RESPIRATORY MUSCLE ACTIVITY DURING SIMULTANEOUS STATIONARY CYCLING AND INSPIRATORY MUSCLE TRAINING

NATHAN J. HELLYER, IAN A. FOLSOM, DAN V. GAZ, ALYNN C. KAKUK, JESSICA L. MACK, AND JACYLN A. VER MULM

Department of Physical Medicine and Rehabilitation, Mayo Clinic, Rochester, Minnesota

ABSTRACT

Hellyer, NJ, Folsom, IA, Gaz, DV, Kakuk, AC, Mack, JL, and Ver Mulm, JA. Respiratory muscle activity during simultaneous stationary cycling and inspiratory muscle training. *J Strength Cond Res* 29(12): 3517–3522, 2015—Inspiratory muscle training (IMT) strengthens the muscles of respiration, improves breathing efficiency, and increases fitness. The IMT is generally performed independently of aerobic exercise; however, it is not clear whether there is added benefit of performing the IMT while simultaneously performing aerobic exercise in terms of activating and strengthening inspiratory muscles. The purpose of our study was to determine the effect of IMT on respiratory muscle electromyography (EMG) activity during stationary cycling in the upright and drops postures as compared with that when the IMT was performed alone. Diaphragm and sternocleidomastoid EMG activity was measured under different resting and cycling postures, with and without the use of the IMT at 40% maximal inspiratory pressure ($n = 10$; mean age 37). Cycling in an upright posture while simultaneously performing the IMT resulted in a significantly greater diaphragm EMG activity than while performing the IMT at rest in upright or drops postures ($p \leq 0.05$). Cycling in drops postures while performing the IMT had a significantly greater diaphragm EMG activity than when performing the IMT at rest in either upright or drops postures ($p \leq 0.05$). Sternocleidomastoid muscle activity increased with both cycling and IMT, although posture had little effect. These results support our hypothesis in that the IMT while cycling increases respiratory EMG activity to a significantly greater extent than when performing the IMT solely at rest, suggesting that the combination of IMT and cycling may provide an additive training effect.

KEY WORDS diaphragmatic breathing, respiratory loading, resistance training

Address correspondence to Nathan J. Hellyer, hellyer.nathan@mayo.edu.

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INTRODUCTION

Exercise-induced ventilation in healthy individuals is rarely performance limiting (18). However, improvements in cycling endurance after respiratory muscle training are not because of cardiac adaptations alone, suggesting that the respiratory system may be an exercise-limiting factor (13). In accordance with this, previous studies demonstrate that inspiratory muscle training (IMT) reduces shortness of breath and effort in trained cyclists (5,19). The IMT is a type of breath training that requires an athlete to breathe through an external device that restricts airflow during inspiration and can be thought of as simply resistance training for the inspiratory muscles. Advantageously, the IMT increases time trial performance in both elite and novice cyclists (11,12,19,22). Therefore, the IMT may be a beneficial addition for improving cycling endurance and performance.

Inspiratory muscles such as the diaphragm are necessary for breathing and perhaps the most active skeletal muscles of the body (21). With exercise, inspiratory muscle activity must further increase to meet ventilatory demands. Therefore, one may assume that the more efficient the inspiratory muscles are, the lower will be the energy cost of breathing. In agreement with this, the IMT strengthens the muscles of respiration, improves breathing efficiency, and increases (4,7,22). For example, in a study conducted by Gething et al. (7), the resting IMT at 80% maximal inspiratory pressure (MIP) 3 times per week for 10 weeks improved cycling time to exhaustion by 36%. Both respiratory strength (measured by MIP) and endurance (measured by sustained MIP [SMIP]) increased by approximately 35% (7). Enright et al. (6) reported that the IMT at 80% SMIP resulted in increased inspiratory muscle strength and endurance (MIP and SMIP), diaphragm thickness, lung volumes, and work capacity as measured by a progressive, incremental exercise cycle ergometer test (6).

Previous studies have concluded that intensities of 50–80% MIP or SMIP are required to produce inspiratory muscle strength gains and improved functional outcomes (4,6,7). In an 8-week randomized controlled trial of moderately active adults (4), the IMT at 80% SMIP resulted in an increased MIP, SMIP, lung volumes, work capacity, and power output. Training at 60% SMIP resulted in an increase in the power output and work capacity only. The IMT intensities <40% SMIP improved the MIP and SMIP but did not result in a significant increase in functional tests, suggesting that improvements in volitional tests do not necessarily match meaningful performance outcomes (4).

During sustained bouts of heavy exercise, hypoxia exaggerates the degree of diaphragmatic fatigue in highly trained endurance cyclists (23) and in healthy individuals loads of >40% MIP cause diaphragmatic fatigue (20). Although the IMT is generally performed independently of aerobic exercise, it is not clear whether there is any added benefit of performing periodic IMT while simultaneously performing aerobic exercise in terms of activating and strengthening inspiratory muscles to increase functional outcomes such as work capacity, power output, and time trial performance. One might assume that the IMT concurrently performed with specific activities would have the additive training benefits.

The primary purpose of our investigation was to examine the influence of IMT on inspiratory muscle electromyography (EMG) activity during stationary cycling compared with that when cycling or IMT alone. The majority of the research on IMT has been conducted in an upright posture at 50–80% MIP; however, we investigated the combination of IMT and cycling together, and therefore, we chose to use a nonfatiguing intensity of 40% so that subjects were able to perform moderately intensive bouts of cycling. We hypothesized that the IMT performed simultaneously with cycling would increase inspiratory muscle activity. In this study, we measure inspiratory muscle activity by surface EMG previously reported to be a valid and reliable method for measuring inspiratory muscle muscle activity during IMT (3).

An additional consideration for respiratory effort during cycling exercise and the IMT is posture. The inspiratory muscles are primary contributors to core stabilization and as such must respond not only to respiratory demand but also to postural demand (1,10). Therefore, the second purpose of our study was to examine the influence of cycling posture on inspiratory muscle EMG activity.

Methods

Experimental Approach to the Problem

In this study, our aim was investigate inspiratory muscle recruitment during the combined activities of IMT and cycling, and a comparison of recruitment in different cycling postures. To measure inspiratory muscle recruitment during IMT and cycling, we recorded diaphragm and sternocleidomastoid EMG activity during stationary cycling in both the upright and drops cycling postures, with and without an IMT. We chose to use an IMT of 40% MIP so as to minimize inspiratory muscle fatigue. The MIP was measured using an electronic IMT device (POWERbreathe Kinetic KH1) that could then be set at a fixed training load of 40% MIP. The fold increase in muscle EMG activity above resting breathing was normalized to the average activity during resting breathing in the upright posture. Diaphragm muscle activity represents the primary inspiratory muscle activity (including intercostal muscles) and sternocleidomastoid activity was chosen to represent accessory inspiratory muscle activity.

Subjects

The Mayo Institutional Review Board approved all methods and procedures, including the use of human subjects. We recruited 10 healthy adult cyclists (7 men, 3 women) aged 23–54 years to participate in the study. The subjects were avid cyclists who cycled a minimum of 90 $min \cdot wk^{-1}$, had a body mass index <26, and were visibly lean. Although some subjects had been competitive cyclists in the past, all the subjects currently self-identified themselves as fit, recreational riders. Investigators excluded subjects acknowledging a history of cardiac, pulmonary, or neuromuscular disease. Each participant gave informed written consent before entering the study. Subject characteristics are given in Table 1.

Procedures

Muscle EMG activities from the diaphragm, external oblique, and sternocleidomastoid muscles were obtained using a Delsys Bagnoli-16 EMG system (20- to 450-Hz bandwidth and a 80-dB per decade bandwidth roll off) at 1,000 Hz with double-differential surface electrodes (Delsys Inc., Boston, MA, USA) under different respiratory conditions. The polycarbonate surface electrodes were rectangular (41 × 20 × 5 mm) with 3 silver bars (10 × 1.0 mm) encased 10 mm apart in a parallel configuration. Skin was cleaned with alcohol before placement, and hair was shaved if present in the desired placement position. The electrode bars were placed perpendicular to muscle fiber direction as best as could be determined. The double differential electrodes were used to minimize crosstalk and are reported to have a $>10^{15}$-Ω input impedance, a −92-dB (at 60 Hz) common mode rejection ratio, and 10 $V \cdot V^{-1}$ of actual gain.

The various respiratory conditions tested were resting in the upright posture (Figure 1A), resting in the drops posture

Table 1. Subject characteristics.*

Age (y)	Height (cm)	Weight (kg)	BMI	40% MIP (mm H_2O)
37 ± 12	178 ± 8	73 ± 11	23 ± 2	38.5 ± 10.1

*BMI = body mass index; MIP = maximal inspiratory pressure.

(Figure 1B), resting in the upright posture while performing the IMT, resting in the drops posture while performing the IMT, cycling in the upright posture, cycling in the drops posture, cycling in the upright posture while performing the IMT, and cycling in the drops posture while performing the IMT. The respiratory period was simultaneously recorded using a 2-belt pneumatic bellows system with 1 monitoring belt under the axilla and a second monitoring belt below the chest line. The placement of the double-differential electrodes for the inspiratory muscles was similar to that described by de Andrade et al. (2,3,8) on the right side of the body. Before surface electrode placement, the skin was cleaned using alcohol pads to reduce the interference of EMG activity. The diaphragm surface electrode was placed on the lowest intercostal space at the midclavicular line at an oblique angle in parallel with the muscle fibers. The external oblique surface electrode was placed directly above the anterior superior iliac spine halfway between the iliac crest and the ribs at an oblique angle in parallel with the muscle fibers. The sternocleidomastoid surface electrode was placed midway between the origin at the mastoid process and the insertion at the sternum. The ground electrode was placed on the bony prominence of the anterior superior iliac spine of the ilium.

Subjects' height and weight were obtained, and the subjects were fitted in a standardized manner for the upright and drops postures (Figure 1) (15–17). In the 3-o'clock position, a plumb line was anchored at the anterior aspect of the knee and dropped to ensure that it was aligned at the end of the crank arm. Maximal inspiratory pressure was recorded using a POWERbreathe Kinetic KH1 (HaB International Ltd., Warwickshire, England, United Kingdom) device with a filter adapter and nose clip. Three trials of MIP were collected. The participants were instructed to fully exhale and then immediately inhale as strongly as possible into the device while wearing a nose clip. Maximal inspiratory efforts for 3 trials were averaged, and 40% of the average was calculated to determine their 40% training intensity. The POWERbreathe Kinetic KH1 was set at a training intensity equivalent to 40% MIP, and the participants then practiced with the device for up to 1 minute. After placing the surface electrodes and bellows on the participant, the bellows were calibrated for maximal inspiration in the upright posture and maximal expiration in the drops posture on the bike with the participant wearing a nose clip and hands on the handlebars.

The EMG activity for each condition was obtained for 60 seconds. In the placement condition, the participants were instructed in left cervical rotation to verify the placement of the sternocleidomastoid surface electrode, left trunk rotation to verify the placement of the external oblique surface electrode, and a sniff or deep breath to verify the placement of the diaphragm surface electrode. The external oblique surface electrode was used to verify that crosstalk did not occur between the diaphragm and external oblique muscles. The directions for all resting conditions were for the participants to sit as quietly as possible with their hands on the handlebars, breathe normally, and not to talk or move during data collection. During all IMT conditions, the participants were instructed to keep the IMT device in their mouth during the testing period unless they felt it was necessary to remove it for their health and safety. Before testing, the participants were given time to warm up on the stationary bike at self-selected watts and a pedal rate between 80 and 100 rpm until they felt they were working at a level of 14–16 on the Borg's Rating of Perceived Exertion scale. The subjects were instructed to maintain their exertion within these ranges during each cycling condition selected.

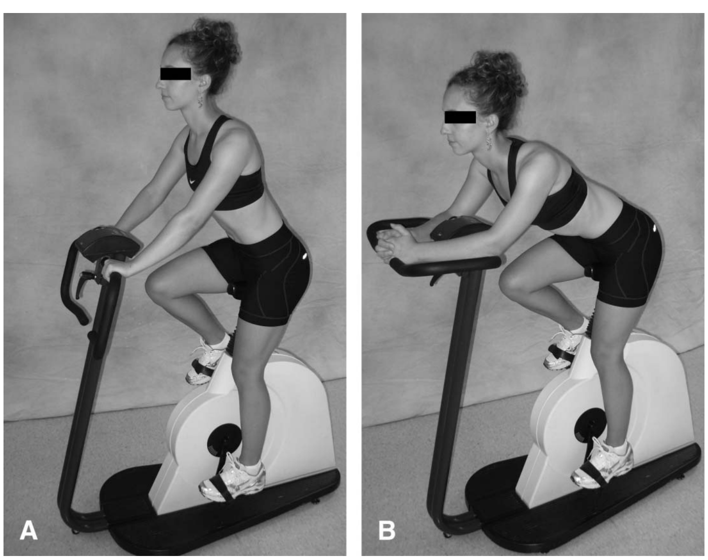

Figure 1. Cycling postures. A) Upright posture as a cyclist might choose for comfort. B) Drops posture as a cyclist might choose for aerodynamics.

Statistical Analyses

Data were analyzed using Delsys EMGworks software (Boston, MA, USA). The EMG recordings used for data analysis were from the first 3 consecutive breaths occurring 30 seconds into the testing condition. The room mean square was calculated for each value and normalized to the EMG activity from the resting

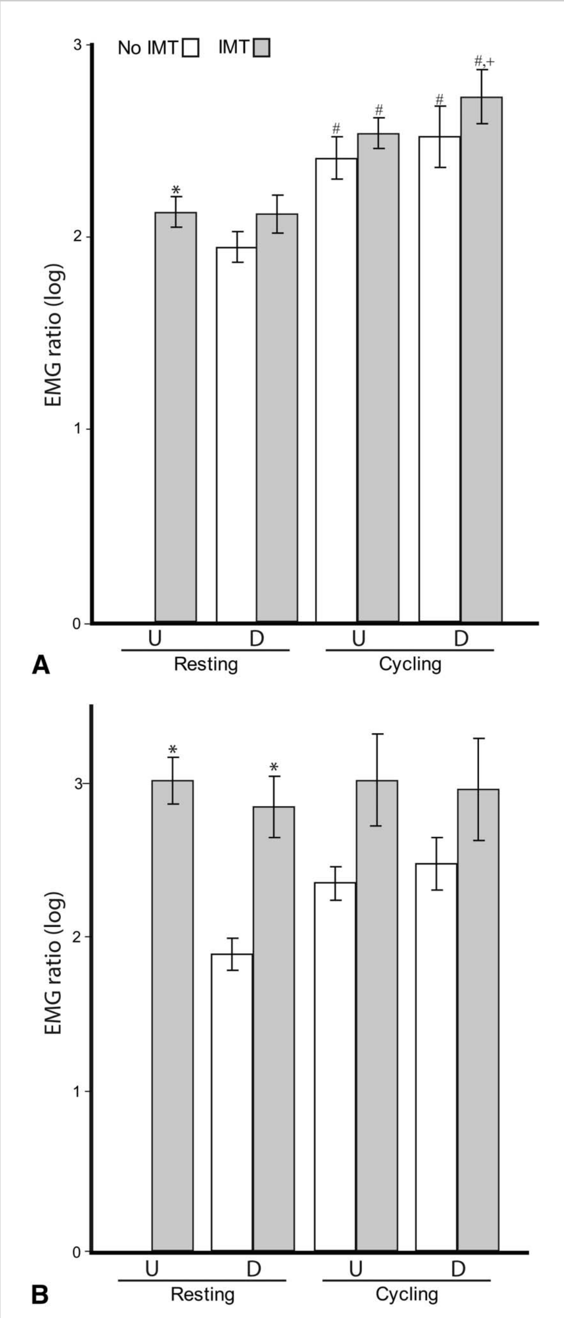

Figure 2. The electromyography activity for A) diaphragm and B) sternocleidomastoid muscles. U = Upright posture; D = drops posture. *Significantly different from resting and upright postures ($p \leq 0.05$), #significantly different from resting in the upright posture and resting in the drops posture ($p \leq 0.05$), +significantly different from all resting conditions ($p \leq 0.05$).

upright condition from the participant for each the diaphragm and sternocleidomastoid. The average peak EMG activity was calculated from the 3 breaths analyzed. As employed by Duiverman et al. (3), we then performed $\log_{10}$ transformation of the data to assign normality to the data and allow for parametric statistical analysis. Using JMP 9.0.0 statistical software (SAS Institute Inc., Cary, NC, USA), we compared conditions using a 3-way between-factor (cycling condition, posture, and IMT) analysis of variance for each muscle. Least squares mean differences were compared using the Tukey honestly significant differences test for the post hoc comparison of the means of individual conditions using an alpha level of significance set at $p \leq 0.05$.

Results

Diaphragm EMG activity generally increased above resting conditions with both cycling and IMT interventions, both alone and in combination (Figure 2A). Three-way interaction effects were detected for cycling, posture, and IMT ($p \leq 0.05$). The addition of the IMT in the upright posture during resting conditions significantly increased diaphragm EMG activity, but the addition of the IMT under other postural conditions did not lead to significant increases in the EMG activity. The addition of cycling significantly increased diaphragm activity above resting conditions independent of posture. During all cycling interventions, independent of the IMT and posture, diaphragm EMG activity was significantly greater than in noncycling conditions that did not incorporate the IMT. Cycling in the drops posture along with the IMT significantly increased the diaphragm EMG activity above all noncycling conditions tested. Significant differences in diaphragm activation were not observed between cycling postures (with or without IMT); however, cycling in the drops posture with IMT had a significantly greater diaphragm EMG activation compared with cycling in the upright posture.

Sternocleidomastoid EMG activity increased above resting conditions with both cycling and IMT activities, both alone and in combination (Figure 2B). Resting in the upright or drops postures combined with IMT showed a significantly greater sternocleidomastoid activity than resting in either the upright or drops posture alone ($p \leq 0.05$). In other words, the IMT while resting in either posture increases the sternocleidomastoid activity more than resting does. Although cycling increased the sternocleidomastoid EMG activity above resting conditions, neither posture nor IMT significantly increased sternocleidomastoid activity while cycling. These results suggest that cycling and IMT both increase sternocleidomastoid muscle activity and that additive effects are not readily apparent.

Discussion

Previous studies have demonstrated that the IMT at 50–80% intensity of the MIP results in diaphragm strength and endurance gains (4,6,7). This study explored whether combining a nonfatiguing IMT intensity (40% IMT) with cycling would significantly increase respiratory muscle recruitment and activity. In agreement with our hypothesis, we observed that the IMT at 40% MIP plus cycling produces a significantly greater EMG activity than does IMT alone. This suggests that cycling plus IMT may provide an additive training effect as compared with traditional IMT training.

Inspiratory Muscle Recruitment and Exercise Mode

The IMT at 40% MIP was sufficient to increase the diaphragm activity above resting conditions. However, the effects of IMT on diaphragm activity were not observed to be as profound as those of cycling. Interestingly, cycling alone significantly increased the diaphragm activity above the resting activity, regardless of the IMT or posture (Figure 2A). We attribute increased diaphragm activity to the increased ventilatory demands of cycling, although we cannot rule out that a greater diaphragm activity may be required for postural stability during cycling (9). We do not believe the latter to be the case because our tests were performed using a stationary cycle and EMG activity was matched breath by breath rather than by tonic postural activity that might be required for trunk stabilization.

In contract to the diaphragm, sternocleidomastoid muscle activity was observed to be most profoundly affected by IMT. Although exercise increased the activity of the accessory muscles as we would anticipate, the activity did statistically distinguish itself above resting, IMT, or postural conditions. In contrast, IMT significantly increased the sternocleidomastoid activity above resting conditions regardless of cycling or posture. We would anticipate that the increased work of breathing induced by IMT would augment the recruitment of accessory muscles. Further, the increased recruitment of the sternocleidomastoid by the IMT likely obscures any additional contributions that may be attributed to the ventilatory demands of cycling.

Postural Considerations

An additional question we asked in this study was whether cycling posture has any impact on inspiratory muscle activity. It is possible that a greater diaphragm activity is required in the drops posture compared with that in the upright posture because of the compression of abdominal organs against the diaphragm (14). With a decrease in abdominal expansion, cyclists may increase breathing frequency because deep breathing becomes more difficult or uncomfortable. Consequently, the inspiratory flow rate is higher and the inspiratory muscle effort and fatigue are greater (14). Therefore, we hypothesized that cycling in a drops posture will increase inspiratory muscle activity by a greater amount as compared with that in the upright conditions.

Interestingly, the aerobic demands of cycling increased inspiratory muscle diaphragm activity above resting activity regardless of posture. In contrast to our hypothesis, postural changes such as cycling in the upright versus drips posture, with or without IMT, do not seem to have a significant effect on the diaphragm activity. This does not support the current belief that the drops posture increases the workload of the diaphragm (14). According to McConnell (14), cyclists increase the breathing frequency because deep breathing is uncomfortable because of decreased space, and this leads to a higher inspiratory flow rate concordant with inspiratory muscle fatigue and effort. Although our data showed a trend toward increased diaphragm activity in the drops posture, it was not significant. It is possible that compensation by accessory and abdominal muscle contributes to respiratory adaptations such that increased efforts by the diaphragm are minimized.

The IMT while resting in either the upright or drops cycling posture displayed a significantly greater sternocleidomastoid EMG activity when compared with resting without IMT in the drops posture. This makes sense in that the resistance of the IMT alone induces greater activity than in resting breathing. The IMT while resting upright also demonstrates a significantly greater sternocleidomastoid EMG activity compared with cycling alone in any posture, suggesting that the IMT recruits more accessory muscles than does cycling alone. This could be because of the observation that the IMT, even at 40% maximal effort, is much more demanding of respiratory muscle activity than is moderately intense aerobic exercise, supporting the rationale for IMT as an advantageous adjunct to aerobic training alone (14).

Practical Applications

Although high-intensity IMT is thought to be necessary for significant inspiratory muscle training effects, we show here that the combination of cycling and moderate IMT at only 40% MIP significantly recruits a greater diaphragm activity compared with that in the resting IMT. We believe that the lower intensity IMT is more feasible and tolerable in combination with moderate intensity cycling than the more extreme IMT intensity. Cyclists can therefore use the IMT while cycling as an additional method to train. This might be especially useful when a cyclist is limited in workload because of recovery from a lower extremity injury and desire to maintain respiratory fitness.

Acknowledgments

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