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Research article

Effect of Additional Respiratory Muscle Endurance Training in Young Well-Trained Swimmers

Frédéric Lemaitre [1], Jérémy B. Coquart ✉[1], Florence Chavallard [1], Ingrid Castres [1], Patrick Mucci [2], Guillaume Costalat [1] and Didier Chollet [1]
[1] Université de Rouen, CETAPS, Faculté des Sciences du Sport, Mont Saint Aignan, France; [2] UDSL, Activité Physique-Muscle-Santé, Faculté des Sciences du Sport, Ronchin, France

Abstract
While some studies have demonstrated that respiratory muscle endurance training (RMET) improves performances during various exercise modalities, controversy continues about the transfer of RMET effects to swimming performance. The objective of this study was to analyze the added effects of respiratory muscle endurance training (RMET; normocapnic hyperpnea) on the respiratory muscle function and swimming performance of young well-trained swimmers. Two homogenous groups were recruited: ten swimmers performed RMET (RMET group) and ten swimmers performed no RMET (control group). During the 8-week RMET period, all swimmers followed the same training sessions 5-6 times/week. Respiratory muscle strength and endurance, performances on 50- and 200-m trials, effort perception, and dyspnea were assessed before and after the intervention program. The results showed that ventilatory function parameters, chest expansion, respiratory muscle strength and endurance, and performances were improved only in the RMET group. Moreover, perceived exertion and dyspnea were lower in the RMET group in both trials (i.e., 50- and 200-m). Consequently, the swim training associated with RMET was more effective than swim training alone in improving swimming performances. RMET can therefore be considered as a worthwhile ergogenic aid for young competitive swimmers.

Key words: Breathing, normocapnic hyperpnea, performance, swimming.

Introduction

While some studies have demonstrated that respiratory muscle endurance training (RMET) improves performances during various exercise modalities, e.g., cycling, rowing, or running (McConnell, 2009) and brings about changes in pulmonary function (i.e., increased vital capacity and decreased residual volume; Esposito et al., 2010), controversy continues about the transfer of RMET effects to swimming performance.

Harms et al. (1997) have found a reciprocal relationship between the work of breathing and legs blood flow during maximal exercise on cycle ergometer. Thereafter, several authors (St Croix et al., 2000; Sheel et al., 2001, 2002) have concluded that the stimulus for limb vasoconstriction was a cardiovascular reflex originating within the inspiratory muscles. As reminded by McConnell (2009), this reflex seems be activated when metabolites are accumulated within the inspiratory muscles. Indeed, these metabolites stimulate the afferent nerve fibers, which increase their firing frequency. This stimulation precipitates an increase in the strength of sympathetic neural outflow, which induces a generalized vasoconstriction. To resume, the inspiratory muscle fatigue (IMF) reduces active limbs blood flow and exacerbates fatigue in these limbs (Romer et al., 2006). Consequently, it may be supposed that RMET may improve performance. This hypothesis has been confirmed by McConnell and Lomax (2006) who have suggested that inspiratory muscle training attenuates or delayed the vasomotor changes induced by the inspiratory muscle metaboreflex, which adaptation may produce an improvement of performance.

Recently, IMF after submaximal and/or maximal 'all-out' 100-, 200- and 400-m freestyle swim trials was found to be greater than the IMF typically observed for on-land sports (Jakovljevic and McConnell, 2009; Lomax and McConnell, 2003). Although these studies evaluated IMF using the maximal inspiratory pressure (MIP), the real effect on expiratory muscle function has been much less extensively studied and the data are currently contradictory, with significant drops in MIP both with and without declines in maximal expiratory pressure (MEP; McConnell, 2009). In fact, it may be supposed that expiratory muscle fatigue may be specific to the exercise modality (water- or land-based exercise) and/or the race distance. Authors (Brown and Kilding, 2011) have already showed that the swimming distance does not substantially influence the degree of IMF for distances included between 100- and 400-m. Nevertheless, no study to our knowledge has examined IMF and expiratory muscle fatigue from these swimming distances with shorter distances (e.g., 50-m freestyle swim trial).

Therefore, the objective of the present study was to determine the effects of RMET on swimming performances in well-trained swimmers. We hypothesized that the addition of RMET to the usual swim training would increase (i) the strength and endurance of the respiratory muscles and ventilatory parameters and (ii) the swimming performances for short and middle distances (50- and 200-m).

Methods

Subjects

Twenty young (between 13 and 18 years) well-trained (at least 14.0 h of training per week) swimmers of the local swimming pole, non-smoking and with normal lung function (Table 1), volunteered for the study. Then, two ho-

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mogenous groups were composed: ten swimmers (16.5 ± 2.4 years, 1.76 ± 0.09 m, 70.4 ± 11.7 kg, 4 females and 6 males) in the RMET group performed their usual training sessions (TS) and received RMET (in the form of normocapnic hyperpnea); and ten swimmers (16.1 ± 2.0 years, 1.76 ± 0.07 m, 70.7 ± 4.5 kg, 3 females and 7 males) were assigned to a control group with no RMET (these swimmers performed only their TS). The groups (RMET or control group) were constituted according to gender and age of participants in order to avoid a possible effect of these factors on data. All swimmers were primarily trained for short and middle distances (between the 50- and 200-m) and generally trained 45-48 weeks per year, with pool and dry land training typically reaching 20.0 ± 2.0 hr per week. All swimmers must be able to potentially add a RMET of 30 min, 5 days per week, and follow the study in full. Subjects refrained from strenuous physical exercise for 2 days before the test sessions and performed no physical exercise on the day prior to as well as on the day of the test. Caffeinated beverages were forbidden before the test and subjects ate their last meal at least 2 hr before each test. Subjects did not receive any financial reimbursement for participating, and all gave their written informed consent. The protocol was approved by the local ethics committee and performed according to the Declaration of Helsinki.

Experimental design

To test the hypothesis that TS+RMET increase (i) the strength and endurance of the respiratory muscles and ventilatory parameters and (ii) the swimming performances for short and middle distances, the group (i.e., RMET vs control group) and time (i.e., before and after the experimental protocol) effects and the group × time interaction were tested.

In a preliminary session, the subjects were thoroughly familiarized with the RMET device and the laboratory procedures, i.e., lung function measurements, respiratory muscle pressure measurements, and performance of normocapnic hyperpnea as required during the respiratory endurance test (RET). In the first experimental session, the following data were assessed: anthropometric variables, ventilatory function, MIP, MEP, and swim parameters (performances, ratings of perceived exertion: RPE, and ratings of perceived dyspnea: RPD). Following this, the subjects started the 8-week training period (the training group performed their usual TS associated with RMET, while the control group performed only their usual TS). In the second experimental session, at least 2 days after the last TS of the experimental period, anthropometric variables, ventilatory function, maximal mouth pressures (i.e., MIP and MEP), and swim parameters were measured again, and after at least 2 days, the RET was repeated. To avoid a possible circadian effect, all tests were performed at the same hour of day (between 7:00 to 9:00 a.m.).

Anthropometric parameters

Measurements of height, body mass and skinfolds were measured at the same time of day (i.e., the morning). The swimmer presented before training in a fasted state and all anthropometric variables were measured by the same investigator. Height was measured with a wall stadiometer (Tanita, Tanita©, Arlington Heights, IL, USA). Body composition (fat mass: FM) was estimated with the skinfold method of Durnin and Womersley (1974) using a calibrated skinfold caliper (Model HSK-BI, Baty International®, West Sussex, UK). For each skinfold, three measurements were obtained (accuracy ± 2%), then the mean was calculated. Higher chest expansion was measured at the level of the xiphoid process using a tape measure. The subject was instructed to perform a maximal exhalation [to residual volume (RV)] and then an inhalation to total lung capacity (TLC). Chest expansion was calculated as the difference between circumferences at RV and TLC.

Ventilatory function

Several parameters were measured for the pulmonary function tests: forced vital capacity (FVC), forced expiratory volume in 1 s (FEV_1), peak expiratory flow (PEF), and maximum voluntary ventilation (MVV_{12s}). For each parameter, the best value was chosen from at least three consecutive maneuvers differing by no more than 5% (Quanjer et al., 1993). All spirometry measurements were performed by the same experimenter according to the guidelines set by the American Thoracic Society and the European Respiratory Society (ATS/ERS, 2002; Miller et al., 2005). All parameters were measured with a Microquark spirometer (Cosmed®, Rome, Italy) in the same conditions, with the subject in a seated position and breathing through the mouthpiece with a nose-clip (accuracy: ± 2%, Cosmed®). The spirometer volume was calibrated with a 3-L calibrated syringe. The results were corrected to BTPS conditions (i.e., body temperature, ambient pressure and saturated with water vapor) and compared with the predicted values (Quanjer et al., 1993). The MIP and MEP were measured at the end of a normal expiration and inspiration (Esposito et al., 2010), respectively, using a small portable mouth pressure meter (ZAN 100 Flowhandy USB, ZAN Messgeräte GmbH®, Oberthulba, Germany). The occlusion was maintained for 2 to 3 s. Tests were repeated until no further improvement was obtained and at least three satisfactory attempts differed by less than 5%. The swimmers received visual feedback of the pressure generated during each effort by viewing the digital display on a computer screen. The feedback was provided in order to maximize their respiratory effort and ensure that they were at the end of normal expiration and inspiration for MIP and MEP measurements. Sufficient rest periods were provided between the attempts (at least 2 min) and the swimmers were verbally encouraged to reach maximal strength (Larson et al., 1993). The highest value was recorded for comparisons before and after RMET.

Respiratory endurance test (RET)

The RET protocol was incremental, in line with the recommendations from ATS/ERS (2002), and it was performed with the SpiroTiger device (Idiag AG®, Fehraltorf, Switzerland). The size of the rebreathing bag was set at 40-50% of vital capacity, and the target minute ventilation (V_E) for the first 3 min was 20% MVV_{12s}. Then, V_E was increased by 10% MVV_{12s} every 3 min until the subject could no longer maintain the target respiratory frequency (f_R) and tidal volume (V_T) despite three consecutive "warnings" by the experimenter. The total test duration and the maximum ventilatory level sustained for at least 3 min were recorded. The RPD was collected before the start of RET and at task failure. A rating of perceived dyspnea scale from 0 to 10 was used, with subjects being asked, "How hard was your breathing during the RET?" The descriptors were 0 = breathing is not hard at all, 2 = breathing is a little hard, 4 = breathing is getting harder, 7 = breathing is hard, 9 = breathing is really hard, and 10 = breathing is very, very hard. Immediately after the rating, a 5-µL capillary blood sample was drawn from a finger and analyzed to determine the lactate concentration (Lactate pro LT-1710, Arkray©, Kyoto, Japan).

Swim tests and swim performances

The field swim performance was evaluated from the swim times on 50- and 200-m during simulated competitions. These exhausting trials were performed in the morning and in randomized order. The swimmers were alone in the lane. Starts were made from the starting blocks with a whistle as the starting signal. Swim times were measured in duplicate by stopwatch, with one stopwatch functioning as backup only. Heart rate (HR) was measured using a heart rate monitor (S810i, Polar Electro®, Kemeple, Finland) continually during each test, then averaged for all trial duration. In addition, at rest and 3 min after the end of each swim trial, the capillary blood lactate concentration was determined (Lactate pro LT-1710, Arkray©, Kyoto, Japan). Then, the delta lactate concentration (i.e., ΔLa: lactate concentration measured 3 min after the end of trials minus lactate concentration at rest) was calculated. The RPE (Borg 6-20 scale) and RPD were also assessed after each swim trial (RPE_{50m}, RPE_{200m}, RPD_{50m}, and RPD_{200m}) (Altose et al., 1985). These assessments were made prior to and at the end of the 8-week RMET program by all swimmers.

Competition performance was assessed by the official international point score (IPS) system used by the International Swimming Federation (Fédération Internationale de Natation Amateur – FINA). The mean time of the eight fastest swims in the history of each event is ascribed the value of 1000 points, with individual performances rated against this reference value. This system allows comparison of a given competitive performance by a male or female athlete in any of the official events (i.e., freestyle, butterfly, backstroke, breast stroke, and individual medley). Competition swim times for each swimmer were also recorded in the most advanced stage reached (i.e., final, semi-final, or heat) in their best competitive event and for the 50- and 200-m trials (IPS_{50m} and IPS_{200m}) 2 weeks before and near the end of RMET.

Training

Swim training

All athletes were engaged in the same TS program (i.e., all groups together in the same swimming pool) specifically designed to enhance competitive swim performance and followed the training program set by their coaches. The coach kept a detailed training logbook for each swimmer that included the duration, distance, and intensity of each workout in the pool. The study was started at the beginning of the base training period [i.e., after detraining from the previous swimming year (transition phase)] and the RMET protocol was initiated after the preliminary session. None of the swimmers suffered any major injury during the study that prevented them from training.

Respiratory muscle endurance training

In the RMET group (i.e., the group that performed RMET), all subjects used the same training device (SpiroTiger, Idiag®, Fehraltorf, Switzerland), which consisted of a hand-held unit with a pouch and a base station. The properties of the training device allowed personalized respiratory training through voluntary normocapnic hyperpnea and without the limitation of lower limb muscle involvement (Verges et al., 2007; 2009). To avoid hypocapnia despite hyperventilation, the device features a two-way piston valve connected to a rebreathing bag. As the subject breathes out through the mouthpiece, the rebreathing bag stores part of the expired air, which contains increased concentrations of carbon dioxide (CO_2). Once the rebreathing bag is filled to capacity, a valve opens and allows the rest of the expired air to be released into the environment. The valve shuts when expiration finishes and inspiration starts. Inspiration empties the rebreathing bag first (containing increased concentrations of CO_2), then the valve opens and some fresh outside air is inspired at the end of each inspiration. This apparatus allows the execution of respiratory cycles with high frequency in conditions of normocapnic hyperpnea (Verges et al., 2007; 2009).

The RMET protocol was based on the protocol from Verges et al. (2007) and consisted of 30-min of TS per day, 5 days per week, for 8 weeks. The size of the rebreathing bag was set at 40-50% of vital capacity, and $\dot{V}E$ of the first TS was set at 60% of the MVV_{12s}. During the first week, participants were familiarized with the instrumentation. If, after 25 min of training, they felt that they would not be exhausted after 30 min of training, they were instructed to increase f_R by 5 breaths·min^{-1} for the last 5 min of the session. In this case, the next TS started with f_R that was 2 breaths·min^{-1} higher than an f_R at the start of the previous session. Otherwise, if subjects could not increase f_R after 25 min of training, the next TS started with f_R only increased by 1 breath.min^{-1}. If, after 25 min of training, subjects felt that they would not able to continue for another 5 min at the same target f_R, they were allowed to decrease f_R by 5 breaths.min^{-1}. In this case, the next TS started with settings identical to those of the previous session. TS were always conducted under expert supervision by an experimenter.

Statistical analysis

A normal distribution (Ryan Joiner test) and the homogeneity of variance (Bartlett test) were verified and authorized parametric statistics. A two-way analysis of variance (ANOVA) with repeated measures (2 groups

Table 1. Effects of respiratory muscle endurance training (RMET) on characteristics of the swimmers. Data are means (±standard deviation).

	Before RMET		After RMET	
	RMET group	Control group	RMET group	Control group
Body mass (kg)	70.4 (11.7)	70.7 (4.5)	69.8 (11.6)	69.8 (3.5)
Fat mass (%)	18.5 (9.2)	21.9 (11.7)	18.3 (8.6)	21.4 (10.9)
FVC (%)	125 (12)	130 (15)	128 (12) *	129 (17)
FEV_1 (%)	116 (11)	121 (11)	117 (9)	119 (6)
PEF (%)	102 (12)	104 (14)	104 (10)	100 (12)
MVV_{12s} (%)	99 (16)	103 (16)	113 (13) *	112 (16)
Field swim times on 50-m (s)	27.7 (2.2)	28.1 (1.8)	28.1 (2.1)	28.8 (1.8) *
Field swim times on 200-m (s)	136.0 (10.2)	137.5 (11.4)	136.7 (8.4)	138.1 (8.8)
Competition swim times on 50-m (s)	27.4 (2.3)	27.8 (2.2)	26.6 (2.1) *	27.6 (2.1)
Competition swim times on 200-m (s)	130.7 (12.8)	135.4 (11.4)	125.5 (8.8) *	126.9 (7.7)
IPS_{50m}	634 (49)	662 (41)	611 (58)	630 (66) *
IPS_{200m}	632 (36)	654 (76)	641 (41)	636 (53)
HR_{50m} (bpm)	164 (12)	162 (14)	167 (8)	166 (11)
HR_{200m} (bpm)	176 (11)	177 (6)	173 (10)	171 (4)
ΔLa_{50m} ($mmol \cdot L^{-1}$)	5.8 (2.4)	6.3 (1.8)	4.8 (1.8)	5.3 (1.6) *
ΔLa_{200m} ($mmol \cdot L^{-1}$)	8.1 (2.5)	9.1 (1.6)	6.9 (1.8)	7.9 (3.2)
Chest expansion (cm)	7.4 (1.4)	7.7 (1.7)	8.2 (1.2) *	7.3 (1.5)

FVC: forced vital capacity; FEV_1: forced expiratory volume in one second; PEF: peak expiratory flow; MVV_{12s}: maximum voluntary ventilation; IPS: international point scores for the 50- and 200-m experimental trials (i.e., simulated competitions); HR: heart rate; ΔLa: delta lactate concentration (i.e., lactate concentration measured 3 min after the end of trials minus lactate concentration at rest). * denotes $p < 0.05$ between before and after training.

× 2 times) was used to assess changes in lung function, respiratory muscle performance, and exercise response in two groups (RMET group vs control group with no RMET) over the protocol period (before vs after). If significance was found, Fisher's protected least-significant difference post-hoc analysis was applied to locate the difference. Moreover, correlations between some variables were examined with the Bravais-Pearson test and quantified by Pearson correlation coefficients. All statistical evaluations were performed using standard statistical software (Statview 5.0; SAS Institute, Cary, NC, USA). All data are presented as means ± standard deviation and $p < 0.05$ was considered statistically significant.

Results

During the experimental period, all swimmers followed the same TS 5-6 times per week for a total of 10-15 hr, covering distances of 14,000-34,000 $m \cdot wk^{-1}$ (attendance during the training sessions: 89%). Their characteristics, lung function data, and swim times for all field and competition trials are shown in Table 1. There were no differences between the two groups in age ($F_{1.15}$ = 0.10, p =0.75), height ($F_{1.15}$ = 0.02, p = 0.89), weight ($F_{1.15}$ = 0.01, p = 0.94) or fat mass ($F_{1.15}$ = 0.46, p = 0.50), and there were no changes in anthropometric variables (with the exception of chest expansion which was higher after the 8-week training period only in RMET group; $F_{1.15}$ = 2.48, p = 0.04) over the 8-week training period in either group (p > 0.05).

Pulmonary function and respiratory muscle strength

No change in pulmonary function was observed during the experimental period, except for FVC and MVV_{12s}, which were increased only in the RMET group ($F_{1.15}$ = 4.16, p = 0.04 and $F_{1.15}$ = 4.56, p = 0.02, respectively). MEP and MIP were increased only in the RMET group after the program compared with before, and with a difference between groups after the experimental period ($F_{1.15}$ = 8.11, p = 0.012 and $F_{1.15}$ = 13.55, p = 0.002, respectively; Figure 1). Any significant group × time interaction was found for pulmonary function and respiratory muscle strength. There was no significant correlation between the individual changes in MIP or MEP and any swimming performance measure (during the field trials or the competitions; p > 0.05).

Respiratory endurance test

Breathing duration was increased after the training period in the RMET group ($F_{1.13}$ = 13.19, p = 0.003) and was

Table 2. Effects of respiratory muscle endurance training (RMET) on the respiratory endurance test parameters for the swimmers. Data are mean s (± standard deviation).

	Before RMET		After RMET	
	RMET group	Control group	RMET group	Control group
Breathing duration (min)	16.0 (1.7)	14.1 (3.2)	24.6 (4.4) *†	17.0 (1.8)
V_{Emax} ($L \cdot min^{-1}$)	111.6 (25.1)	104.7 (9.9)	124.1 (24.8) *†	109.1(7.6) *
V_{Tmax} ($L \cdot min^{-1}$)	3.7 (.5)	3.8 (.1)	3.6 (.7)	3.9 (.3)
f_{Rmax} ($cycle \cdot min^{-1}$)	29.6 (4.3)	27.0 (2.5)	34.2 (3.7) *†	28.1 (3.4)
ΔLa ($mmol.L^{-1}$)	-.2 (.8)	-.7 (.7)	-.5 (.4)	-.7 (.8)

V_{Emax}: maximal minute ventilation during the respiratory endurance test; V_{Tmax}: maximal tidal volume during the respiratory endurance test; f_{Rmax}: maximal breathing frequency during the respiratory endurance test; ΔLa: delta lactate concentration (i.e., lactate concentration measured 3 min after the end of trials minus lactate concentration at rest). * denotes $p < 0.05$ between before and after RMET. † denotes $p < 0.05$ between the RMET group and controls.

higher in the RMET group than in the control group ($F_{1.13}$ = 9.41, p = 0.009) (Table 2). The maximal V_E and the maximal f_R were also increased but only for the RMET group after the training period ($F_{1.13}$ = 6.61, p = 0.02 and $F_{1.13}$ = 5.22, p = 0.039, respectively), while the maximal V_T remained similar after the experimental protocol for both groups (Table 2). Any significant group × time interaction was found for these values. ΔLa was not changed ($F_{1.13}$ = 1.13, p = 0.31).

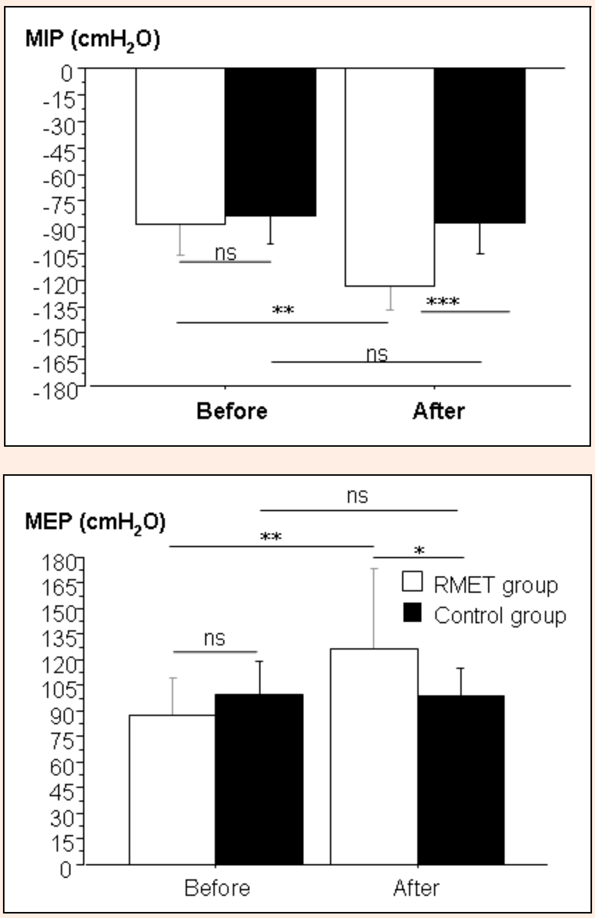


Figure 1. Effects of respiratory muscle endurance training (RMET) on maximal inspiratory and expiratory muscle strength (i.e., maximal inspiratory and expiratory pressures, MIP and MEP, respectively). Data are means (± standard deviation). * , ** and *** denote p < 0.05, 0.01 and 0.001, respectively.

Swimming competition performance and field exercise test

The performance times on distances were expressed as a percentage of the current world record and were 90.4% and 91.2% for the 50- and 200-m events, respectively. The IPS of the field exercise tests did not change, except for decreased IPS_{50m} in the control group (Table 1). Similar results were found for the actual swim times for all field trials (Table 1). Any significant group × time interaction was found for IPS. The ΔLa values were lower after the 50-m swim trial only in the control group and did not differ for the other distance or between groups (Table 1). In competition, swim times for the 50- and 200-m trials were improved only in the RMET group (3% and 4%, $F_{1.15}$ = 5.4, p = 0.02 and $F_{1.15}$ = 3.4, p = 0.03, respectively) (Table 1). Also in competition, IPS_{50m} was improved after RMET for both groups and IPS_{200m} was improved only in the RMET group ($F_{1.15}$ = 6.51, p = 0.02 and $F_{1.13}$ = 3.59, p = 0.03, respectively; Figure 2). Similar results were found for the actual swim times for all competition trials. Any significant group × time interaction was found for swim times. RPE and RPD were decreased in the RMET group, and for the 50- and 200-m trials after RMET (Figure 3a and 3b). Intragroup differences were found for RPE_{200m} and RPD_{200m} after RMET ($F_{1.15}$ = 8.1, p = 0.02 and $F_{1.15}$ = 5.7, p = 0.03, respectively). The RPD_{50m} was decreased in the control group after the training period (Figure 3b). Mean HR during the trials did not change whatever the group (Table 1). A significant correlation was found between the changes in RPE_{200m} and RPD_{200m} and the change in competition IPS_{200m} (r = 0.68, p < 0.01 and r = 0.59, p < 0.05). No significant correlation was found between RPE_{50m}, RPD_{50m} and IPS_{50m}. Chest expansion was increased only in the RMET group at the end of the experimental period (Table 1).

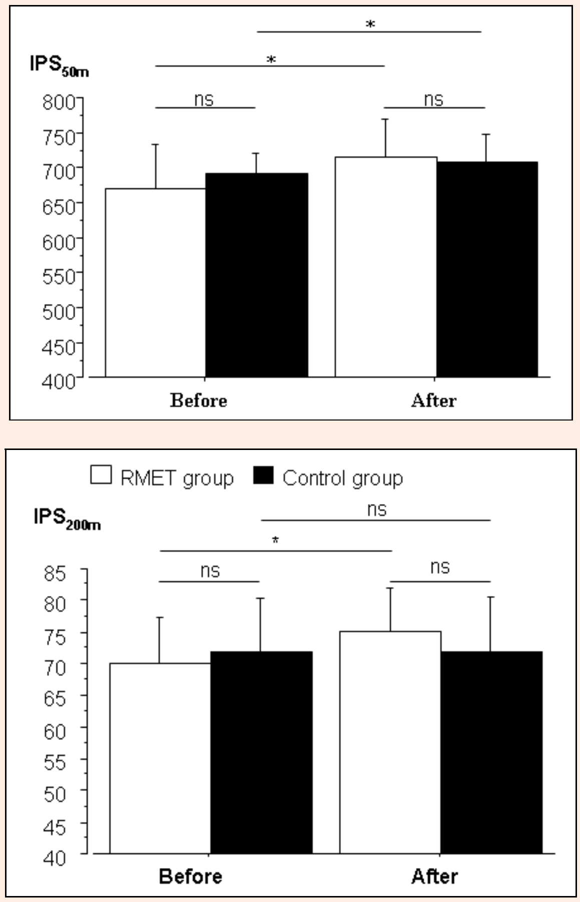
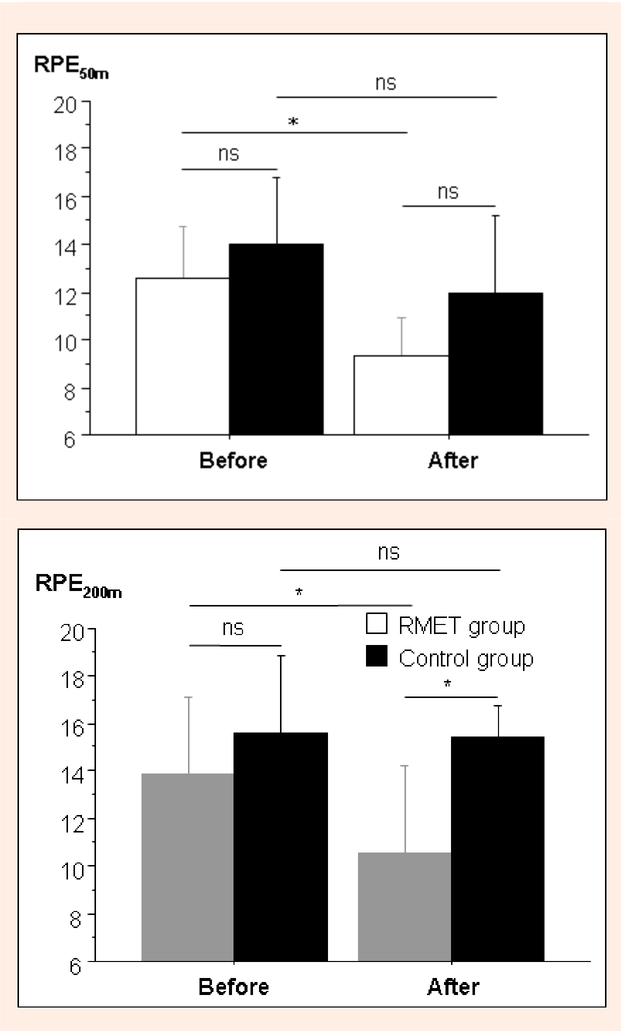


Figure 2. Effects of respiratory muscle endurance training (RMET) on change in international point scores (IPS) during the actual competitions. Data are means (± standard deviation). * denote sp < 0.05.

Discussion

The main results of the present study showed that an 8-week RMET program in well-trained swimmers increased

FVC and the strength and endurance of the respiratory muscles. In addition, the TS associated with RMET resulted in better time trials during swimming competition (in comparison with TS alone).



Figures 3. Effects of respiratory muscle endurance training (RMET) on the ratings of perceived exertion and the ratings of perceived dyspnea (RPE and RPD, respectively) measured after 50- and 200-m trials. Data are means (± standard deviation). * denote $p < 0.05$.

Exercise performance, ventilatory function

RMET has been shown to improve performances (between 1.8% and 4%) in both sedentary and trained subjects during cycling (Markov et al., 2001; McMahon et al., 2002; Stuessi et al., 2001) and running (Leddy et al., 2007), although not systematically when associated with inspiratory resistance strength training (Sonetti et al., 2001). Wells et al. (2005) evaluated the effects of a 12-week inspiratory and expiratory muscle training program (using an inspiratory and expiratory resistance training device). These authors failed to elicit improvement in either respiratory muscle strength or swimming performance and observed no change in perceptions of breathing effort. In the present study, the swimming performances observed during competition were improved more in the RMET group than in the control group (3% and 4% for the 50- and 200-m trials, respectively) with reduced RPD. To our knowledge, only one study has evaluated the effect of inspiratory muscle training (IMT) "alone" and showed improvements in swimming (Kilding et al., 2010). When compared with this previous study involving swimmers, the 3% and 4% improvements in the 50- and 200-m swim times were respectively higher than the improvements observed for the 100- and 200-m front crawl time trials (by 1.7% and 1.5% compared with control group) (Kilding et al., 2010) and similar to those observed in running (i.e., 4% in the study of Leddy et al., 2007). Wells et al. (2005) and Mickleborough et al. (2008) respectively found that a TS+inspiratory and expiratory muscle training program and TS+IMT were as effective as a TS+sham-inspiratory and expiratory muscle training program and TS+sham-IMT. They reported, however, improvements in several measures of pulmonary function (FEV_1 and/or forced inspiratory volume in 1 s: FIV_1) that were observed only in the RMET group. Kilding et al. (2010) found that IMT did not change pulmonary function in swimmers, although their swimming performance was improved. The discrepancies in these results may have been due to (i) the specific concurrent inspiratory and expiratory respiratory muscle training, which more closely mimicked the ventilatory constraints encountered during swimming and which may have improved chest expansion (inspiratory muscles) and contraction (expiratory muscles), and (ii) the younger age of our participants (16.5 ± 2.4 years). In the study of Wells et al. (2005), an inspiratory and expiratory muscle training program in swimmers of similar age induced changes consistent with our finding for FVC but not for FEV_1, although their training period was longer (12 vs 8 weeks). We believe the discrepancies are essentially due to differences in study design. Indeed, in the previous studies, the recruited populations were elite and adult swimmers, whereas in the present study the swimmers, although well-trained, were less trained and younger than their counterparts. The functional outcome of these conditions (i.e., being less well-trained and younger) was that the swimmers of the current study achieved maximum inspiration and expiration more quickly (Clanton et al., 1987). Although we did not measure any breathing parameters during swimming, this latter point would be particularly important for elite swimmers, since they need to increase the amount of air they inhale in the limited time their faces are out of the water and will consequently exhale more air during swimming.

The divergence of our results with those of the literature may be explained in part by methodological differences. Indeed, some studies have either omitted a control group (Boutellier et al., 1992; Boutellier and Piwko, 1992) or used a control group that participated in sham training (Wells et al., 2005; Mickleborough et al., 2008; Kilding et al., 2010) or no training at all (Holm et al., 2004). In swimming, some studies have observed enhanced swimming performance (Kilding et al., 2010) or enhanced underwater swimming performance in experienced divers (Wylegala et al., 2007), while no improvement was noted in the study of Wells et al. (2005). Indeed, it seems difficult to use sham respiratory training with this type of equipment (SpiroTiger®) without provoking distorted perceptions, and thus this type of sham training group cannot be likened to a placebo group. It was also suggested that the respiratory training "load" might be insignificant when included in the usual training programs of competitive swimmers and thus overwhelmed by the TS effects (Mickleborough et al., 2008). In our study, RMET was performed in the base phase of training, whereas in the other studies IMT was performed during the competition phase (Mickleborough et al., 2008). The study of Kilding et al. (2010), which found a significant effect of IMT, was nevertheless performed in the early phase of TS. No information about the training period was provided in the study of Wells et al. (2005), yet the effects of an inspiratory and expiratory muscle training program might be significant in the beginning of the season because they help swimmers to adapt their respiratory function to swimming effort. In periods of competition, the much more highly trained swimmers may not benefit from these effects. The training period might therefore be an important confounding factor that at least partly explains the differences in the observed results.

Respiratory muscle function

The present results are among the first to indicate that both the strength and endurance of the respiratory muscles in young well-trained swimmers can be further improved by RMET (+40.2% and +30.2% for inspiratory and expiratory muscle strength, respectively, and +37.5% for endurance). This finding is in agreement with Kilding et al. (2010), who showed increased inspiratory muscle strength as a result of TS+IMT. It has been shown that an increase in inspiratory muscle strength enhances lung volumes (i.e., FVC), increases diaphragm thickness, and improves exercise capacity in healthy subjects (Enright et al., 2006; Sheel, 2002). The improvement shown in our study for the RMET group can be explained, at least in part, by the relatively long duration of the program (i.e., 8 weeks) and the combination of inspiratory and expiratory muscle training. It may be suggested that respiratory muscle work limits exercise performance through a respiratory fatigue-induced metaboreflex, which increases sympathetic vasoconstrictor outflow and compromises perfusion of limb locomotor muscle, thereby limiting its ability to perform work (Romer and Polkey, 2008). Since ΔLa was not changed after RMET, it seems that RMET don't modify blood lactate concentration at rest neither the one measured 3 min after the end of trials in young well-trained swimmers.

We also found changes in the dyspnea measures, possibly for the same reasons. Increased fatigue resistance after RMET (Verges et al., 2008) may have contributed to reducing the perception of adverse respiratory sensations, as respiratory muscle fatigue was previously shown to increase the perception of respiratory effort (Gandevia et al., 1981). Moreover, numerous studies have showed that RPE (which is defined as the degree of heaviness and strain experienced in physical exercise; Borg, 1998) is influenced by several factors (Robertson and Noble, 1997). These factors have various origins (e.g., psychological and environmental factors), but the RPE is mainly determined by physiological mediators (Morgan, 1973). Among these physiological factors, the respiratory variables (e.g., respiratory rate, oxygen uptake and ventilation) seem be the best correlated to RPE compared to other physiological variables (e.g., HR, blood lactate concentration) (Chen et al., 2002). Consequently, the respiratory adaptation linked to RMET may explain the reduction of RPE in group with RMET.

The breathing duration, V_{Emax} and f_{Rmax} measured during the RET were increased after RMET and were higher in the RMET group than in the control group. This increase in respiratory muscle endurance is consistent with data from animal experiments that demonstrated increased oxidative metabolism activity in the diaphragm following various types of endurance training (Powers et al., 1992). It has also been hypothesized that specific respiratory muscle hyperpnea training may result in reduced chemoreceptor sensitivity via the repeated exposure to high levels of ventilation (McMahon et al., 2002). Wells et al. (2005) found a reduction in the ventilatory response to hypercapnia in swimmers after 12 weeks of inspiratory and expiratory muscle training program but no differences with their control group, indicating that the changes in chemoreflex threshold were the result of the TS. Although we did not measure the chemoreflex responses in our study, the increases in breathing duration, V_{Emax} and f_{Rmax} may indicate changes in the chemoreflex responses as a consequence of TS+RMET.

Interests for training

Our results suggest that TS+RMET (in comparison with only TS) contributes to improve the swimming performances mainly for middle distances (i.e., on the 200-m). However, the fact that the performance was also improved in control group (on the 50-m) suggests than the swimming performance was improved at least in part thanks to the TS. Consequently, it is not possible to conclude that RMET alone permits to improve the performance in swimmers, but the association of TS+RMET permits a higher improvement than TS alone on the 200-m. It may be recommended to associate RMET and TS in young swimmers specialized on the 200-m distance.

Limitations of the study

In the current study, the recruited population did have a large age range (between 13 and 18 years). Consequently, it is possible that this large age range has influenced our results. For example, the improvement performances in the younger swimmers (young adolescents of 13 years) may be due to adaptations linked to growth. Indeed, during the 2 months of the study, anthropometrical (e.g., increase of lean mass and decrease of fat mass) and physiological (e.g. increase of maximal oxygen uptake) modifications have maybe permitted to improve the performances in the younger swimmers, generating significant statistical difference in full group (but not in young adult swimmers of 18 years).

Similarly, we have recruited 7 female and 13 male swimmers. From the puberty, the discrepancy in performances increases between genders mainly because hormonal differences between females and males. Thus, it is possible that the results of the current study have been influenced by hormonal differences (e.g., higher production of testosterone in male swimmers) between the genders.

Another limitation of our study is that RMET has been performed during only 8 weeks. Indeed, although this duration was sufficient to improve the swimming performances and several pulmonary parameters, a longer duration might have produced higher pulmonary adaptations, and thus better performances.

Finally, it should be kept in mind that the swimming performance is a multi-factorial phenomenon (e.g., physiological, biomechanical psychological factors) in which each factor have probably play a major role in the performance. It is thus illusive to attribute entirely the improvement of performances at RMET alone.

Conclusion

The results of the present study indicated that TS+RMET were more effective than TS alone in eliciting improvements in swimming performance (50- and 200-m). Indeed, TS+RMET seems improve the performance for approximately 3-4%. The present data suggest that RMET also has beneficial effects on pulmonary function, dyspnea and perceived exertion. RMET can therefore be considered a worthwhile ergogenic aid for competitive swimmers. Further studies are clearly needed to evaluate the effect of RMET vs IMT on swimming performance in competitive swimmers.

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Key points

- Respiratory muscle endurance training improves the performance.
- Respiratory muscle endurance training improves the ventilatory function parameters, chest expansion, respiratory muscle strength and endurance.
- Respiratory muscle endurance training decreases the perceived exertion and dyspnea.
- • Respiratory muscle endurance training can be considered as a worthwhile ergogenic aid for young competitive swimmers.

✉ **Jérémy Coquart**
CETAPS, EA n°3832, Faculté des Sciences du Sport, Boulevard Siegfried, Université de Rouen, 76130 Mont-Saint-Aignan, France

AUTHORS BIOGRAPHY

Frédéric LEMAITRE
Employment
Associate professor at Rouen University (Faculty of Sport Sciences), and member of the CETAPS laboratory.
Degree
PhD
Research interests
Exercise physiology, respiratory physiology, apnea, swimming.
E-mail: frederic.lemaitre@univ-rouen.fr

Jérémy B. COQUART
Employment
Associate professor at University of Rouen (Faculty of Sport Sciences), and member of CETAPS laboratory.
Degree
PhD
Research interests
Exercise physiology, metabolic physiology, effort perception.
E-mail: jeremy.coquart@voila.fr

Florence CHAVALLARD
Employment
Member of CETAPS laboratory.
Degree
PhD candidate
Research interests
Biomechanics, motor control, exercise physiology applied to swimming.
E-mail: florence.chavallard@univ-rouen.fr

Ingrid CASTRES
Employment
Member of CETAPS laboratory.
Degree
PhD
Research interests
Exercise physiology, metabolic physiology, rehabilitation.
E-mail: ingrid.castres@univ-rouen.fr

Patrick MUCCI
Employment
Professor at Lille 2 University (Faculty of Sport Sciences), and member of the LEMH laboratory.
Degree
PhD
Research interests
Exercise physiology, respiratory physiology.
E-mail: patrick.mucci@univ-lille2.fr

Guillaume COSTALAT
Employment
Member of CETAPS laboratory.
Degree
PhD candidate
Research interests
Exercise physiology.
E-mail: guillaume.costalat@univ-rouen.fr

Didier CHOLLET
Employment
Professor at Rouen University (Faculty of Sport Sciences), and head of the CETAPS laboratory.
Degree
PhD
Research interests
Biomechanics, motor control, exercise physiology applied to swimming.
E-mail: didier.chollet@univ-rouen.fr