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EFFECTS OF INSPIRATORY MUSCLE TRAINING ON INSPIRATORY MUSCLE STRENGTH AND SPRINT SWIMMING PERFORMANCE IN YOUNG FEMALE AND MALE SWIMMERS

UČINEK VADBE ZA MOČ VDIŠNIH MIŠIC NA ŠPRINTERSKO ZMOGLJIVOST MLADIH PLAVALK IN PLAVALCEV

ABSTRACT

The purpose of this study was to investigate the effects of inspiratory muscle training (IMT) on inspiratory muscle strength and sprint swimming performance in young swimmers. Twelve healthy participants (seven females, five males; age: 14 ± 1 years, height: 1.70 ± 0.06 m, body mass: 58 ± 9 kg) were divided into two groups: an experimental (Group E) and placebo IMT control (Group C). IMT was added to the usual daily swimming practice. It was performed twice daily for six weeks using a spring-loaded threshold inspiratory muscle trainer. Group E performed 30 dynamic inspiratory efforts against a pressure-threshold load of ~50% maximal inspiratory pressure. In contrast, Group C trained with a protocol involving 30 slowly protracted breaths against a pressure-threshold load of ~15% maximal inspiratory pressure. Participants completed the following tests in the same order in pre- and post-training: tests of pulmonary function, tests of respiratory muscle strength, and 50 m and 100 m swim time trials. After IMT, Group E showed higher inspiratory (+62 ± 42%; p=0.00) and expiratory muscle strength (+17 ± 10%; p=0.00) and swam the 50 m butterfly (+2 ± 2%; p=0.03) and the 100 m front crawl (+2 ± 2%; p=0.04) faster. However, the times in other sprint swimming trials (50 m front crawl and 50 m breaststroke), stroking and breathing characteristics did not change throughout the IMT in Group E. As expected, these parameters were unchanged in Group C. In conclusion, the IMT increased respiratory muscle strength in the young swimmers. However, these improvements are only partially transferable to sprint swimming performance.

Keywords: inspiratory muscles, training, swimming

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IZVLEČEK

Namen raziskave je bilo ugotoviti učinek šest tedenske vadbe za moč vdišnih mišic na šprintersko zmogljivost mladih plavalk in plavalcev. Dvanajst preiskovancev (sedem deklet, pet fantov; starost: 14 ± 1 let, višina: 1.70 ± 0.06 m, teža: 58 ± 9 kg) je bilo razdeljenih v dve skupini: poskusno (skupina E) in referenčno (skupina C). Vadba za moč vdišnih mišic je bila dodana običajni plavalni vadbi. Skupina E je tako dvakrat dnevno vadila s 30 dinamičnimi vdihi in izdihi s pomočjo dihalnega trenažerja, pri čemer je bil upor vdiha določen s približno 50% največjega vdišnega pritiska. Skupina C je opravila enako pogosto vadbo, le intenzivnost in izvedba je bila drugačna. Opravila je namreč placebo vadbo s 30 počasnimi vdihi in izdihi proti približno 15% največjega vdišnega pritiska. Pred vadbo in po njej smo pri obeh skupinah izmerili spirometrijo in moč dihalnih mišic. Ob tem so preiskovanci kar najhitreje odplavali tudi 50 metrov kravl, 50 metrov prsno, 50 metrov delfin in 100 metrov kravl. Skupina E je z uporabljeno dodano vadbo povišala moč vdišnih (+62 ± 42%; p=0.00) in izdišnih (+17 ± 10%; p=0.00) mišic. Očiten vadbeni napredek se je izrazil tudi v hitrejšem plavanju 50 metrov delfin (+2 ± 2%; p=0.03) in 100 metrov kravl (+2 ± 2%; p=0.04). Pri drugih kazalcih (hitrost plavanja, frekvenca dihanja in frekvenca zaveslajev), merjenih med plavalnimi testi, statistično pomembnih razlik nismo ugotovili. Tudi učinki vadb skupine E in skupine C na te kazalce se niso statistično značilno razlikovali. Glede na dobljene rezultate lahko zaključimo, da je vadba za moč vdišnih mišic povišala moč teh mišic pri mladih plavalkah in plavalcih. Vendar so se ti vadbeni učinki le delno izrazili tudi v višjih hitrosti pri šprinterskih plavanjih.

Ključne besede: vdišne mišice, vadba, plavanje

INTRODUCTION

In the 1970s, Leith and Bradley (1976) demonstrated that respiratory muscle strength and endurance can be improved by specific respiratory muscle training. Currently, two distinct forms of respiratory muscle training are used in healthy subjects: respiratory muscle strength training, which is performed by breathing against an external inspiratory and/or expiratory load, and respiratory muscle endurance training by using normocapnic hyperapnea (Illi, Held, Frank and Spengler, 2012). In the previous studies, the effects of inspiratory muscle training have been by far the most widely investigated among the group of respiratory muscle strength training with different protocols. It was shown that inspiratory muscle training (IMT) increases diaphragm thickness, i.e. induces hypertrophy and elicits an improvement in strength (Downey et al., 2007). Consequently, IMT enhances the exercise performance of athletes across a range of endurance sports (Griffiths and McConnell, 2007; Romer, McConnell and Jones, 2002; Volianitis et al., 2001), as well as during repeated sprinting (Romer et al., 2002). Although such questions are relevant to all athletic groups, the impact IMT on swimmers is particularly interesting. This is because swimmers exercise in a horizontal or near horizontal position and are subjected to hydrostatic forces. Together, these present some unique challenges to the breathing musculature. As previously highlighted by Wells, Plyley, Thomas, Goodman and Duffin, (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, Ceretelli, Cruz, & Rahn, 1969); (3) increased flow-resistive load due to the high flow rates during inspiration and expiration (Courteix, Obert, Lecoq, Guenon, & Koch, 1997); and (4) increased respiratory muscle contraction velocity and increased tidal volume (Dicker, Lofthus, Thornton, & Brooks, 1980). In addition, some respiratory muscles are also involved in the swimming stroke. For example, the muscles of the abdominal wall are used to stabilise the body in front crawl and backstroke as well as to create the wave motion during butterfly and breaststroke. Further, the chest muscles should create a stable structure from which the muscles of the shoulders can create the swimming strokes (Wells et al., 2005). Considering the presented demands, the development of inspiratory muscle fatigue can be expected during intense swimming. Indeed, Lomax and McConnell (2003) determined that a single 200 m front crawl swim corresponding to 90–95% of race pace, i.e. less than 2.7 min. of swim effort was sufficient to induce inspiratory muscle fatigue. Recently, it was shown that inspiratory muscle fatigue during swimming increased breathing frequency in part as an attempt to alleviate dysapnea (Lomax & Castle, 2011). Due to the fact that breathing is synchronised with swimming strokes, the regulation of breathing can only be realised by changing the breathing pattern and/or changing the arm coordination during front crawl swimming. Given that a number of identical muscles are recruited during deep inspirations and the front crawl arm stroke, the latter could also be the consequence of inspiratory muscle fatigue (Lomax & Castle, 2011).

Recent evidence suggests that IMT has a small positive effect on swimming performance in adult trained swimmers in events shorter than 400 m (Kilding, Brown, & McConnell, 2010). The fact that no studies to date examining the influence of specific IMT on the performance of younger swimmers, i.e. swimmers in their adolescence, is surprising given that the regulation of breathing (via changing the breathing pattern, stroke length and stroke rate) is an important limiting factor during maximal swimming, especially among less skilled (Cardelli, Chollet, & Lerda, 2000) and less experienced swimmers (Kapus, Ušaj, Štrumbelj, & Kapus, 2008). Therefore, the purpose of this study was to explore the effects of inspiratory muscle training on inspiratory muscle strength measured on land in an upright position and sprint swimming performance (50 m and 100 m) in different swimming techniques (front crawl, breaststroke and butterfly) in young swimmers.

MATERIALS AND METHODS

Participants

Twelve healthy participants (seven females, five males; age: 14 ± 1 years, height: 1.70 ± 0.06 m, body mass: 58 ± 9 kg) volunteered to participate in this study. They had been competitive swimmers for at least six years and were recruited from two swimming clubs. They were mostly sprint and middle-distance specialists at the national level. Due to the small sample, the participants were of both genders. To our knowledge, no study to date has shown any significant differences between genders in the effects of IMT or breathing response during maximal swimming, which were both considered in our study. The participants were free from respiratory diseases. They were fully informed of the purpose and possible risks of the study before giving their parents' written consent to participate. The study was approved by the National Ethics Committee of the Republic of Slovenia.

Testing protocol

Participants completed the following tests in the same order in pre- and post-training: (1) tests of pulmonary function; (2) tests of respiratory muscle strength; and (3) 50 m and 100 m swim time trials.

Pulmonary function. A pneumotachograph spirometer (Vicatest P2a, Mijnhardt, Netherlands) was used to measure resting flow-volume profiles. The following variables were measured: vital capacity (VC), forced vital capacity (FVC) and forced expiratory volume in one second (FEV1.0). Pulmonary function measurements were made according to recommendations of the European Respiratory Society (Miller et al., 2005).

Respiratory muscle strength was assessed by measuring the maximal inspiratory mouth pressure (MIP) at residual volume and maximal expiratory mouth pressure (MEP) at total lung capacity. Both parameters were measured using a portable hand-held mouth pressure metre (MicroRMP, MicroMedical Ltd, Kent, UK) in a standing position. The assessment of maximal pressures required a sharp, forceful effort maintained for a minimum of 2 s. All participants became well accustomed to the procedure during two separate familiarisation sessions. Participants received visual feedback of the pressure achieved during each effort by viewing the digital display on the hand-held device in order to maximise their inspiratory and expiratory effort. The MIP and MEP measurements were taken repeatedly until a stable baseline of each parameter was achieved. The criteria for determining the MIP and MEP stability were successive efforts within 5% of each other. The highest value recorded was included in the subsequent analysis.

Participants performed four *swimming tests* in the following order: 1) 50 m breaststroke; 2) 50 m butterfly; 3) 50 m front crawl; and 4) 100 m front crawl. Before testing, participants warmed up with some flexibility exercises on land and with 800 m of swimming at a lower intensity. Following the warm-up, swimmers performed a maximal swim for the selected test. They were instructed to swim as fast as possible without any predefined swimming strategy. They chose their own patterns of velocity, stroke rate (SR) and breathing frequency (BF) during the swimming. The swimming time for each distance of 50 m was measured by using a digital CASIO stopwatch (Casio Electronics Co., London, United Kingdom). The swimming test was filmed from the side using a video camera (DCR-TRV 410E, PAL standard recorder, Sony, Tokyo, Japan) operating at 25 Hz. The measurements of the stroke parameters were taken from the videotapes. The elapsed time for three complete one-arm stroke cycles during about a 12 m section of each pool length was measured to calculate the SR (stroke cycles × s^{-1}). BF was calculated by dividing the number of breaths by the time, which were both measured during the swimming test. SR and BF were measured for each 50 m. All swimming tests were performed during a morning swimming training session in a 50 m indoor pool with a water temperature of 27 °C. Fifteen minutes were provided as a resting period between the trials.

Training protocol

The participants were categorised according to gender and their baseline MIP measures and divided into matched pairs or trios. From each of these they were assigned at random to the experimental group (Group E) or the placebo group (Group C). Therefore, each intervention group consisted of swimmers of both genders and from both clubs. Descriptive measures of the participants and training groups are presented in Table 1.

The study was conducted during the early competitive season, i.e. the general preparation phase. The emphases of the swimming training were to improve general aerobic capacity, strength, flexibility, stroke mechanics, starts and turns. Therefore, the training sessions consisted of stroke drills, pulling and kicking at basic endurance speed in all strokes with no emphasis on the swimmers' specialties. All of the swimming training sessions were performed in a 50 m indoor pool with a water temperature of 27 °C. IMT was added to the usual daily swimming practice. It was performed twice daily (in the morning and following the afternoon's swim training sessions) for six weeks using a spring-loaded threshold inspiratory muscle trainer (POWERbreathe, Gaiam Ltd., Southham, UK). Group E performed 30 dynamic inspiratory efforts against a pressure-threshold load of ~50% maximal inspiratory pressure. After the initial setting of training loads, the participants were instructed by an independent observer to increase the load periodically once a week to a level that would permit them to only just complete 30 manoeuvres. The participants initiated each inspiratory effort from residual volume and strove to maximise the tidal volume. This IMT protocol is known to be effective in eliciting an adaptive response (Griffiths & McConnell, 2007; McConnell, 2011; McConnell & Lomax, 2006; McConnell & Sharpe, 2005; Romer et al., 2002; Volianitis et al., 2001). In contrast, Group C trained with a placebo protocol involving 30 slowly protracted breaths against a pressure-threshold load of ~15% maximal inspiratory pressure. Their training loads did not change throughout the training period. The participants completed a training diary throughout the study to record their training adherence. The IMT had ceased 48 h before the post-training testing.

Statistical analyses

The results are presented as means and standard deviations. Intra-group differences between the pre- and post-training values were calculated with a paired, two-tailed t-test. Analysis of covariance (ANCOVA), with pre-training values as covariates and post-training values as dependent variables, was used to test for differences between the groups resulting from the different training interventions. Statistical significance was accepted at the $p \leq 0.05$ level. Effect sizes were calculated using Cohen's d statistics to assess the magnitude of treatment with 0.2 being deemed small, 0.5 medium and 0.8 large (Cohen, 1988). All statistical parameters were calculated using the statistics package SPSS (version 15.0, SPSS Inc., Chicago, USA) and the graphical statistics package Sigma Plot (version 9.0, Jandel, Tübingen, Germany).

RESULTS

Descriptive measures of the participants and training groups are presented in Table 1.

Table 1. Descriptive characteristics of the participants and training groups.

Parameter	All subjects	Group E (N = 7; 4 F, 3 M)	Group C (N = 5; 3 F, 2 M)
Age (yrs)	14 ± 1	14 ± 1	14 ± 1
Height (cm)	170 ± 7	169 ± 4	172 ± 10
Body mass (kg)	58 ± 9	57 ± 6	59 ± 12
VC (l)	4.53 ± 0.78	4.62 ± 0.36	4.4 ± 1.2
$FEV_{1.0}$ ($l.s^{-1}$)	3.85 ± 0.75	3.79 ± 0.43	3.94 ± 1.11
MIP (cm H_2O)	112 ± 22	110 ± 21	114 ± 25
MEP (cm H_2O)	116 ± 16	111 ± 11	123 ± 20

Values are means ± SD. VC, vital capacity; FVC, forced vital capacity; $FEV_{1.0}$, forced expiratory volume in one second; MIP, maximal inspiratory mouth pressure; MEP, maximal mouth expiratory pressure.

Analysis of the training diaries showed that the participants completed 81 ± 5 (96% adherence) and 83 ± 3 (98% adherence) of the 84 prescribed IMT sessions, respectively for Group E and Group C. Pool-based training during the intervention period was similar between groups, with no apparent differences in training frequency (Group E: 42 ± 11 training sessions, Group C: 36 ± 9 training sessions), volume or intensity. The spirometry parameters and the parameters of respiratory muscle strength measured in the pre- and post-training testing are shown in Table 2.

Table 2. Spirometry parameters and parameters of respiratory muscle strength pre- and post-training

Parameter	Group	Pre-training	Post-training	
Height (cm)	E	169 ± 4	170 ± 4††	
	C	172 ± 10	173 ± 10	
Body mass (kg)	E	57 ± 6	57 ± 6	
	C	59 ± 12	59 ± 12	
VC (l)	E	4.63 ± 0.36	4.84 ± 0.38 †	
	C	4.4 ± 1.2	4.54 ± 1.2	
$FEV_{1.0}$ (l)	E	3.79 ± 0.43	4.09 ± 0.39 †	
	C	3.94 ± 1.11	3.96 ± 0.95	
MIP (cm H_2O)	E	110 ± 21	173 ± 25 ††	**
	C	114 ± 25	133 ± 11	
MEP (cm H_2O)	E	111 ± 11	129 ± 15 ††	
	C	123 ± 20	151 ± 36	

Values are means ± SD. VC, vital capacity; FEV1.0, forced expiratory volume in one second; MIP maximal inspiratory pressure; MEP, maximal expiratory pressure. Significant training effect (paired t-test): †† - $p<0.01$. Significant differences between groups after the training (ANCOVA): ** - $p<0.01$.

As shown in Table 2, height, VC and $FEV_{1.0}$ were enhanced by the IMT in Group E (p=0.00, d=0.27, p=0.03, d=0.62 and p=0.04, d=0.89). In addition, MIP differed between the groups in response to the IMT period (p<0.01). As expected, higher values (p=0.00, d=2.99) were observed after the IMT in Group E compared with the pre-training values. Post-training MEP was also significantly higher than the pre-training values in Group E (p=0.00, d=1.51). In contrast, the spirometry parameters and the parameters of respiratory muscle strength were unchanged in Group C.

After the IMT, Group E swam the 50 m butterfly (p=0.03, d=0.38) and the 100 m front crawl (p=0.04, d=0.51) faster (Table 3). However, the times in the other sprint swimming trials (50 m front crawl and 50 m breaststroke), BF and SR did not change throughout the IMT in Group E. As expected, these parameters were unchanged in Group C.

Table 3. Time to complete the trials, breathing frequencies and stroke rates obtained during the pre- and post-training swim tests

Swim test	Parameter	Group	Pre-training	Post-training
50 m front crawl	Time (s)	E	30.89 ± 1.26	30.34 ± 1.78
		C	32.26 ± 2.70	31.72 ± 2.60
	BF (1/min)	E	18 ± 5	17 ± 6
		C	21 ± 6	23 ± 1
	SR (1/min)	E	48 ± 4	48 ± 4
		C	47 ± 5	47 ± 6
50 m butterfly	Time (s)	E	34.93 ± 2.00	34.17 ± 2.43 ††
		C	35.23 ± 4.81	34.83 ± 4.99
	BF (1/min)	E	22 ± 3	20 ± 7
		C	25 ± 3	24 ± 3
	SR (1/min)	E	48 ± 6	50 ± 6
		C	50 ± 5	51 ± 5 ††
50 m breaststroke	Time (s)	E	40.57 ± 2.50	39.78 ± 2.64
		C	41.00 ± 2.72	40.23 ± 2.92
	BF (1/min)	E	36 ± 3	39 ± 6
		C	35 ± 1	37 ± 3
	SR (1/min)	E	41 ± 4	44 ± 6
		C	41 ± 3	42 ± 4
100 m front crawl	Time (s)	E	67.53 ± 3.08	66.03 ± 3.23 ††
		C	69.64 ± 7.09	68.10 ± 5.83
	BF (1/min)	E	27 ± 7	27 ± 6
		C	30 ± 5	35 ± 4
	SR (1/min)	E	45 ± 4	44 ± 3
		C	44 ± 4	45 ± 4

Values are means ± SD. BF, breathing frequency; SR, stroke rate. Significant training effect (paired t-test): †† - p<0.01. Significant differences between the groups after the training (ANCOVA): * - p<0.05.

DISCUSSION

To our knowledge, this study is the first to explore the influence of IMT on inspiratory muscle strength and sprint swimming performance in young swimmers. The data indicated that the six weeks of the IMT that was added to the usual daily swimming practice did improve the ability to generate maximal inspiratory pressure. In addition, a small improvement in swimming speeds in the 50 m butterfly and 100 m front crawl due to the IMT was observed. On the basis of the large (measures of MIP) to moderate (times of the swim trials) effects, it may be suggested that the training intervention *per se* was primarily responsible for the increased inspiratory muscle strength.

The data of this study showed a larger increase in MIP due to the IMT (62 ± 42%; Table 2) than was obtained in previous studies. The magnitude of the increase in the inspiratory muscle strength following IMT varies from 9% in competitive swimmers (Kilding, Brown, & McConnell, 2010) to 17% in competitive cyclists (Johnson, Sharpe, & Brown, 2007), 20% in elite rowers (Klusiewicz, Borkowski, Zdanowicz, Boros, & Wesolowski, 2008), 20% and 30% in elite runners (Inbar, Weiner, Azgad, Rotstein, & Weinstein, 2000), and up to 45% in competitive rowers (Volianitis et al., 2001). These discrepancies may be related, in part, to the ages of the subjects. In all the aforementioned previous studies, adult subjects were investigated. In contrast, much younger swimmers participated in our study. However, no studies to date have studied the trainability of inspiratory muscles with respect to the different ages of participants. Height, VC and $FEV_{1.0}$ were enhanced during the training period in Group E (Table 2). This could be expected due to fact that our participants were adolescent swimmers. Therefore, it is possible that growth and development may have been a factor in the observed increases in pulmonary function, particularly in the VC results in this group.

Considering previous studies involving land exercises, the 2 ± 2% improvement in the 50 m and in the 100 m front crawl due to the IMT (Table 3) is smaller than the twice greater improvements for 20 km (from 3.8% to 4.6%; Romer et al., 2002), 25 km (from 3.8% to 4.6%; Johnson, Sharpe, & Brown, 2007) as well as 6 minutes of "all out" rowing (approximately 3%; Volianitis et al., 2001) in well-trained athletes following IMT. However, it is narrowed to a 1.7% and 1.5% improvement in the 100 m and 200 m front crawl, respectively, in the results obtained by Kilding, Brown & McConnell (2010). Further, the lack of observed differences in the times of the other two swim tests, i.e. the 50 m front crawl and the 50 m breaststroke, countered our expectations despite an improvement in MIP. The reason for these unclear results could be the study design itself. Interestingly, throughout the training period swimmers in Group E reported some potential benefits of the IMT which were related to breathing during swimming such as: (1) easier inspiration during maximal and submaximal swimming; (2) easier swimming with fewer breaths; and (3) longer underwater phases (flip turns, gliding, and underwater strokes).

However, it is well known that competitive swimmers are able to precisely regulate their breathing (via changes in the stroke rate and stroke length) and velocity during maximal swimming so as to create the appearance of critical acidosis only at the end of swimming (Štrumbelj, Ušaj, Kapus, & Bednarik, 1999). Therefore, it seemed that the swim tests used in the present study were too general to detect and confirm these swimmers' experiences. A test with more controlled breathing should be employed to evaluate possible specific effects of IMT which follow to increase the inspiratory muscle strength. Indeed, Kapus and Ušaj (2012) recently investigated the influence of IMT on breathing during exercise with a prescribed and unchanged breathing frequency. They determined that IMT increased MIP and consequently the tidal volume during incremental exercise where breathing frequency was restricted.

CONCLUSION

In conclusion, the IMT increased respiratory muscle strength in the young swimmers. However, these improvements are only partially transferable to sprint swimming performance.

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