IMPACT OF WEEKLY SWIMMING TRAINING DISTANCE ON THE ERGOGENICITY OF INSPIRATORY MUSCLE TRAINING IN WELL-TRAINED YOUTH SWIMMERS

MITCH LOMAX,1 JERNEJ KAPUS,2 PETER I. BROWN,3 AND MARK FAGHY4
1Department of Sport and Exercise Science, University of Portsmouth, Portsmouth, United Kingdom; 2Laboratory of Biodynamics, Faculty of Sports, University of Ljubljana, Ljubljana, Slovenia; 3English Institute of Sport, Loughborough Performance Center, Loughborough University, Loughborough, United Kingdom; and 4Sport, Outdoor and Exercise Science, University of Derby, Derby, United Kingdom

ABSTRACT
Lomax, M, Kapus, J, Brown, PI, and Faghy, M. Impact of weekly swimming training distance on the ergogenicity of inspiratory muscle training (IMT). Thirty-three youth swimmers were recruited and separated into a LOW and HIGH group based on weekly training distance (≤31 km·wk⁻¹ and >41 km·wk⁻¹, respectively). The LOW and HIGH groups were further subdivided into control and IMT groups for a 6-week IMT intervention giving a total of 4 groups: LOWcon, LOWIMT, HIGHcon, and HIGHIMT. Before and after the intervention period, swimmers completed maximal effort 100- and 200-m front crawl swims, with maximal inspiratory and expiratory mouth pressures (PImax and PEMax, respectively) assessed before and after each swim. Inspiratory muscle training increased PImax (but not PEMax) by 36% in LOWIMT and HIGHIMT groups (p ≤ 0.05), but 100- and 200-m swims were faster only in the LOWIMT group (3 and 7% respectively, p ≤ 0.05). Performance benefits only occurred in those training up to 31 km·wk⁻¹ and indicate that the ergogenicity of IMT is affected by weekly training distance. Consequently, training distances are important considerations, among others, when deciding whether or not to supplement swimming training with IMT.

KEY WORDS breathing, adolescents, exercise

INTRODUCTION
The benefits of pressure-threshold inspiratory muscle training (IMT) on sport performance are well documented and include improved cycling (16), running (23,30), and rowing (39) performance. In addition, dyspnea (31,39,40) and exercise blood lactate may be lower during both submaximal exercise (1,28,38) and volitional hyperpnea (1), whereas recovery time after high-intensity repetitive sprint running is shortened (31), and oxygen uptake kinetics are accelerated (1).

Only a few studies have investigated the impact of IMT or respiratory muscle training (RMT) on swimming performance (17,19,29,40). These studies used strength-based training protocols, which required swimmers to complete 30–36 training breaths per training session (17,29,40). By contrast, only 1 RMT study (19) adopted an endurance-based protocol, whereby swimmers were required to complete 30 minutes of exhaustive breathing per session. It is surprising that so few studies have examined the role of breathing muscle training given that swimming presents some unique challenges to the breathing musculature (13), causing their functional weakening. For example, maximal inspiratory mouth pressure, a measure of inspiratory muscle strength, was significantly reduced after 100- (3), 200- (23,24), 300-, and 400-m (36) front crawl swimming, 200-m back stroke, breast stroke, and butterfly swimming (23).

Supplementing routine swimming training with 6 weeks of IMT or 8 weeks of RMT has been shown to increase inspiratory muscle strength and improve 50-, 100-, and 200-m swimming time trial performance (17,19). However, the improvements reported in swimming time trial performance by Kilding et al. (17) and Lemaître et al. (19) are not universal. Mickleborough et al. (29) reported that 12-week IMT failed to improve respiratory muscle strength in National and International level swimmers undertaking at least 40 km·wk⁻¹ of swimming training. Similarly, Wells et al. (40) reported that 12-week of RMT improved inspiratory muscle strength but not peak velocity or velocity at the lactate threshold in National standard swimmers completing in excess of 45 km·wk⁻¹ of training.

Although Kilding et al. (17) did not report their swimmers average weekly training distance, those examined by Lemaître et al. (19) swam between 14 and 34 km·wk⁻¹. Consequently, it is possible that differences in weekly training distance may have influenced the observed differences in IMT and RMT interventions.
training distance were responsible for the conflicting findings of these 4 studies. Indeed, an increase in training distance is a method recommended to improve performance in youth swimmers (27), and so it is likely that the natural inspiratory muscle conditioning effect induced by immersion and the horizontal body position will be accentuated with longer training distances (6,7). It is, therefore, possible that supplementing high weekly training distances in swimmers with strength-training IMT could fail to induce functional swimming benefits because the relatively high training distance could create a whole body training effect that IMT is unable to supplement. In support of this line of reasoning, both Williams et al. (41) and Sonetti et al. (35) have shown that supplementing routine whole body training with breathing training distances (6,7). It is, therefore, possible that supplementing routine whole body training with breathing muscle training in well-trained runners and cyclists fails to enhance exercise capacity or peak performance despite increasing respiratory muscle strength. This likely reflects the benefits because the relatively high training distance would require selecting trained swimmers and changing their training histories.

The aim of this study was to determine the effect of weekly swimming training distance on IMT ergogenicity. Specifically, we assessed the impact of IMT on inspiratory and expiratory muscle strength and sprint swimming time trial performance in trained swimmers completing more than, or less than, 31 km·wk⁻¹. It was hypothesized that IMT would increase inspiratory muscle strength (but not expiratory muscle strength) regardless of weekly training distance, but that IMT would only enhance swimming time trial performance in those swimming up to 31 km·wk⁻¹.

**METHODS**

**Experimental Approach to the Problem**

It was our intention to address the impact of weekly training distance (on the basis that weekly session frequency and weekly training duration will dictate this) on the ergogenicity of IMT in well-trained youth swimmers. We did this by focusing on swimming performance time trial times and swimming kinematics in response to IMT in male and female swimmers with different training histories.

To do this, trained swimmers undertaking different weekly training distances were recruited and separated into LOW and HIGH training distance groups. Swimmers were then further subdivided into IMT and control groups: thus each training distance permutation contained a control group. Training distance was kept consistent throughout the 6-week period with all LOW swimmers undertaking the same overall weekly training program and all HIGH groups undertaking the same overall weekly training program: this was confirmed by the respective coaches. It was not our intention to control how the swimming training distance was achieved because this would require selecting trained swimmers and changing their routine program (which would

### TABLE 1. Baseline participant and swimming descriptive data for LOW and HIGH group swimmers: mean ± SD.†

| Parameter                                      | LOW      | HIGH     | p     | d or r  |
|-----------------------------------------------|----------|----------|-------|---------|
| N                                             | 18       | 15       | –     | –       |
| Males (no.)                                   | 11       | 7        | –     | –       |
| Weekly training distance (km)                 | 15–31    | 42–56    | –     | –       |
| Weekly training duration (h)                  | 10.5     | 14–19    | –     | –       |
| Weekly session frequency                      | 6        | 8–9      | –     | –       |
| Competitive experience (y)                    | 5–8      | 3–4      | –     | –       |
| Standard Training period                      | National | International | – | –    |
| Preparatory                                  |          | Specific preparatory | |       |
| 100-m swimming time (s)                       | 66.4 ± 6.6 | 57.3 ± 4.1 | <0.001 | Large effect |
| 200-m swimming time (s)                       | 146.5 ± 13.8 | 125.7 ± 8.1 | <0.001 | Large effect |
| Age (y)                                       | 16 ± 3   | 16 ± 1   | 0.957 | No effect |
| Mass (kg)                                     | 65.9 ± 13.7 | 65.2 ± 8.3 | 0.851 | No effect |
| Stature (m)                                   | 1.76 ± 0.12 | 1.75 ± 0.11 | 0.828 | No effect |
| Pmax (cmH₂O)                                  | 124 ± 22 | 123 ± 24 | 0.893 | No effect |
| PEmax (cmH₂O)                                 | 135 ± 42 | 133 ± 28 | 0.845 | No effect |
| FVC (L)                                       | 5.23 ± 1.22 | 4.48 ± 1.25 | 0.090 | Moderate effect |
| FEV₁ (L·s⁻¹)                                  | 4.40 ± 1.14 | 3.94 ± 1.08 | 0.243 | Small/moderate effect |
| FEV₁/FVC (%)                                  | 84 ± 8   | 88 ± 6   | 0.123 | Moderate effect |

*FVC, forced vital capacity; FEV₁ = forced expired volume in 1 second.*
†Italic = nonparametric analyses. Highest Pmax and PEmax regardless of trial. T and U = independent t-test and Mann-Whitney U-test, respectively, between LOW and HIGH groups. d and r = effect sizes.
be unreflective of their actual training environment) or selecting untrained swim-able individuals and prescribing a swimming and IMT training program. Both of these approaches have the potential to confound swimming performance irrespective of IMT. Consequently, the approach we adopted, although not without limitation, was chosen to maximize ecological validity and provide swimmers and coaches with directly applicable information regarding the usefulness of IMT inclusion into routine swimming training.

**Subjects**

Thirty-three well-trained youth swimmers (18 men and 15 women) volunteered for this study (including 1 asthmatic who did not require any medication for asthma during the study). Swimmers were initially separated into 2 groups based on their weekly training distance defined as either low (LOW) or high (HIGH): the selection of training distances were consistent with those reported in similar studies (19,29,40). Throughout the 6-week period, the swimming coaches of the LOW and HIGH groups confirmed that the overall swimming training program was the same for both IMT and control swimmers. Descriptive data for the LOW and HIGH groups as a whole are in Table 1. Participants provided informed written consent (in addition to parental consent for those subjects under the age of 18) after being informed of the benefits and risks of the study, and local institutional ethical approval was obtained from the University of Portsmouth before the start of the study.

**Procedures**

Forced vital capacity (FVC) and forced expired volume in 1 second (FEV1) were measured (MicroLab MK8 digital spirometer; CareFusion, Kent, United Kingdom) in a seated position and from total lung capacity pre-IMT for descriptive purposes of lung function (Table 1). Maximal inspiratory and expiratory mouth pressures (PImax and PEmax, respectively) were measured upright with the nose occluded on poolside using a hand-held respiratory pressure meter (Micro Medical, Rochester, United Kingdom). PImax and PEmax were measured pre (before the warm-up) and post each performance test from residual volume and total lung capacity, respectively.

Each swimmer completed a maximum effort 100- and 200-m front crawl swim from a dive start in a counterbalanced order and on separate occasions within 1 week of each other. Swimming time was recorded per swim using a stopwatch, and in the case of the 200-m swim, per 100-m partial also. Clean swimming velocity and stroke rate (SR) were recorded from total stroke cycles to cycles per second (Hz) using achieved velocity (meters per second) and then multiplied by 60 to achieve cycles per minute (cycles per minute) (5,20).

Stroke length (SL: meters per cycle) was then calculated as achieved velocity divided by SR in Hz (4,5).

Inspiratory muscle training was performed (POWER-breathe; POWERbreathe International Ltd., Warwickshire, United Kingdom; Power Lung; Power Lung, Houston, TX, USA) twice daily, 7 d·wk⁻¹ for 6 weeks. Each session consisted of 30 breaths at an intensity equivalent to 50% PImax (10,15,17,30). After the initial setting of training loads, participants were instructed by an investigator to increase periodically the load on the inspiratory muscle trainer so that 30 breaths could only just be completed (17). Those assigned to the control condition undertook their usual (coach prescribed) training only.

**Study Overview.** After a pulmonary and respiratory muscle familiarization session, all participants completed a race-paced 100- and 200-m front crawl swim (time trial tests) in their usual indoor training pool. The LOW and HIGH groups were then further separated with half the swimmers in the LOW and HIGH groups randomly assigned IMT (LOWIMT n = 9; HIGHIMT n = 8) and the remaining swimmers serving as controls (LOWCON n = 9; HIGHCON n = 7). Thus, there were a total of 4 experimental groups: LOWIMT, HIGHIMT, LOWCON, and HIGHCON. The IMT regimen was identical for both groups, see below.

After the time trial tests, those in the LOWIMT and HIGHIMT groups undertook...
their usual training plus 6 weeks of IMT. Those in the LOW\textsubscript{con} and HIGH\textsubscript{con} continued with their usual training only. All swimmers then repeated the time trial and respiratory muscle function tests in the same indoor pool as their pre-IMT time trial tests and after the same warm-up.

**Statistical Analyses**

Baseline (i.e., pre-IMT) descriptive data (age, mass, stature, FVC, FEV\textsubscript{1}, FEV\textsubscript{1}/FVC, Pmax, PEmax, 100, and 200-m swimming time trial times) were first assessed for normality and then compared between LOW (pooled LOW\textsubscript{con} and LOW\textsubscript{IMT}) and HIGH (pooled HIGH\textsubscript{con} and HIGH\textsubscript{IMT}) groups as a whole using independent samples t-tests and a Mann-Whitney U-test for age. Baseline and post-IMT PImax and PEmax were recoded as the highest value regardless of time trial test.

Mixed model repeated measures analysis of variances (ANOVAs) were used to assess differences in PImax, inspiratory muscle fatigue (IMF), expiratory muscle fatigue (EMF), PEmax, swimming time, velocity, SR, and SL per 100 and 200 m swim in LOW\textsubscript{con}, LOW\textsubscript{IMT}, HIGH\textsubscript{con}, and HIGH\textsubscript{IMT} groups. In the case of the 200-m swim, this was also extended to per 100-m partial. Inspiratory muscle fatigue and EMF were defined by the transient reduction (cm\textsubscript{H2O}) in mouth pressure pre- (before the warm-up) vs. postexercise.

Post hoc, repeated measures ANOVAs with Bonferroni adjustments were used to assess differences in swimming time, velocity, SR, and SL for all groups, per 200 m swim. Paired and independent samples t-tests assessed differences in swimming time, velocity, and SR for the 100-m swim pre- and post-IMT. Between-group ANOVAs with Bonferroni adjustments and independent t-tests were used to assess for differences in the highest recorded PImax and PEmax values pre- and post-IMT between groups.

\( p \) was set at 0.05, and analyses were undertaken using IBM SPSS statistics version 22. Effect sizes were calculated using Cohen's \( d \) for parametric data with an effect size of 0.2 deemed small, 0.6 moderate, 1.2 large, 2.0 very large, and 4.0 extremely large (14).

For nonparametric data, \( r \) was used, whereby \( r \) is the z score divided by the square root of the total number of observations. A value of 0.1 is deemed small, 0.3 medium, and 0.5 and above large (11). Data are presented as mean and SD unless otherwise stated.

**RESULTS**

**Respiratory Muscle Strength**

Baseline PImax and PEmax were similar between all groups. PEmax was unaffected by IMT, but PImax did increase (\( F = 105.142, p < 0.001 \)) after IMT. The biggest improvement in PImax was seen in the LOW\textsubscript{IMT} (98 ± 4% IMT compliance) and HIGH\textsubscript{IMT} (91 ± 3% IMT compliance) groups (\( F = 16.355, p < 0.001, d = 0.97–1.29 \)) (Figure 1).

Inspiratory muscle fatigue was highly variable among swimmers (Figure 2). These differences in IMF magnitude were not significant and were unaffected by IMT. There was no evidence of EMF.
### TABLE 2. Before and after IMT 100- and 200-m swimming time trial characteristics for each group: mean ± SD.*†

|                  | Pre-IMT | Post-IMT | Pre-IMT | Post-IMT | Pre-IMT | Post-IMT | Pre-IMT | Post-IMT |
|------------------|---------|----------|---------|----------|---------|----------|---------|----------|
|                  | LOWcon  | LOWcon   | LOWIMT  | LOWIMT   | HIGHcon | HIGHcon  | HIGHIMT | HIGHIMT  |
| 100-m swim       |         |          |         |          |         |          |         |          |
| Swim time (s)    | 66.2 ± 6.4 | 65.7 ± 6.5 | 66.6 ± 7.2 | 64.5 ± 6.0† | 61.7 ± 1.0 | 62.5 ± 5.0 | 57.3 ± 3.8 | 59.2 ± 5.5‡ |
| Velocity (m·s⁻¹) | 1.52 ± 0.14 | 1.53 ± 0.15 | 1.52 ± 0.16 | 1.56 ± 0.15§ | 1.62 ± 0.03 | 1.60 ± 0.0 | 1.78 ± 0.13 | 1.49 ± 0.62 |
| SR (cycles·min⁻¹) | 41 ± 4 | 42 ± 3 | 43 ± 5 | 44 ± 4 | 48 ± 4 | 46 ± 4 | 49 ± 1 | 48 ± 4 |
| SL (m·cycle⁻¹)   | 2.28 ± 0.26 | 2.22 ± 0.22 | 2.16 ± 0.19 | 2.16 ± 0.18 | 2.03 ± 0.18 | 2.11 ± 0.19 | 2.16 ± 0.16 | 2.17 ± 0.18 |
| 200-m swim       |         |          |         |          |         |          |         |          |
| Total swim time (s) | 146.0 ± 13.5 | 137.3 ± 14.8 | 146.9 ± 15.0 | 136.7 ± 16.6† | 126.1 ± 6.6 | 130.3 ± 7.5| 125.3 ± 9.6 | 125.1 ± 6.8 |
| Swim time₁st 100 m (s) | 72.4 ± 7.1 | 71.2 ± 6.9 | 72.4 ± 7.4 | 69.8 ± 5.7‡ | 61.2 ± 3.6 | 63.3 ± 3.7| 60.9 ± 4.7 | 62.0 ± 4.6 |
| Swim time₂nd 100m (s) | 73.7 ± 6.5 | 72.6 ± 6.7# | 74.5 ± 7.6# | 72.7 ± 7.1‡ | 65.2 ± 3.0** | 67.2 ± 3.9**| 64.9 ± 5.0** | 65.6 ± 5.0# |
| Mean velocity     | 1.38 ± 0.14 | 1.40 ± 0.12| 1.37 ± 0.14| 1.41 ± 0.13§ | 1.59 ± 0.09 | 1.54 ± 0.09‡ | 1.60 ± 0.13 | 1.60 ± 0.89 |
| Velocity₁st 100 m (m·s⁻¹) | 1.39 ± 0.12 | 1.42 ± 0.12| 1.39 ± 0.14| 1.44 ± 0.12‡ | 1.64 ± 0.10 | 1.59 ± 0.09‡ | 1.65 ± 0.13 | 1.62 ± 0.12§ |
| Velocity₂nd 100 m (m·s⁻¹) | 1.37 ± 0.11 | 1.39 ± 0.11| 1.36 ± 0.14| 1.39 ± 0.13# | 1.54 ± 0.07# | 1.49 ± 0.09§** | 1.55 ± 0.12 | 1.53 ± 0.12 |
| SR₁st 100 m (cycles·min⁻¹) | 36 ± 4 | 38 ± 3|| 38 ± 4| | 38 ± 4| | 46 ± 3 | 43 ± 4§ | 43 ± 3 | 42 ± 3§ |
| SR₂nd 100 m (cycles·min⁻¹) | 37 ± 3 | 38 ± 3| | 38 ± 3| | 38 ± 4| | 44 ± 4 | 41 ± 4§ | 41 ± 2** | 40 ± 3# |
| SL₁st 100 m (m·cycle⁻¹) | 2.32 ± 0.27 | 2.27 ± 0.23 | 2.26 ± 0.22 | 2.26 ± 0.25 | 2.15 ± 0.14 | 2.23 ± 0.20 | 2.29 ± 0.18 | 2.34 ± 0.2 |
| SL₂nd 100 m (m·cycle⁻¹) | 2.27 ± 0.28** | 2.21 ± 0.26** | 2.19 ± 0.17** | 2.21 ± 0.22** | 2.13 ± 0.17** | 2.19 ± 0.18** | 2.25 ± 0.18** | 2.31 ± 0.27** |

*IMT = inspiratory muscle training; SR = stroke rate; SL = stroke length.
†All velocity data are based on clean swimming velocity.
‡p < 0.01 different to pre-IMT.
§p < 0.05 different to pre-IMT.
||p < 0.01 different to HIGHcon and HIGHIMT.
||p < 0.05 different to HIGHcon and HIGHIMT.
#p < 0.05 different to first 100-m partial.
**p < 0.01 different to first 100-m partial.
Swimming Time and Velocity
Pre-IMT 100- and 200-m swimming times were on average 14% faster (9.1 and 20.8 seconds, respectively) \((p < 0.001)\) in the HIGH (pooled HIGHcon and HIGHIMT) compared with LOW (pooled LOWcon and LOWIMT) group swimmers (Table 1). IMT improved 100-m \((F = 14.455, p < 0.001, \text{power} = 0.954)\) and 200-m \((F = 21.108, p < 0.001, \text{power} = 0.993)\) swimming times (and hence velocity) in the LOWIMT group (100 m: \(d = 0.32; 200 m: d = 0.64\)) but not the HIGHIMT, LOWcon, or HIGHcon groups (Table 2). One hundred and 200-m swimming times were slower after IMT in HIGHIMT and HIGHcon, respectively \((p \leq 0.05); 100 m: d = 0.65; 200 m: d = 0.59\).

The first and second 100-m partials of the 200 m differed between the HIGH and LOW groups \((F = 10.844, p = 0.003, \text{power} = 0.889)\). The first 100-m \((d = 0.39)\) and second 100-m \((d = 0.24)\) partials were faster after IMT in the LOWIMT group \((p \leq 0.05)\). The first 100-m \((d = -0.58)\) and second 100-m \((d = -0.58)\) partials were slower \((p \leq 0.05)\) after the intervention in the HIGHcon group (Table 2). The improvement in PImax post-IMT in the LOWIMT group was not correlated with the change in 100- or 200-m swimming times pre- and post-IMT \((p > 0.05)\).

Stroke Rate and Length
One hundred \((F = 8.298, p = 0.008, \text{power} = 0.789)\) and 200-m \((F = 35.578, p < 0.001, \text{power} = 1.000)\) SR was higher in the HIGHcon and HIGHIMT groups than the LOWcon and LOWIMT groups pre- and post-IMT (Table 2). No differences were observed between partials \((p > 0.05)\), although SR was lower in HIGHcon per partial (first 100 m: \(d = 0.84\); second 100 m: \(d = 0.75\)) after IMT and was lower in the second 100-m partial for the HIGHIMT group regardless of whether assessed pre- or post-IMT \((p < 0.05)\); post-IMT: \(d = 0.67\) \((F = 18.257, p < 0.001, \text{power} = 1.000, \text{Table 2})\).

Stroke length (100 m) was unaffected by IMT status \((p > 0.05)\). Although SL was similar in the HIGHIMT and LOWIMT groups, the tendency for SL to be lower in the HIGHcon group compared with the LOWcon group pre- and post-IMT \((d = 0.40–0.52)\) just missed statistical significance \((F = 4.096, p = 0.054, \text{power} = 0.493)\). Stroke length in the second 100-m partial of the 200 m was consistently shorter than the first 100-m partial in all groups \((F = 23.748, p < 0.001, \text{power} = 0.997, d = 0.12–0.36)\). However, IMT did not affect SL, and no differences were observed between the LOW and HIGH groups \((p > 0.05)\); Table 2).

DISCUSSION
The aim of this study was to investigate the effect of weekly training distance on the ergogenicity (100- and 200-m swimming time trial tests) of 6-week pressure threshold IMT. The main findings were that IMT increased PImax, but swimming time (and hence velocity), were only improved when swimming training distance was no greater than 31 km·wk\(^{-1}\).

Past studies have shown that PImax of trained swimmers varies between 83 and 146 cmH\(_2\)O in those aged 13–17 years (19,23,26,32,36,40) and between 123 and 148 cmH\(_2\)O in individuals aged 19–30 years (3,15,21,24,25); although, 1 study reported substantially higher pressures of 182 ± 27 cmH\(_2\)O in swimmers aged 18.2 ± 1.6 years (29). Our baseline PImax data (Table 1) is, therefore, consistent with that of youth swimmers and substantially greater than their age-predicted PImax: 144 ± 29% for LOW (pooled LOWcon and LOWIMT) and 142 ± 25% for HIGH (pooled HIGHcon and HIGHIMT) groups (42).

Inspiratory muscle training has been shown to increase PImax by 9–17% after only 6 weeks of IMT (17) or RMT (40), by ~40% after 8 weeks of RMT (19), and by as much as 64% after 12 weeks of RMT (40). We observed a 36% improvement in PImax after 6 weeks of IMT. However, as the LOWcon and HIGHcon groups collectively improved PImax by 9%, which most likely reflects a learning effect, we cannot rule out the possibility that the LOWIMT and HIGHIMT groups experienced a similar phenomenon.

The 100- and 200-m performance tests were 3 and 7% faster \((p < 0.05)\) after IMT in the LOWIMT group, which represented a lower standard group of swimmers. However, these improvements were not correlated with the increase in PImax \((p > 0.05)\). We are not the first to observe such a disconnect and evidence in cycling, and running suggests that improved performance after acute or chronic improvements in PImax is not due to PImax per se (9,10,16). Rather, it seems likely that the improved 100- and 200-m swimming times of the LOWIMT group after IMT reflects a number of mechanistic changes secondary to the IMT-induced structural and functional changes occurring in the inspiratory muscles (10,16,31). These might include an increase in the oxidative capacity of the inspiratory muscles including enhanced lactate kinetics (1,2) and a fall in the oxygen cost of breathing. The latter would facilitate oxygen availability to the working muscles (37) and potentially reduce the perception of both breathlessness and limb muscle discomfort (10,31,38). Furthermore, given that the magnitude of increase in PImax does not dictate the magnitude of exercise improvement, this might partly explain why IMF is not necessarily reduced after IMT (10) or correlated with performance after RMT (39). In support of this, we found that IMF had no impact on the magnitude of IMF experienced by swimmers. However, it should also be noted that although IMF did occur in some swimmers, it was highly variable (Figure 2).

Our swim time and velocity data suggest that training distance is a key factor in determining the ergogenicity of IMT. Our data also support the contradictory observations reported in the literature. For example, Kilding et al. (17) and Lemaire et al. (19) found that 50-, 100-, and 200-m time trial swims were 1.7–4% faster after 6-week IMT or 8-week RMT, whereas Wells et al. (40) found that IMT did not enhance peak swimming velocity when training distance...
was 45–88 km·wk⁻¹. The swimmers recruited by Wells et al. (40) were of National standard, whereas Kilding et al. (17) and Lemaitre et al. (19) examined club-level and well-trained swimmers, respectively. Although Kilding et al. (17) did not provide details of their swimmers weekly training distance, Lemaitre et al. (19) reported that their swimmers completed 14–34 km·wk⁻¹, which was substantially lower than that reported by Wells et al. (40) and is consistent with the distances completed by the LOW con and LOW IMT groups of the present study. Furthermore, it is interesting to note that pre-IMT/RMT 200- and 100-m swimming times were around 130–133 and 64 seconds, respectively, in the studies of Kilding et al. (17) and Lemaitre et al. (19), which are faster than the 200- and 100-m swimming times of LOW con and LOW IMT groups but slower than the HIGH con and HIGH IMT groups (Table 2). However, based on our findings, it would be unwise to attribute the inability of IMT to improve performance in the HIGH IMT group to an absolute training distance threshold phenomenon that once exceeded mean values that IMT is unable to enhance performance. Because both HIGH IMT and HIGH con groups tended to swim more slowly after the 6-week intervention (Table 2), we cannot exclude the possibility that swim training volume per se resulted in a state of holistic fatigue or overreaching compared with the LOW groups. Although LOW and HIGH group swimmers were in endurance and high volume–focused periods at the time of testing (preparatory for the LOW groups and specific preparatory for the HIGH groups), HIGH group swimmers completed an additional 66–246 km more than LOW group swimmers over the 6-week intervention. Indeed, González-Boto et al. (12) found that increasing training distance from 28–32 km to 45 km or greater in Regional standard swimmers (age 15.5 ± 7.5 years) over a 6-week period significantly increased the signs of overtraining (diminished recovery and elevated stress). These signs only reversed when training distance was reduced to 39 km or less. Thus, it is possible that the administration of IMT in the HIGH IMT group coincided with a period of overreaching masking any potential IMT-mediated benefits.

Unfortunately, the current study is unable to identify how 100- and 200-m velocities increased after IMT in the LOW IMT swimmers. Swimming velocity is the product of SR and SL, and at faster velocities typically increases by increasing SR and decreasing SL (8,33,34). The faster swimming 100- and 200-m velocities observed in the HIGH compared with LOW groups were consistent with this (Table 2). However, the increase in 100- and 200-m velocities after IMT in the LOW IMT group was not associated with an increase in SR. Because of the relationship between SR and SL, velocity will increase if the force exerted per stroke, and hence distance traveled, increases without an accompanying rise in SR (8). But SL was also unchanged in the LOW IMT group after IMT (Table 2). Our findings are, therefore, difficult to explain. It is possible that the nonsignificant increase in SR (d = −0.24) lead to an increase in 100-m mean velocity, but this does not explain the increased mean 200-m velocity. Indeed, the increase in velocity was mainly because of improvements observed in the first 100-m partial (ρ = 0.05, d = −0.30), yet SR and SL were unchanged after IMT. Only during the second 100-m partial did SL exhibit a tendency to increase after IMT (ρ > 0.05, d = −0.10). We have no satisfactory explanation for this, and unfortunately, no other swimming IMT/RMT studies have examined the impact of IMT/RMT on SR or SL. It is conceivable that the measurement methods adopted were simply not sensitive enough to detect IMT-induced changes or partition the effect of IMT-induced, from swim training–induced, changes. Indeed, there was a nonsignificant tendency for swim time to improve in the LOW con group after IMT. This might indicate that IMT in the LOW IMT group supplemented the swim training–induced changes making them statistically significant. Given that SR, SL, and velocity provide no information about technique or arm coordination measures (33,34), analysis of arm coordination parameters (e.g., entry, pull, push, and recovery phases) might prove more revealing than simply SR and SL when investigating the impact of IMT on stroke characteristics and in-turn velocity.

In conclusion, as 100- and 200-m swimming times, and hence velocity, improved after IMT only when swim training distance did not exceed 31 km·wk⁻¹, our data indicate that IMT should not be advocated as a blanket training adjunct to all swimmers. Although swimming performance did not improve once training distance exceeded 41 km·wk⁻¹, this training distance is unlikely to reflect a fixed threshold value in determining the ergogenicity of IMT. Rather, the independent effects of the competitive level of swimmers, training volume training cycle phase, and other routine training considerations more likely, and collectively, dictate the ergogenicity of IMT.

Furthermore, it is important to reiterate that the swimmers in the current study were adolescent and, therefore, unlikely to have reached physically maturity at the time of testing (18,27). Caution is, therefore, advised if applying our findings to Senior and Master swimmers who are likely to be fully mature and better able to cope with the physiological, biomechanical, and psychological demands associated with the greater weekly training distances routinely undertaken (27).

**Practical Applications**

Six week of pressure threshold IMT significantly increased PImax in well-trained youth swimmers, although this did not automatically translate into improved swimming time trial performance. One hundred and 200-m swim times after IMT improved only in adolescent swimmers who undertook no more than 31 km·wk⁻¹ of swim training. However, the merits of supplementing swimming training with IMT should not be based on weekly training distance in isolation.
but rather on a combination of the competitive level of swimmers, swim training, and IMT.

ACKNOWLEDGMENTS

The authors thank all the swimmers and their coaches who volunteered for this study.

REFERENCES

1. Brown, PI, Sharpe, GR, and Johnson, MA. Inspiratory muscle training abolishes the blood lactate increase associated with volitional hyperpnoea superimposed on exercise and accelerates lactate and oxygen uptake kinetics at the onset of exercise. *Eur J Appl Physiol* 112: 2117–2129, 2012.

2. Brown, PI, Sharpe, GR, and Johnson, MA. Inspiratory muscle training reduces blood lactate concentration during volitional hyperpnoea. *Eur J Appl Physiol* 104: 111–117, 2008.

3. Brown, S and Kilding, AE. Exercise-induced inspiratory muscle fatigue during swimming: The effect of race distance. *J Strength Cond Res* 25: 1204–1209, 2011.

4. Cardelli, C, Chollet, D, and Lerda, R. Analysis of the 100-m front crawl as a function of skill level in non-expert swimmers. *J Hum Mov Stud* 36: 51–74, 1999.

5. Cardelli, C, Lerda, R, and Chollet, D. Analysis of breathing in the crawl as a function of skill and stroke characteristics. *Percept Mot Skills* 90: 979–987, 2000.

6. Clanton, TL, Dixon, GF, Drake, J, and Gadek, JE. Effects of swim training on lung volumes and inspiratory muscle conditioning. *J Appl Physiol* 62: 39–46, 1987.

7. Cordain, L and Stager, J. Pulmonary structure and function in swimmers. *Sports Med* 6: 271–278, 1988.

8. Craig, AB and Pendergast, DR. Relationship of stroke rate, distance per stroke, and velocity in competitive swimming. *Med Sci Sports Exerc* 11: 278–283, 1979.

9. Dunham, C and Harms, CA. Effects of high-intensity training on pulmonary function. *Eur J Appl Physiol* 112: 3061–3068, 2012.

10. Faghy, MA and Brown, PI. Training the inspiratory muscles improves running performance when carrying a 25 kg thoracic load in a backpack. *Eur J Sports Sci* 16: 585–594, 2016.

11. Field, AF. Everything You Never Wanted to Know about Statistics. In: *Discovering Statistics Using IBM SPSS Statistics*. London, United Kingdom: Sage, 2013. pp. 40–88.

12. González-Boto, R, Salguero, A, Tuero, C, González-Gallego, J, and Márquez, S. Monitoring the effects of training load changes on stress and recovery in swimmers. *J Physiol Biochem* 64: 19–26, 2008.

13. Hing, SK, Cerretelli, P, Cruz, JC, and Rahn, H. Mechanics of respiration during submersion in water. *J Appl Physiol* 27: 535–538, 1969.

14. Hopkins, WG, Marshall, SW, Batterham, AM, and Hanin, J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 41: 3–12, 2009.

15. Jakovljevic, DG and 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* 23: 1169–1174, 2009.

16. Johnson, MA, Sharpe, GR, and Brown, PI. Inspiratory muscle training improves cycling time-trial performance and anaerobic work capacity but not critical power. *Eur J Appl Physiol* 101: 761–770, 2007.

17. Kilding, AE, Brown, S, and McConnell, AK. Inspiratory muscle training improves 100 and 200 m swimming performance. *Eur J Appl Physiol* 108: 505–511, 2010.

18. Kojima, K, Jamison, PL, and Stager, JM. Multi-age-grouping paradigm for young swimmers. *J Sports Sci* 30: 313–320, 2012.

19. Lemaitre, F, Coquart, JB, Chavallard, F, Castres, I, Mucci, P, Buchheit, M, Costalat, G, and Chollet, D. Effect of additional respiratory muscle endurance training in young well-trained swimmers. *J Sports Sci Med* 12: 630–638, 2013.

20. Lerda, R and Cardelli, C. Breathing and propelling in crawl as a function of skill and swim velocity. *Int J Sports Med* 24: 75–80, 2003.

21. Lomax, M and Castle, S. Inspiratory muscle fatigue significantly affects breathing frequency, stroke rate and stroke length during 200 m front crawl swimming. *J Strength Cond Res* 25: 2691–2695, 2011.

22. Lomax, M, Grant, I, and Cobbett, J. Inspiratory muscle warm-up and inspiratory muscle training: Separate and combined effects on intermittent running to exhaustion. *J Sports Sci* 29: 563–569, 2011.

23. Lomax, M, Iggeden, C, Tourell, A, Castle, S, and Honey, J. Inspiratory muscle fatigue after race-paced swimming is not restricted to the front crawl stroke. *J Strength Cond Res* 26: 2729–2732, 2012.

24. Lomax, M and McConnell, AK. Inspiratory muscle fatigue in swimmers after a single 200 m swim. *J Sports Sci* 21: 659–664, 2003.

25. Lomax, M, Tasker, L, and Bostanci, O. An electromyographic evaluation of dual role breathing and upper body muscles in response to front crawl swimming. *Scand J Med Sci Sports* 25: e472–e478, 2015.

26. Lomax, M, Thomaidis, SP, Iggeden, C, Toubekis, AG, Tiligadas, G, Tokamakis, SP, Oliveira, RC, and Costa, AM. The impact of swimming speed on respiratory muscle fatigue during front crawl swimming: A role for critical velocity? *Int J Sport Kinérz 2*: 3–12, 2013.

27. Maglischo, EW. Age Group Swimming. In: *Swimming Even Faster*. California City, CA: Mayhew Publishing Company, 1993. pp. 249–268.

28. McConnell, AK and Sharpe, GR. The effect of inspiratory muscle training upon maximum lactate steady-state and blood lactate concentration. *Eur J Appl Physiol* 94: 277–284, 2005.

29. Mickleborough, TD, Stager, JM, Chatham, K, Lindley, MR, and Ionescu, AA. Pulmonary adaptations to swim and inspiratory muscle training. *Eur J Appl Physiol* 103: 635–646, 2008.

30. Romer, LM and McConnell, AK. Specificity and reversibility of inspiratory muscle training. *Med Sci Sports Exerc* 35: 237–244, 2003.

31. Romer, LM, McConnell, AK, and Jones, DA. Effects of inspiratory muscle training upon recovery time during high intensity, repetitive sprint activity. *Int J Sports Med* 23: 353–360, 2002.

32. Santos, MARC, Pinto, ML, Sant’Anna, CC, and Bernhoeft, M. Maximal respiratory pressures among adolescent swimmers [in English, Portuguese]. *Rev Port Pneumol* 17: 66–70, 2011.

33. Seifert, L, Chollet, D, and Bardy, BG. Effect of swimming velocity on arm coordination in the front crawl: A dynamic analysis. *J Sports Sci* 22: 651–660, 2004.

34. Seifert, L, Toussaint, HM, Albert, M, Schnitzler, C, and Chollet, D. Arm coordination, power, and swim efficiency in national and regional front crawl swimmers. *Hum Mov Sci* 29: 426–439, 2010.

35. Sonetti, DA, Wetter, TJ, Pegelow, DF, and Dempsey, JA. Effects of respiratory muscle training versus placebo on endurance exercise performance. *Respir Physiol* 127: 185–199, 2001.

36. Thomaidis, SP, Toubekis, AG, Mpousmoukili, SS, Douda, HT, Antoniou, PD, and Tokamakis, SP. Alterations in maximal inspiratory mouth pressure during a 400-m maximum effort front-crawl swimming trial. *J Sports Med Phys Fitness* 49: 194–200, 2009.

37. Turner, LA, Tecklenburg-Lung, SL, Chapman, RF, Stager, JM, Wilhite, DP, and Mickleborough, TD. Inspiratory muscle training lowers the oxygen cost of voluntary hyperpnea. *J Appl Physiol* 112: 127–134, 2012.
38. Verges, S, Lenherr, O, Haner, AC, Schulz, C, and Spengler, CM. Increased fatigue resistance of respiratory muscles during exercise after respiratory muscle endurance training. *Am J Physiol Regul Integr Comp Physiol* 292: R1246–R1253, 2007.

39. Volianitis, S, McConnell, AK, Koutedakis, Y, McNaughton, L, Backx, L, and Jones, DA. Inspiratory muscle training improves rowing performance. *Med Sci Sports Exerc* 33: 803–809, 2001.

40. Wells, GD, Plyley, M, Thomas, S, Goodman, L, and Duffin, J. Effects of concurrent inspiratory and expiratory muscle training on respiratory and exercise performance in competitive swimmers. *Eur J Respir Physiol* 94: 527–540, 2005.

41. Williams, JS, Wongsathikun, J, Boon, SM, and Acevedo, EO. Inspiratory muscle training fails to improve endurance capacity in athletes. *Med Sci Sports Exerc* 34: 1194–1198, 2002.

42. Wilson, SH, Cooke, NT, Edwards, RHT, and Spiro, SG. Predicted normal values for maximal respiratory pressures in caucasian adults and children. *Thorax* 39: 535–538, 1984.