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Respiratory muscle specific warm-up and elite swimming performance

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ABSTRACT

Background Inspiratory muscle training has been shown to improve performance in elite swimmers, when used as part of routine training, but its use as a respiratory warm-up has yet to be investigated.

Aim To determine the influence of inspiratory muscle exercise (IME) as a respiratory muscle warm-up in a randomised controlled cross-over trial.

Methods A total of 15 elite swimmers were assigned to four different warm-up protocols and the effects of IME on 100 m freestyle swimming times were assessed. Each swimmer completed four different IME warm-up protocols across four separate study visits: swimming-only warm-up; swimming warm-up plus IME warm-up (2 sets of 30 breaths with a 40% maximum inspiratory mouth pressure load using the Powerbreathe inspiratory muscle trainer); swimming warm-up plus sham IME warm-up (2 sets of 30 breaths with a 15% maximum inspiratory mouth pressure load using the Powerbreathe inspiratory muscle trainer); and IME-only warm-up. Swimmers performed a series of physiological tests and scales of perception (rate of perceived exertion and dyspnoea) at three time points (pre warm-up, post warm-up and post time trial).

Results The combined standard swimming warm-up and IME warm-up were the fastest of the four protocols with a 100 m time of 57.05 s. This was significantly faster than the IME-only warm-up (mean difference=1.18 s, 95% CI 0.44 to 1.92, $p<0.01$) and the swim-only warm-up (mean difference=0.62 s, 95% CI 0.001 to 1.23, $p=0.05$).

Conclusions Using IME combined with a standard swimming warm-up significantly improves 100 m freestyle swimming performance in elite swimmers.

INTRODUCTION

The goal of elite swimmers is to improve race performance and race times to achieve competitive success. The differences between winning and losing are small. Training has traditionally focused on building skeletal muscle strength and endurance; recently the focus has recently shifted to training the inspiratory musculature.[1–4]

The untrained pulmonary system was originally considered able to cope with the additional stresses imposed by exercise,[5] however several studies have demonstrated that training the inspiratory muscle system using an inspiratory muscle training regime (IMT) has additional benefits. IMT has been shown to enhance exercise performance in untrained[6–8] and trained individuals in several endurance sports[9–13] as well as during repeated sprinting.[14 15]

Competitive swimming presents several unique challenges to the respiratory system. Tight regulation of the breathing pattern (due to breath holding), at high flow rates and lung volumes, is required. Swim training has been shown to improve inspiratory muscle function[3] suggesting that swimming does place extraload on inspiratory dynamics.[16–18]

The effect of IMT in competitive swimmers has been assessed previously. One study found that supplemental respiratory muscle training with 12 weeks of concurrent inspiratory and expiratory muscle training improved dynamic pulmonary function variables including forced inspiratory volume in 1 s (FIV_1) and forced expiratory volume in 1 s (FEV_1). There was no additional improvement above that of swim training alone on ventilatory response to hypercapnia, pulmonary function, sustainable breathing power or swimming performance. The study concluded that swimming training itself may well act as a form of IMT.[4]

A recent study from Kilding's group assessed the role of 6 weeks of IMT in a sham controlled trial of 16 competitive club-level swimmers. The IMT consisted of 30 repetitions, twice per day using a hand-held pressure threshold device. The IMT group had a small improvement in swim times over 100 and 200 m with larger effects for maximal inspiratory pressure and rates of perceived exertion when compared to the sham control group.[2]

Although a set period of IMT training in conjunction with normal swim training has been assessed, the effect of an IME-specific warm-up has not. A warm-up is routinely employed by swimmers prerace. There are few studies demonstrating the effects of a whole body warm-up on performance, but it is believed that warm-up may improve athletic performance[19–21] through a variety of biomechanical, physiological and biochemical responses,[20–23] as well as accelerate the oxygen consumption response to subsequent exercise.[24 25] Prior exercise (in the form of a warm-up) may change the metabolic profile of exercise by speeding up overall oxygen uptake and blunting the blood lactate response.[24] A warm-up is also intended to reduce the risk of injury.[26]

OBJECTIVE

We set out to examine whether incorporating an IME warm-up would improve 100 m freestyle swimming performance, pulmonary function and systemic markers of exercise-induced stress in elite swimmers.

DESIGN

A total of 17 participants were initially contacted; however, two participants were not able to commit to the four sessions. A total of 15 participants from Loughborough University's elite swim team were recruited into the randomised single-blind cross-over study with the help of British Swimming and Loughborough University. Elite swimmers were defined as those who were selected to represent British Swimming in international competitions. The athletes' swim specialties were butterfly (n=3), breaststroke (n=2), backstroke (n=3) and freestyle (n=7).There were a total of nine male swimmers and six female swimmers, each swimmer completed all four warm-up protocols acting as their own controls (see table 1). Each swimmer was randomly allocated to one of four different warm-up protocols each week for a period of four consecutive weeks. The sessions were all held at 9:00 on Tuesday mornings. All procedures were approved by the Loughborough University ethics committee and all participants consented to the requirements of the study in writing.

The primary outcome was 100 m freestyle sprint time-trial time following warm-up in a 25 m (short-course) pool.

Secondary outcomes included the following physiological parameters which were, measured both before and after the warm-up protocols and before and after the 100 m freestyle time-trial:

1. Exhaled nitric oxide at 50 mL/s (Aerocrine NIOX MINO technique, Aerocrine, Sweden).
2. Spirometry forced vital capacity (FVC), FVC per cent predicted, FEV_1/FVC ratio, ratio percent predicted, peak flow (PEF), PEF percent predicted (using the Micromed spirometer, Micro Medical Ltd).
3. Maximum inspiratory and expiratory pressure (cm H_2O) (using the MicroRPM (respiratory pressure meter, Micro Medical Ltd)).
4. Ear lobe capillary blood lactate (mmol/L) (Lactate Pro LT-1710, Fact Canada Consulting Ltd).
5. Heart rate (bpm) and arterial blood oxygen saturation (PaO_2) (using Pulse Oximeter, Micro Medical Ltd).
6. Rate of perceived exertion scale.[27]
7. Dyspnoea scale.[27]

The four warm-up protocols were

Protocol 1: Standard swimming warm-up consisting of 2500 m (100×25 m lengths), with a mixture of all four strokes (butterfly, backstroke, breaststroke and freestyle), leg only work (kicking with a float), arm only work (using a pull buoy) and underwater work.

Protocol 2: A respiratory muscle-specific warm-up, using the Powerbreathe inspiratory muscle trainer. A standard protocol was followed consisting of 2 sets of 30 inspirations at 40% of maximal inspiratory muscle pressure. Forty per cent load was used to prevent undue fatigue during the warm-up. See below for determination inspiratory pressures.

Protocol 3: Standard swimming warm-up (protocol 1) was performed followed by sham IME warm-up with a resistance load equal to 15% maximal inspiratory muscle pressure.

Protocol 4: Standard swimming warm-up (protocol 1) followed by the IME warm-up (protocol 2).

Inspiratory muscle pressure settings

The swimmers had their Powerbreathe device set up individually: Each participant performed maximum inspiratory muscle pressure manoeuvres using the MicroRPM (respiratory pressure meter) until five measurements within 5% of each other were obtained. The maximum value of those five measurements was set as the maximum inspiratory muscle pressure for each participant.

None of the swimmers were told which load they were using (sham of 15%, active of 40%) but were informed that different loads were being compared rather than an active versus sham effect. The Powerbreathe device was setup with a resistance load equal to 40% maximum inspiratory muscle pressure for the IME-only warm-up (protocol 2) and the combined warm-up (protocol 4). Each participant was assigned the same Powerbreathe device for each session.

Statistical analysis

The analysis was performed using repeated measures ANOVA to detect the 100 m freestyle time trial differences between the four different warm-up protocols. We checked for cofounders in age, FEV_1 and predominant stroke, but we found nothing which indicated an adjustment was required. The same process was used to detect differences between pre warm-up, post warm-up and post time trial measurements in physiological parameters. The differences were analysed between pre warm-up versus post warm-up, pre warm-up versus post time trial and post warm-up versus post time trial. All statistical analyses were performed using STATA V.11.

RESULTS

The 15 participants completed 100% of the sessions and 100% of the physiological measurements.

There were significant differences between the four different warm-up protocols and the resulting 100 m freestyle times. The fastest protocol was swimming plus IME warm-up with a 100 m time of 57.05 s (see table 2). The swimming plus IME warm-up was significantly faster than both the IME only warm-up (Mean

Table 1 Descriptive baseline demographics (preintervention) for the participants studied

Number of participants	15
Gender	
Male (%)	9 (60%)
Female (%)	6 (40%)
Age (years)	21.2±1.6
Height (cm)	180.17±7.84
Weight (kg)	75.2±9.05
Baseline FEV_1 (L)	4.84±(0.81)
Baseline FEV_1% predicted	112±(12.19)
Baseline FVC (L)	5.90±(0.95)
Baseline FVC% predicted	115±(9.14)
Baseline peak flow (L/min)	600±(134)
Baseline F_ENO 50 mL/s (ppb)	29±(20)

Data displayed as percentage or (mean±SD).
FEV_1, forced expiratory volume in 1 s; F_ENO, fraction of exhaled nitric oxide; FVC, forced vital capacity.

Table 2 Results for 100 m swimming performance

	Swim and IME warm-up	Swim and sham IME warm-up	Swimming-only warm-up	IME-only warm-up	ANOVA p value*
100 m time (s)	57.05	57.39	57.67	58.24	0.0001

*ANOVA shows a statistically significant difference between the four groups.
ANOVA, analysis of variance; IME, inspiratory muscle exercise.

difference=1.18 s, 95% CI 0.44 to 1.92, $p<0.01$) and the swimming only warm-up (Mean difference=0.62 s, 95% CI 0.001 to 1.23, p=0.05). The swimming plus IME warm-up was faster than the swimming plus sham IME warm-up, however the difference was not statistically significant (mean difference=0.33 s, 95% CI −0.44 to 1.11, p=1.00). The IME only warm-up was also significantly faster than the swimming plus sham IME warm-up (Mean difference=0.85 s, 95% CI 0.05 to 1.65, p=0.035).

There were no significant differences between any other of the warm-up protocols. Nor were there any differences in physiological parameters between the four different warm-up protocols across the groups.

DISCUSSION

The use of a swimming warm-up utilising IME appeared to have significant benefits to performance. The use of a combined swimming plus IME (with the Powerbreathe device) warm-up improved 100 m swimming performance by 0.62 s when compared to a standard swimming warm-up alone and resulted in the fastest swimming time over 100 m (57.05 s). There were no significant differences observed in any of the physiological parameters measured across the four different warm-up protocol groups. This was expected as the study was of short duration and there was no training effect over time, as the IME device was used as part of a warm-up protocol rather than for long-term training. Changes in swimming performance are measured in small time-trial and physiological increments, and many factors contribute to overall performance, the study controls as many factors as possible; including time of day, race lane and swim wear.

To our knowledge this is the first randomised controlled study of IME as an adjunct to swimming warm-up and performance. The sample size was consistent with another study[2] evaluating IME as an aid to swim training. Other strengths included each participant acting as their own control, measurements being performed at the same time of day and the use of a sham technique.

Our study suffers from weaknesses similar to others in this area; the numbers were relatively small, swim performance can vary by small amounts in an unpredictable manner, and we did not employ a group that had no warm-up at all. The fact that there was no significant difference between sham IME and swim versus swim-only warm-up is reassuring and suggests that the sham IME was a true placebo.

Our study finding is similar to others.[2] Kilding *et al*[2] , used IME as a part of a training routine over a period of 6 weeks in 16 competitive club-level swimmers at 50% load. Their group found an improvement in 100 and 200 m swimming performance, but not 400 m. The study demonstrated a significant improvement in the rate of perceived exertion in swimmers who used IME. The study highlighted the complex nature of the mechanisms underlying changes in inspiratory muscle function and improvements in performance.

Precise mechanistic explanations for the observed improvement in performance seen in this study and others have been proposed. These include an increase in the threshold for activation of the inspiratory muscle metaboreflex[28–30] and modification of fatigue perception through a central metabolic control/central (brain) governor.[31] Other studies suggest that the mechanism for respiratory muscle specific warm-up is neural in origin.[16 32] It is possible that these effects occurred in our study too. Another explanation is that the use of IME results in an augmentation of blood flow to respiratory muscles. Given the use of IME as a warm-up with a relatively low load over a short time course it seems unlikely that warm-up IME results in long-term physiological changes in the respiratory muscles. Consistent with this, there were no differences in physiological parameters between the four warm-up protocols.

CONCLUSION

In conclusion we have shown that IME employed as a tool for warm-up improves swimming performance. The mechanisms behind these improvements require significant further investigation. Given the magnitude of change seen in performance the use of IME in a warm-up regime should be explored further.

What are the new findings?

- Inspiratory muscle exercise (IME) has not been used as a warm-up regime previously. Traditionally it has been used as a long-term (6 weeks plus) training aid.
- IME as a warm-up device in addition to a standard swimming warm-up can improve swimming performance in elite swimmers.
- No physiological or biochemical parameters were shown to change with the use of IME warm-up.

How might it impact upon clinical practice in the near future?

- Further investigation is required into the use of inspiratory muscle exercise (IME) as a warm-up device, but it is a practical, safe and simple addition to the standard swimming warm-up.
- Warming-up the respiratory muscles and the respiratory system in addition to the cardiovascular and muscular-skeletal system is likely to demonstrate added performance benefits given the results of the study.
- Elite swimming performance may be improved with the use of an IME warm-up device, which is beneficial for success at international competitions.

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Competing interests None.

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Data sharing statement All data from the study is stored in a linked anonymised encrypted database at Nottingham Respiratory Research Unit. Only Emma Wilson, Dominick Shaw and Glenn Hearson currently have access to this database.

REFERENCES

1 Jakovljevic DG, McConnell AK. Influence of different breathing frequencies on the severity of inspiratory muscle fatigue induced by high-intensity front crawl swimming. *J Strength Cond Res* 2009;23:1169–74.
2 Kilding AE, Brown S, McConnell AK. Inspiratory muscle training improves 100 and 200 m swimming performance. *Eur J Appl Physiol* 2010;108:505–11.
3 Mickleborough TD, Stager JM, Chatham K, *et al*. Pulmonary adaptations to swim and inspiratory muscle training. *Eur J Appl Physiol* 2008;103:635–46.
4 Wells GD, Plyley M, Thomas S, *et al*. Effects of concurrent inspiratory and expiratory muscle training on respiratory and exercise performance in competitive swimmers. *Eur J Appl Physiol* 2005;94:527–40.
5 Amann M, Hopkins WG, Marcora SM. Similar sensitivity of time to exhaustion and time-trial time to changes in endurance. *Med Sci Sports Exerc* 2008;40:574–8.
6 Edwards AM, Cooke CB. Oxygen uptake kinetics and maximal aerobic power are unaffected by inspiratory muscle training in healthy subjects where time to exhaustion is extended. *Eur J Appl Physiol* 2004;93:139–44.
7 Gething AD, Williams M, Davies B. Inspiratory resistive loading improves cycling capacity: a placebo controlled trial. *Br J Sports Med* 2004;38:730–6.
8 Sheel AW. Respiratory muscle training in healthy individuals: physiological rationale and implications for exercise performance. *Sports Med* 2002;32:567–81.
9 Edwards AM, Wells C, Butterly R. Concurrent inspiratory muscle and cardiovascular training differentially improves both perceptions of effort and 5000 m running performance compared with cardiovascular training alone. *Br J Sports Med* 2008;42:823–7.
10 Griffiths LA, McConnell AK. The influence of inspiratory and expiratory muscle training upon rowing performance. *Eur J Appl Physiol* 2007;99:457–66.
11 Johnson MA, Sharpe GR, Brown PI. Inspiratory muscle training improves cycling time-trial performance and anaerobic work capacity but not critical power. *Eur J Appl Physiol* 2007;101:761–70.
12 Romer LM, McConnell AK, Jones DA. Effects of inspiratory muscle training on time-trial performance in trained cyclists. *J Sports Sci* 2002;20:547–62.
13 Volianitis S, McConnell AK, Koutedakis Y, *et al*. Inspiratory muscle training improves rowing performance. *Med Sci Sports Exerc* 2001;33:803–9.
14 Romer LM, McConnell AK, Jones DA. Effects of inspiratory muscle training upon recovery time during high intensity, repetitive sprint activity. *Int J Sports Med* 2002;23:353–60.
15 Tong TK, Fu FH, Chung PK, *et al*. The effect of inspiratory muscle training on high-intensity, intermittent running performance to exhaustion. *Appl Physiol Nutr Metab* 2008;33:671–81.
16 Lomax M, Castle S. Inspiratory muscle fatigue significantly affects breathing frequency, stroke rate, and stroke length during 200-m front-crawl swimming. *J Strength Cond Res* 2011;25:2691–5.
17 Lomax M, Iggleden C, Tourell A, *et al*. Inspiratory muscle fatigue after race-paced swimming is not restricted to the front crawl stroke. *J Strength Cond Res* 2012;26:2729–33.
18 Brown S, Kilding AE. Exercise-induced inspiratory muscle fatigue during swimming: the effect of race distance. *J Strength Cond Res* 2011;25:1204–9.
19 Fradkin AJ, Zazryn TR, Smoliga JM. Effects of warming-up on physical performance: a systematic review with meta-analysis. *J Strength Cond Res* 2010;24:140–8.
20 Hedrick A. Exercise physiology: physiological responses to warm-up. *Natl Strength Cond Assoc J* 1992;14:25–7.
21 Shellock FG, Prentice WE. Warming-up and stretching for improved physical performance and prevention of sports-related injuries. *Sports Med* 1985;2:267–78.
22 Bishop D. Warm up II: performance changes following active warm up and how to structure the warm up. *Sports Med* 2003;33:483–98.
23 Bishop D. Warm up I: potential mechanisms and the effects of passive warm up on exercise performance. *Sports Med* 2003;33:439–54.
24 Burnley M, Doust JH, Jones AM. Effects of prior warm-up regime on severe-intensity cycling performance. *Med Sci Sports Exerc* 2005;37:838–45.
25 Hajoglou A, Foster C, De Koning JJ, *et al*. Effect of warm-up on cycle time trial performance. *Med Sci Sports Exerc* 2005;37:1608–14.
26 Woods K, Bishop P, Jones E. Warm-up and stretching in the prevention of muscular injury. *Sports Med* 2007;37:1089–99.
27 Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc* 1982;14:377–81.
28 Chiappa GR, Roseguini BT, Vieira PJ, *et al*. Inspiratory muscle training improves blood flow to resting and exercising limbs in patients with chronic heart failure. *J Am Coll Cardiol* 2008;51:1663–71.
29 McConnell AK, Lomax M. The influence of inspiratory muscle work history and specific inspiratory muscle training upon human limb muscle fatigue. *J Physiol* 2006;577(Pt 1):445–57.
30 Witt JD, Guenette JA, Rupert JL, *et al*. Inspiratory muscle training attenuates the human respiratory muscle metaboreflex. *J Physiol* 2007;584(Pt 3):1019–28.
31 Edwards AM, Walker RE. Inspiratory muscle training and endurance: a central metabolic control perspective. *Int J Sports Physiol Perform* 2009;4:122–8.
32 Hawkes EZ, Nowicky AV, McConnell AK. Diaphragm and intercostal surface EMG and muscle performance after acute inspiratory muscle loading. *Respir Physiol Neurobiol* 2007;155:213–19.

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