Diaphragmatic breathing for fencing: is it worth it?

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2023 IEEE International Workshop on Sport, Technology and Research (STAR) | 979-8-3503-1605-6/23/$31.00 ©2023 IEEE | DOI: 10.1109/STAR58331.2023.10302645

***Abstract*— Breathing is important for any sport. Because of the mask, fencers often complain of difficult progressive breathing during matches. In addition, during a fencing bout, the athletes have a few times to rest, during which they have to recover both concentration and breathing. We hypothesized that good breath control during the recovery time from an assault through diaphragmatic breathing might be of help. Eight (1 female) elite professional senior épée fencers (i.e.: qualified for the Fencing World Cup) were recruited for this pilot study. Four (DIA+) were trained to adopt diaphragmatic breathing during recovery and four were naïve to diaphragmatic breathing (CTR). The two groups were similar in age (27.3 vs 26.3 years; p= 0.510), height (182.5 vs 183.5 cm, p=0.756) and weight (79.6 vs 79.5 kg; p= 0.438). Nine minutes' assault was simulated. The 1-minute break occurring between the three-minute intervals of fencing footwork and the 15 seconds stop called by the referee were recorded through opto-electronic plethysmography. At baseline, the ventilatory pattern was similar between the two groups, while during recovery DIA+ tended to breathe with lower ventilation, and lower tidal volume and seemed to perceive lower dyspnoea. The results of this pilot study seem to encourage elite fencers to try to recruit the diaphragm during their recovery breathing. If confirmed in larger future studies, this breathing strategy seems to be associated with lower ventilation and lower exertional dyspnoea. Saving ventilatory reservoirs and reducing laboured breathing can have important beneficial implications for their performance.**

Keywords—diaphragmatic breathing, fencing, opto-electronic plethysmography, ventilatory pattern, dyspnoea

I. INTRODUCTION

Breathing is important for any sport.

Little is being said about proper breathing for fencing. Because of the mask, fencers often complain of difficult progressive breathing during matches. Wearing the mask restricts air, light, and heat circulation.

The mask has been proven to increase breathing impairment in fencers compared to similar physical activity without the mask[1]. Passali et al. found the mask significantly increased inspiratory flow's impairment because of a relative increase in inspiratory resistance. They concluded that the mask creates an unfavourable environment for breathing ability, causing discomfort for fencers [1]. The mask, therefore, represents a resistive load for the respiratory muscles in addition to the performance per se[2].

In addition, during a fencing bout, the athletes have a few times to rest, during which they have to recover both concentration and breathing. Individual Olympic fencing competitions can last for a maximum of nine minutes long that are divided into three separate periods, each consisting of three minutes. Each period has one minute of rest in between for the fencers to recuperate and prepare themselves for another bout[14].

When one of the fencers scores a hit (by touching the opponent) or when the rules are violated in some way (*i.e.,* in the case of corps a corps when fencers come into physical contact with one another with any portion of their bodies or hilts or a penalty, or when both fencers return to passivity), the referee will stop or pause the action for ~ 15 seconds during which the athlete may rest.

Traditionally, fencers do not receive specific respiratory indications or training. However, respiratory muscle training is known to positively affect healthy individuals and athletes[3]–[7].

The most important respiratory muscle is the diaphragm[8]. It is an inspiratory muscle shaped like a dome that descends during contraction. Its piston-like movement can lead to a quieting response modulated by the parasympathetic nervous system[9], and this might have important implications for performance purposes.

We hypothesised that good breath control during the recovery times within an assault through diaphragmatic breathing might be a way to help elite fencing improve their ventilation during recovery. To test this hypothesis, we perform a pilot study on elite senior épée fencers trained to adopt diaphragmatic breathing during the recovery times of the match. A group of peer fencers naïve of diaphragmatic recovery was included as a control group.

II. MATERIALS AND METHODS

A. Subjects

Elite senior épée fencers were voluntarily enrolled in the pilot study (1 female). Inclusion criteria: athlete to be a professional fencer qualified for the Fencing World Cup not having respiratory issues or any physical injury.

B. Opto-Electronic Plethysmography

Opto-Eelectronic plethysmography (OEP System; BTS, Milan, Italy) is a motion analysis system that allows for 3D tracking of body movements non-invasively[10]. OEP exploits 89 infrared passive reflective markers placed on subjects' skin according to precise anatomical reference points (Figure 1), creating a grid over the subject's thorax. The OEP system uses infrared charge-coupled device cameras to capture the markers' 3D motion.

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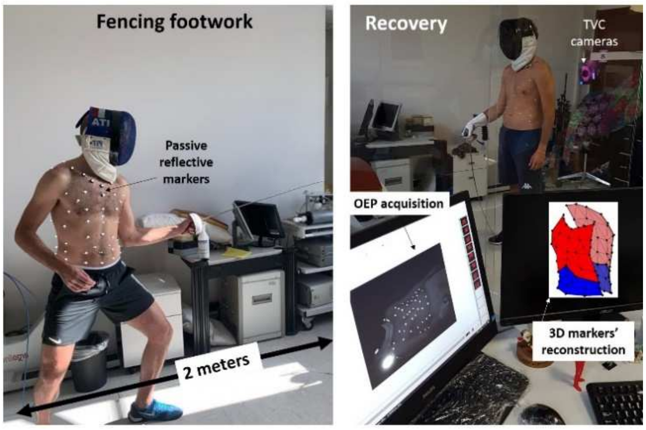

Fig. 1. Experimental set-up of an épée fencer wearing the passive markers on his thorax during fencing footwork (left) and opto-electronic plethysmography (OEP) acquisition (right).

Light-emitting diodes send light from the cameras to the markers, and the light reflection is collected, the markers identified, and their centroids computed and stored. Surface triangulation of the centroids is then applied through successive integration the chest wall volumes enclosed by the markers are thus computed. OEP accuracy has been established and improved over time[11].

In addition, because markers are put according to anatomical points, the volumes of the ribcage and the abdomen are accurately determined. The former is under the action of ribcage muscles, the latter under the action of the diaphragm during inspiration and abdominal muscles during active expiration.

All breaths during the resting periods were selected and a normalized breath was derived from them. The volume variation of the chest wall (i.e.: the tidal volume) as well as its two compartments (i.e.: ribcage and abdomen) were calculated on the normalized breath. The thoraco-abdominal volumes were expressed as percentage values of the tidal volume. The product of tidal volume and respiratory rate gives minute ventilation, which represents the exchange of gas per minute.

C. Protocol of acquisition

Firstly, the athletes were asked to breathe normally and perform a maximal manoeuvre that consisted of a full inspiration followed by a forced full expiration. The maximal volume variation is the vital capacity.

Figure 2 describes the protocol of acquisition. The athlete was asked to keep a controlled fencing footwork (i.e.: moving forward (sometimes called advances) and backwards (sometimes called retreats) within 2 meters, the length of a standard strip) while wearing the mask, the glove and keeping the sword (Figure 1).

A period was defined as the alternation of 30 seconds of fencing footwork at three different speeds (45, 55 and 65 bpm imposed by a metronome) and 15 seconds of rest (simulating the period of stop called by the referee) for 3 minutes of effective exercise. Three periods were repeated 3 times with 1 minute of recovery in between, for 9 minutes of effective exercise. In this way, we have simulated the maximal time of an assault.

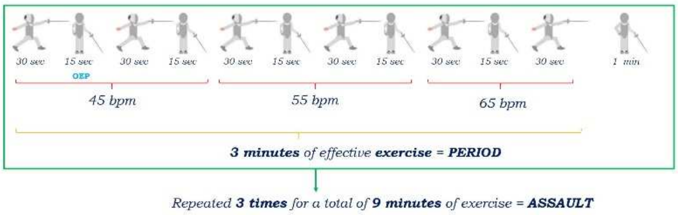

Fig. 2. Schematic of the timing of the acquisition. The athlete alternates 30 seconds of fencing footwork (FT) at three different speeds (45, 55 and 65 bpm imposed by a metronome) with 15 seconds of rest (REC) for 3 minutes of effective exercise. This period was repeated 3 times with 1-minute break occurring in between the three-minute intervals. The opto-electronic plethysmography acquisition was performed (OEP) during all the recovery time.

OEP acquisition was performed during all the recovery times with the athlete in a standing position in front of the cameras (Figure 1, photos published with the permission of the athlete).

The fencer wore the mask during the 15 seconds of acquisition, while they removed the mask during the minute of acquisition.

No instructions on the breathing recovery modality were given to the athlete.

Athletes were asked to rate their task-specific dyspnoea and leg fatigue at the end of each minute of recovery by the Borg CR10 scale (0: nothing at all; 0.5: extremely weak; 1: very weak; 2: weak; 3: moderate; 5: strong; 7: very strong; 9: very very severe (almost maximum); 10: maximal) [12].

The study was approved by the local Ethics Committee of Politecnico di Milano (Opinion n. 39/2020). Written informed consent for investigation was given by all the athletes, and the study was conducted in accordance with the declaration of Helsinki.

D. Statistic Analysis

The distribution of the data was tested using the Kolmogorov-Smirnov test. If the normality test passed, the t-test was used; while the Kruskal-Wallis One Way Analysis of Variance on Ranks was used otherwise to test the difference between the two groups.

Significance was set as $p<0.05$. Data in the text are presented as median.

III. RESULTS

A. Subjects

Eight elite épée senior fencers (1 female; (age: 23.5 years; height: 175 cm; weight: 73.5 kg) were enrolled in the study. According to the diaphragmatic training, the athletes were split into two groups: 4 DIA+ (fencers taught to use the diaphragm during recovery) and 4 CTR (fencers who received no diaphragmatic training). The two groups were similar in terms of age (27.3 vs 26.3 years; p= 0.510), height (182.5 vs 183.5 cm, p=0.756) and weight (79.6 vs 79.5 kg; p= 0.438).

B. Baseline

At baseline condition, before exercise, the two groups were similar in tidal volume (DIA+: 0.73, CTR: 0.79 L; p= 0.990), breathing frequency (DIA+: 16.1, CTR: 14.5

breaths/min; p= 0.982), minute ventilation (DIA+: 12.6, CTR: 11.4 L/min; p= 0.259) and abdominal contribution to tidal volume (DIA+: 43.3, CTR: 31.2 %; p= 0.696).

Vital capacity was similar between the two groups as an absolute value (DIA+: 5.59, CTR: 5.88 L; p= 0.882) but also when expressed as percentage of predicted values (DIA+: 102, CTR: 109 %; p= 0.215), computed according the Global Lung Initiative equation (http://gli-calculator.ersnet.org/)[13].

C. Ventilatory pattern during 1-min recovery

Figure 3 reports the ventilatory pattern (i.e., breathing frequency, tidal volume and minute ventilation) at the end of the minute recovery of each period in the two groups of athletes.

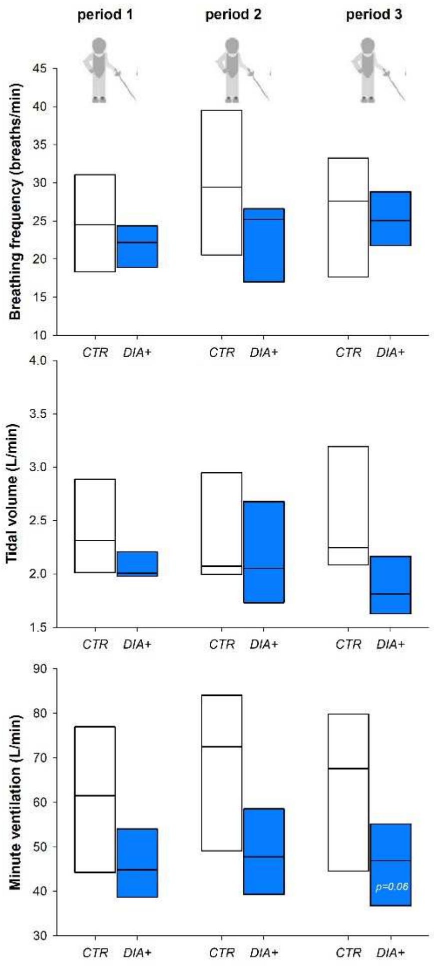

Fig. 3. Box-plot of the ventilatory pattern: breathing frequency (top panel), tidal volume (middle panel) and minute ventilation (bottom panel) at the end of each period of the fencers taught to use the diaphragm during recovery (DIA+) and the fencers who received no diaphragmatic training (CTR). The length of the box indicates the interquartile range, the line in the middle of the box the median of the data.

During 1 minute recovery, minute ventilation tended to be lower in DIA+, approaching the statistical significance in the third period. The reduced minute ventilation seemed to be due to lower tidal volume, with similar breathing frequency. At the end of the third period, and therefore of the assault, the difference in minute ventilation was close to the statistical significance (p=0.06).

D. Thoraco-abdominal pattern during 1-min recovery

Figure 4 reports the abdominal percentage contribution to tidal volume (of note, the thoracic contribution is the complementary, by definition) of the recovery at the end of each period in the two groups of athletes.

DIA+ athletes recovered with a significantly increased abdominal breathing, particularly at the end of the second and the third period.

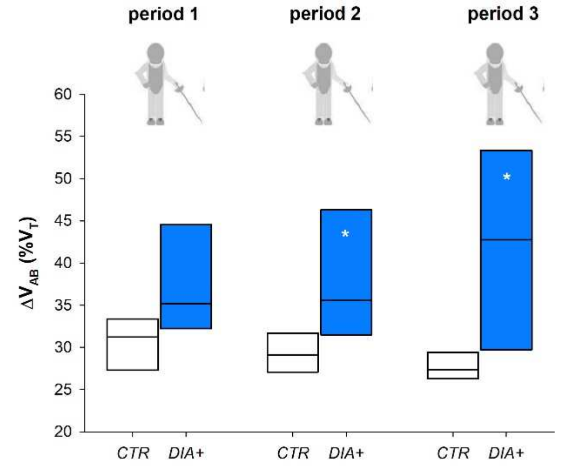

Fig. 4. Box-plot of the percentage abdominal contribution to tidal volume at the end of each period of the fencers taught to use the diaphragm during recovery (DIA+) and the fencers who received no diaphragmatic training (CTR). The length of the box indicates the interquartile range, the line in the middle of the box the median of the data. *: p<0.05 DIA+ vs CTR

E. Ventilatory pattern during 15-sec recovery

Figure 5 reports the minute ventilation at the end of all the 15 seconds recovery of each period in the two groups of athletes.

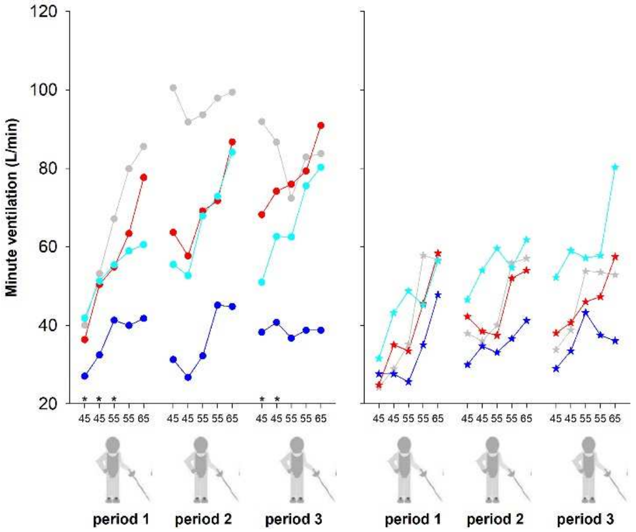

Fig. 5. Minute ventilation at the end of each 15 seconds recovery of fencers taught to use the diaphragm during recovery (right panel) and the fencers who received no diaphragmatic training (left panel). Each symbol represents a single athlete. *: p<0.05 DIA+ vs CTR

During 15 seconds recovery, minute ventilation tended to be lower in DIA+, being statistical significant after lower speed (45 bpm).

Figure 6 and figure 7 report the breathing frequency and the tidal volume at the end of the 15 seconds recovery of each period in the two groups of athletes.

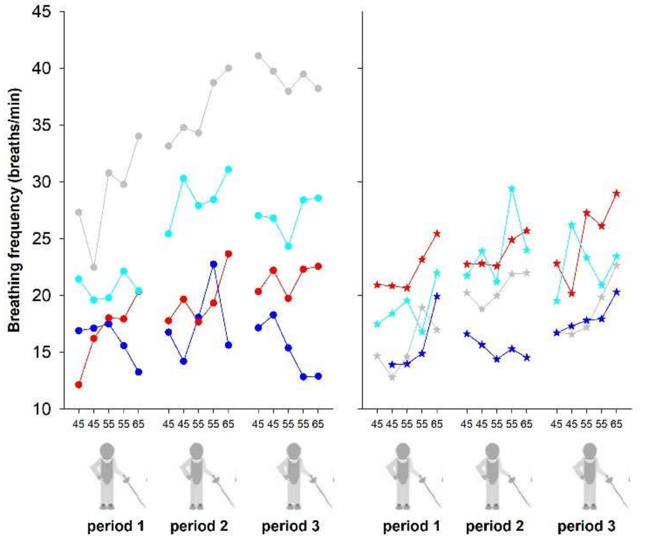

Fig. 6. Breathing frequency at the end of each 15 seconds recovery of fencers taught to use the diaphragm during recovery (right panel) and the fencers who received no diaphragmatic training (left panel). Each symbol represents a single athlete.

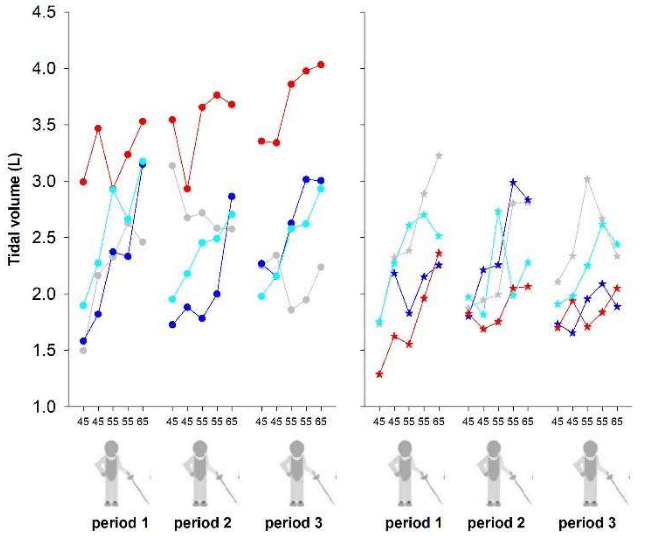

Fig. 7. Tidal volume at the end of each 15 seconds recovery of fencers taught to use the diaphragm during recovery (right panel) and the fencers who received no diaphragmatic training (left panel). Each symbol represents a single athlete.

Althought the two parameters seem lower in the fencers taught to use the diaphragm during recovery, no differences were found.

F. *Thoraco-abdominal pattern during 15-sec recovery*

Figure 8 reports the abdominal percentage contribution to tidal volume (of note, the thoracic contribution is the complementary, by definition) at the end of the 15 seconds recovery of each period in the two groups of athletes.

Also during the 15 seconds recovery, DIA+ athletes recovered with a significantly increased abdominal breathing.

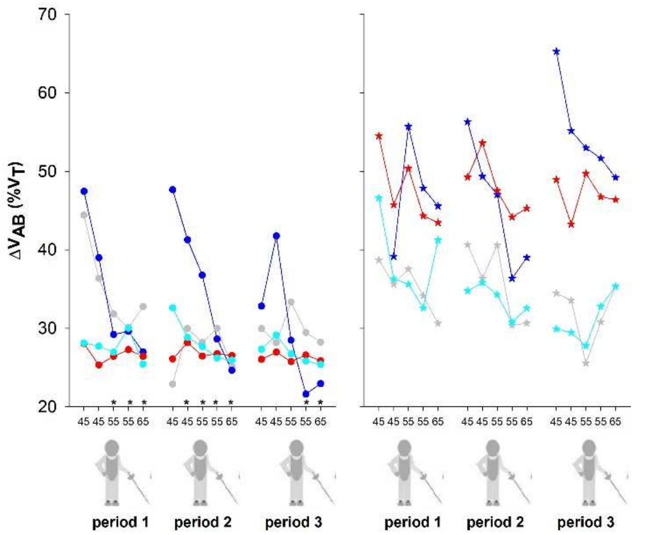

Fig. 8. Percentage abdominal contribution to tidal volume at the end of each 15 seconds recovery of fencers taught to use the diaphragm during recovery (right panel) and the fencers who received no diaphragmatic training (left panel). Each symbol represents a single athlete. *: $p<0.05$ DIA+ vs CTR

F. *Dyspnoea and leg fatigue*

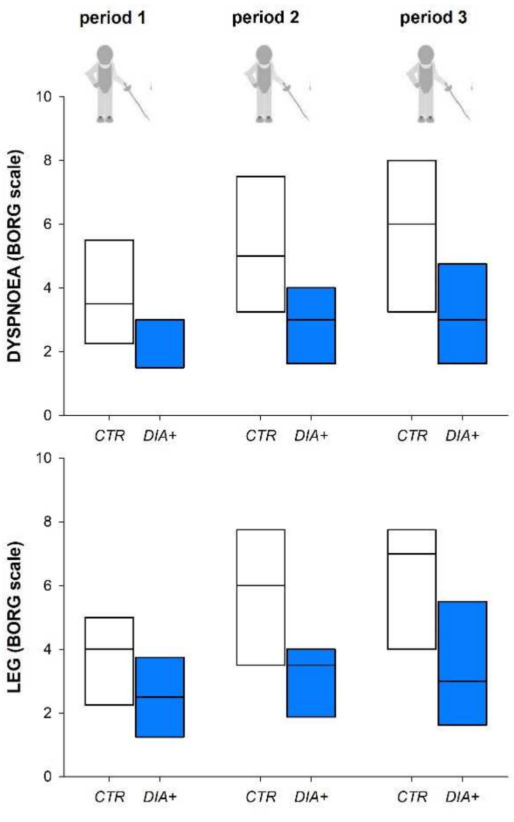

Fig. 9. Box-plot of the dyspnoea (top panel) and leg fatigue (bottom panel) at the end of each period of the fencers taught to use the diaphragm during

recovery (DIA+) and the fencers who received no diaphragmatic training (CTR). The length of the box indicates the interquartile range, the line in the middle of the box the median of the data.

Figure 9 reports the dyspnoea and leg fatigue of the recovery at the end of each period in the two groups of athletes. Both exertional dyspnoea and leg muscle fatigue tended to be lower in DIA+ than CTR.

IV. DISCUSSION

In this pilot study, we tested whether diaphragmatic breathing during the recovery times within a fencer assault might be worthwhile for the athletes. Higher use of the diaphragm to control the breath during recovery seemed to reduce minute ventilation, mainly because of lower tidal volume. Dyspnoea tended to be lower when the diaphragm was mostly recruited. These results appeared to encourage the introduction of diaphragmatic training for fencers to optimize the resting time and the ventilatory reservoir.

According to the international fencing rules, the time to rest for a fencer during the assault is limited, and it should be optimized for concentration and breathing. During the 1-minute break, the athlete usually takes off the mask. In contrast, during the 15-second break, the mask is kept in position, representing a further resistive load for breathing and, therefore, for the respiratory muscles. More in detail, the mask represents a significantly greater impairment in inspiratory flow and, thus, a relative increase in inspiratory resistance[1].

The diaphragm is the most important respiratory muscle that facilitates blood movement towards the heart and helps manage life stressors.

When it contracts, the diaphragm increases abdominal pressure so that the abdomen expands, increasing its contribution to tidal volume[15]. The contraction of the diaphragm also generates negative intrathoracic pressure so that air enters the lung. The diaphragm is therefore an inspiratory muscle.

The sub-atmospheric thoracic pressure generated by the contraction of the diaphragm contributed to pull the blood into the thorax through a vacuum effect. Diaphragmatic breathing, therefore, makes the venous return to the heart increase. The main consequence is increased stroke volume, which triggers arterial stretch receptors, increased parasympathetic activity, and decreased sympathetic activity. These changes in the balance of sympathetic and parasympathetic influence on the heart bring about reduced heart rate and total peripheral resistance as well as increased heart rate variability[9], [16].

Respiration, thus, is one of the most powerful modulators of the arterial baroreflex through the diaphragm[9], [17], [18].

In addition, a systematic review proved the effectiveness of diaphragmatic breathing in reducing physiological and psychological stress in adults[19].

For these characteristics, the diaphragm is a candidate for being a potential ally for the fencer during the competition, particularly during the minute of resting between two periods of the assault and during the few seconds of interruption. During these breaks, the fencers have to recover both mentally and physically.

To test this hypothesis, we trained four elite senior épée fencers to recruit the diaphragm while resting between two periods and during the few seconds of interruption. The results showed that they assimilated the technique, as they recovered with significantly higher diaphragmatic breathing (as indicated by the increased abdominal contribution) than the control group. This occurred during both the short and the long periods of resting.

Aliverti et al. [20] showed that the inspiratory reserve volume is mainly located in the ribcage during incremental exercise. They demonstrated that the end-inspiratory abdominal volume was nearly constant, so the increase in end-inspiratory chest wall volume was almost entirely due to ribcage expansion. They concluded that the increase in ribcage tidal volume during exercise resulted from recruiting only the ribcage muscles[20]. Recruiting the diaphragm during exercise (and maybe also immediately after it) is not a spontaneous strategy.

Athletes, therefore, should be taught and trained to do it. Our results showed that the fencers who recruited more the diaphragm tended to recover with lower ventilation, presumably due to reduced tidal volume. Ultimately and more importantly, they seemed to perceive less dyspnoea.

Although only qualitative and speculative, because of the exiguous statistical significance, the results of this pilot study align with the expected benefit of recruiting the diaphragm during the recovery periods (both the short and the long ones). These comprise reduced ventilation and reduced dyspnoea on exertion, both fundamental issues before starting a new period of fencing. Indeed, it seemed that the diaphragmatic breathing increased the reservoir of ventilation to be used for the next effort. Most importantly, this tendency seemed to occur not only during the long period of recovery but also during the short one indicating an immediate efficacy of the virtuous process induced by recruiting the diaphragm.

Of course, these data must be confirmed on a larger scale, but they seemed encouraging for the fencers to learn to recruit the diaphragm while recovering. It would be interesting to test also the cardiac implication in future investigations. The cardiac signal analysis would confirm if diaphragmatic breathing can lead to a self-managed quieting response modulated by the parasympathetic nervous system.

Limitation and strength

The main limitation of this pilot study was the number of subjects enrolled, which was the main reason for the poor statistical significance.

Indeed, statistically significant findings are harder to detect with small sample sizes. Small sample sizes decrease statistical power. Finding non-significant differences with small sample sizes often leads to committing type II errors or "false negative" results (*i.e.*: the failure to reject a null hypothesis that is actually false).

However, Italian professional senior épée fencers qualified for the Fencing World Cup is a small population *per se*. Although Italy has an important fencing tradition, the selected group of senior épée fencers comprises only 24 athletes (12 females and 12 males). In this pilot study, therefore, we have enrolled one-third of the entire Italian population.

Another limitation of the protocol is the partial simulation of the competition. Although we have simulated the maximal timing of an assault, we have considered only the physical stress fencer experienced during real competition. The offensive and defensive actions, such as lunging or parrying, performed by the two fencers during the bout imply important mental concentration and stress in addition to the physical demand. Indeed, the uncomfortable feeling of lacking air could be caused not only by the athletic competition and the type of attack but also by the psychological messages from the adversary or by the psychological impact of the importance of the competition. Dyspnoea is known to have a causal relationship with the development of symptoms of anxiety and depression in normal people[21]. However, sport-related anxiety is a well-known issue among athletes. It can affect sports performance, both in practice and competitive settings, to the point that employing a range of psychological strategies to manage anxiety is an important part of the training program for elite athletes[22]. Evidence suggests that diaphragmatic breathing may decrease stress[19].

Given the benefits of diaphragmatic breathing on stress reduction, team sports should include it in their training strategies' multidimensional perspective. Such multidimensionality includes not only physical, but also cognitive, technical, physiological, psychological, morphological, and preventive training[23].

Enrolling senior professional fencers qualified for the Fencing World Cup is a strength of the study, as they are such elite athletes that the margin of improvement is narrow. Finding a way to improve the performance at that level makes a huge difference in victories.

The use of opto-electronic plethysmography is another strength of the study. Most methods used to measure the ventilatory pattern require instrumentation of the airways (i.e., mask or mouthpiece and nose clip) incompatible with the fencing mask. Opto-electronic plethysmography allows measuring the ventilatory pattern during the 15 seconds of recovery with the fencer wearing the mask.

In addition, the standard methods to assess ventilatory pattern provide global measurements of the air entering the lungs, with no possibility of evaluating the contribution of the different respiratory muscles. In turn, opto-electronic plethysmography allows accurate quantification of the thoraco-abdominal volumes, surrogates of the action of the different respiratory muscles. The abdominal compartment expands only because the diaphragm contracts[24]. Therefore, the inspiratory abdominal contribution to tidal volume gives an indirect evaluation of the contribution of the diaphragm to breathing.

To conclude, the results of this pilot study seem to encourage elite fencers to try to shift towards the abdomen (and to recruit the diaphragm) their recovery breathing during the bout. If confirmed in larger future studies, this breathing strategy seems to be associated with lower ventilation and lower exertional dyspnoea. Saving ventilatory reservoirs and reducing laboured breathing can have important beneficial implications for their performance.

ACKNOWLEDGMENT

The authors are deeply thankful to all the athletes who kindly participated in the acquisition. We wish them all the best for their career and future competitions: break a leg!

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