseline MIP (~182 cm H_2O) and reported only small differences (2.3%) in MIP between the swim + IMT group versus the swim-only group after 12 weeks of training initiated at the baseline training stage. In contrast, our study involved club-level swimmers, was shorter in duration, but was deliberately undertaken close to the competition phase. In contrast to the findings of Mickleborough et al. (2008), we would anticipate negligible gains in MIP to occur at this time of the competitive season in response to swim training alone (Table 2). That we were able to differentiate the EXP and CON groups on the basis of their MIP, close to the competitive phase, suggests that IMT can be a useful addition to swim training in already well-conditioned swimmers.

Notwithstanding the size of the change in MIP within and between groups, the IMT group experienced a substantial reduction in RPE following the intervention (Fig. 2a, b), which is also consistent with previous observations during cycling (Romer et al. 2002a), running (Edwards et al. 2008) and rowing (Volianitis et al. 2001). Conversely, however, we observed no substantial change to V_{LT}, confirming that the performance-enhancing influence of IMT is not due to improvement in lactate metabolism. The absence of a lower lactate concentration at the same intensity of exercise post-IMT differs from previous studies, albeit using a range of approaches to establish lactate measures (Griffiths and McConnell 2007; McConnell and Sharpe 2005; Romer et al. 2002b; Volianitis et al. 2001). Like our study, the tendency for a reduction in lactate has not always reached statistical significance (Romer et al. 2002a).

Finally, in common with previous studies (Griffiths and McConnell 2007; Guenette et al. 2006), we observed no correlations between relative percent changes in MIP or RPE and changes in performance for any distance after IMT. This highlights the complex nature of the mechanisms underlying changes in inspiratory muscle function and improvements in performance. A precise mechanistic explanation for the observed improvement in performance is beyond the scope of the present study. A number of mechanisms have been proposed previously, including (1) an increase in the threshold for activation of the inspiratory muscle metaboreflex (Chiappa et al. 2008; McConnell and Lomax 2006; Witt et al. 2007); and/or (2) modification of fatigue perception via a central metabolic control/central (brain) governor (Edwards and Walker 2009).

Conclusion

In conclusion, the present data suggest that IMT has a beneficial effect on 100 and 200 m swimming performance, but the influence upon 400 m performance was unclear. Inspiratory muscle training was also associated with a marked reduction in perceived exertion over a range of swim speeds. These findings are consistent with previous studies of TT performance following IMT in terrestrial sports. Inspiratory muscle training can therefore be considered a worthwhile ergogenic aid for club-level competitive swimmers.

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