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Letter to editor

Training Load Influences the Response to Inspiratory Muscle Training

Dear Editor-in-chief

The studies by Szczepan et al. (2020a; 2020b), which demonstrated no increase in inspiratory or expiratory muscle strength, no change in cardiorespiratory fitness, and no change in lipid utilization during exercise in recreational swimmers following six weeks of moderate-intensity swimming with added respiratory dead space, highlights a key factor which influences the response to exercise training, and especially training targeting the respiratory muscles. Although exercise with added respiratory dead space differs from traditional inspiratory muscle training (IMT), as noted by the authors in their second paper (Szczepan et al., 2020a), this intervention should nonetheless increase the work required of the respiratory muscles during exercise, and thus a putative training effect that might mimic other forms of IMT. As the authors point out in their discussion, it is likely that the stimulus from their training intervention was insufficient to elicit a training adaptation in the study participants in either study. This crucial factor, the total training load, and in particular the load placed on the respiratory muscles, has been an elusive, yet important factor in driving whether IMT enhances respiratory muscle function or fails to elicit a training response.

Many IMT loading protocols, some of which were developed for patients with chronic cardiorespiratory diseases, may not sufficiently overload the inspiratory muscles in healthy athletes (Karsten et al., 2018). The inspiratory muscles are skeletal muscles, and thus in order to elicit a training adaptation, they must be sufficiently overloaded in order to adapt to IMT. Studies in limb locomotor resistance training have shown the largest effect when training is conducted to task failure (Shei and Mickleborough 2019). It is reasonable to posit that this paradigm may be applicable to the respiratory muscles as well, suggesting that an IMT loading protocol that progresses to "task failure" may be an optimal method of training the inspiratory muscles (Shei and Mickleborough, 2019). In this context, "task failure" may be defined in several ways, such as the failure to generate a pre-defined level of inspiratory pressure, failure to maintain a pre-defined level of minute ventilation, or failure to maintain a pre-defined tidal volume and/or respiratory rate. Regardless of the method used to assess task failure, it is important that the pre-defined "failure" threshold requires a sufficient amount of respiratory muscle work to overload the muscles and thus induce a training adaptation. Generally, protocols involving inspiratory resistance training (such as pressure-threshold or flow-resistive IMT, (Shei et al., 2016) appear to be more common and, perhaps, more efficacious than volume-based protocols (such as normocapneic hyperpnea,). Training protocols which utilize a progressive work-rest ratio, such as the test of incremental respiratory endurance (TIRE) regimen (Mickleborough et al., 2008; Shei et al., 2016), are a method by which the training session becomes progressively more difficult until subjects are unable to complete the required task, or a given level of respiratory muscle work is achieved. These types of protocols may be better suited to prolonging IMT to "task failure."

This approach may be especially effective in athletes, who have otherwise healthy cardiopulmonary systems which are well-adapted to high levels of respiratory muscle work during exercise (Dempsey et al., 2020). The application of IMT in athletes seems to be optimized when the IMT training protocol is matched with the ventilatory demands of the criterion exercise task (Shei, 2018a). The ventilatory demands of a given exercise modality vary greatly, but perhaps none more so than in swimming exercise compared to conventional land-based exercise. Water-based exercise, including swimming, diving (underwater diving, e.g., SCUBA), and other aquatic sports, requires athletes to exercise while immersed in water, which creates a fluid column exerting hydrostatic pressure around the thoracic cavity (Shei, 2018b). This creates an additional load which must be overcome by the inspiratory muscles to generate a given flow and/or pressure in the airways. Previous investigations have demonstrated that swimmers have above-normal spirometry and pulmonary diffusion capacity (Mickleborough et al., 2008), and that regular aquatic exercise may mimic resistive inspiratory muscle training (Mickleborough et al., 2008; Shei et al., 2016; Lomax et al., 2019). Experienced swimmers tend to adapt their breathing patterns to water-based activity by making a rapid inspiration to near total lung capacity (TLC), followed by a breath hold at this volume, before exhaling rapidly immediately before the next breath. This pattern allows for rapid expiration while the face is still immersed in water, followed by a rapid inspiration while the mouth and nose are exposed to the air during each stroke cycle. In addition, by holding the inspired air at or near TLC, the swimmer increases the buoyancy of the thorax, which may enhance performance during swimming exercise. This unique breathing pattern, in addition to the aforementioned hydrostatic pressure load of water immersion, may mimic the effects of IMT, and thus in experienced swimmers, a higher IMT training load may be necessary in order to achieve an ergogenic effect. This has been demonstrated independently by Mickleborough (2008) and Shei (2016), and Lomax et al. (2019). The former group found that elite swimmers undertaking a high volume of swim training did not benefit from IMT in addition to their regular swim training routine, but sub-elite swimmers, who completed a lower volume of swim training, did benefit from adding IMT to their swim training routine. Similarly, Lomax et al. (2019) found a dose-dependent effect of swim training on respiratory muscle adaptation in well-trained youth swimmers, and that only swimmers who completed less than 31 $km \cdot wk^{-1}$ of swim training benefited from IMT. Together,

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these findings suggest that in order for swimmers to benefit from IMT, either a higher resistance, increased number of repetitions, and/or prolonged time period of training may be necessary to sufficiently overload the respiratory muscles in order to induce a training adaptation, compared to non-swimmers.

A final consideration is whether IMT undertaken concurrently during exercise is beneficial, or whether specific IMT completed at rest may be a better approach (Karsten et al., 2018; Shei, 2018a). While no studies to date have directly compared these two approaches, it appears that both of these approaches may have merit in eliciting an ergogenic effect. The use of IMT at rest as an ergogenic aid in many sports is well established (Karsten et al., 2018; Shei, 2018a), but only more recent investigations have studied concurrent IMT and exercise. Collectively, these studies suggest an additive effect of concurrent IMT and exercise training (Shei, 2018a). The duration of training exemplifies a further consideration in the potential synergy between IMT and exercise training. For example, a recent review of concurrent exercise and IMT training protocols showed that 3 weeks of exercise training alone produced similar effects to 3 weeks of exercise training completed with an additional inspiratory load of 15% of maximal inspiratory pressure (Shei, 2018a). When the combined exercise and IMT regimen was continued out to 6 weeks however, this intervention improved cycling time trial performance compared to exercise training alone, suggesting that when combining IMT with concurrent exercise, a longer training period may be necessary to induce an appreciable adaptation to the inspiratory muscles.

In light of these considerations, it is likely that the chosen volume of added respiratory dead space in the studies by Szczepan et al. (2020a; 2020b) did not elicit a sufficient level of respiratory muscle work to induce a training adaptation in the inspiratory muscles. A combination of a study population habituated to swimming exercise, even at a low volume of swim training, insufficient overload, the use of a volume, rather than resistance-based protocol, and perhaps too brief of a training period, may explain the lack of training effect observed in this study. Future studies on using added respiratory dead space to enhance respiratory muscle function in swimmers should aim to quantify the inspiratory muscle training workload and optimize the prescribed training to increase the total training load so that it sufficiently induces a training adaptation. Furthermore, considering the population and training modality, it is likely that a higher level of training load and longer intervention period may be required in order to observe an ergogenic effect. Nevertheless, these results provide important information regarding how this intervention may be applied to recreational swimmers, and highlight the need to provide a sufficient training stimulus in order to induce respiratory muscle and other training adaptations in these swimmers.

Ren-Jay Shei
Carlsbad, CA, 92010 USA

✉ **Ren-Jay Shei, PhD**
E-Mail: reshei@alumni.iu.edu

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