SEPARATE TRUNK VOLUMES AND RIBS MOTION CORRELATIONS IN SWIMMERS

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The purpose of this study was that to analyze the separate trunk volumes and ribs motion correlations aiming to verify swimmers present better motor coordination or control during breathing. The trunk was represented by 53 markers, attached to the ribs, vertebrae, thorax and abdomen of 13 male swimmers and 10 non-athletes. From the 3D coordinates of the markers, obtained by a kinematical analysis system equipped with 6 digital video cameras (60Hz), in function of time, the rotation angles of the 2^{nd} to the 10^{th} ribs around the quasi-transversal axis and the volumes of 4 separate compartments of the trunk were calculated (superior thorax, inferior thorax, superior abdomen and inferior abdomen). Correlating the curves of ribs rotation angles with the curves of the separate volumes, swimmers presented higher values during vital capacity manoeuvers when the correlation involved the inferior thorax and the superior and inferior abdomen. These results showed a better coordination between the trunk volumes and the ribs motion in the swimmers during vital capacity manoeuvers, suggesting that swimming practice leads to the formation of an optimized breathing pattern when larger efforts are required from the respiratory system.

KEY WORDS: trunk volumes, ribs, swimming.

INTRODUCTION: It is already known that swimming training can modify the pulmonary function leading to higher pulmonary volumes and capacities than the predicted or than other sport activities. However it remains unclear if these alterations are due to the increment in inspiratory muscle strength, alveolar distensibility, size of the lungs or chest wall or hereditary factors (Armour *et al.*, 1993). Eastwood *et al.*, (2001) concluded that in marathon runners the increase of inspiratory muscles performance was a consequence of a difference in the breathing pattern adopted. Although several physiological mechanisms involved with swimming practice have already been investigated, it is unknown if the coordination or the motor control of the chest wall is also altered. Regarding the ribs motion, a previous study showed that swimmers presented higher correlation among the movements of the ribs during maximal breathings when compared with non-athletes (Sarro *et al.*, 2005). Since ribs motion is a precursor of trunk volume variation being directly related to lung volumes (Ferrigno et al., 1994), this work analyses the separate trunk volumes and ribs motion correlations, aiming to verify that swimmers have better motor coordination or control during breathing. The evaluation of the coordination between these variables could be helpful for a better understanding of the breathing mechanics; of special interest are the alterations caused by intensive swimming practice, since the ventilatory apparatus (lungs and chest wall) is centrally involved in this sport.

METHOD:

Data Collection: A group of 13 male swimmers (SG) and a control group of 10 healthy non-athletes volunteers (CG) were compared. The criteria of inclusion in the SG were: competition training for more than 3 years, at least three times a week or covering an average of over 30.000 meters/month in the period. The CG was composed by male volunteers without cardiopulmonary or postural diseases, non-athletes without swimming practice.
Fifty-three spherical retro-reflective markers (ϕ=5mm) were attached to the trunk of the subjects (figure 1) and the three-dimensional coordinates of the markers were obtained by

the kinematical analysis system Dvideow (Figueroa et al., 2003), with 6 digital video cameras (JVC-GR 9500) sampled at 60Hz.
The volunteers were seated with abduction of the shoulders on a chair without back support. They were asked to perform 5 breathing cycles in vital capacity (VC).
From the 3D coordinates of the markers, the separate volumes of the trunk and the ribs rotation angles (2nd to 10th rib) were calculated.

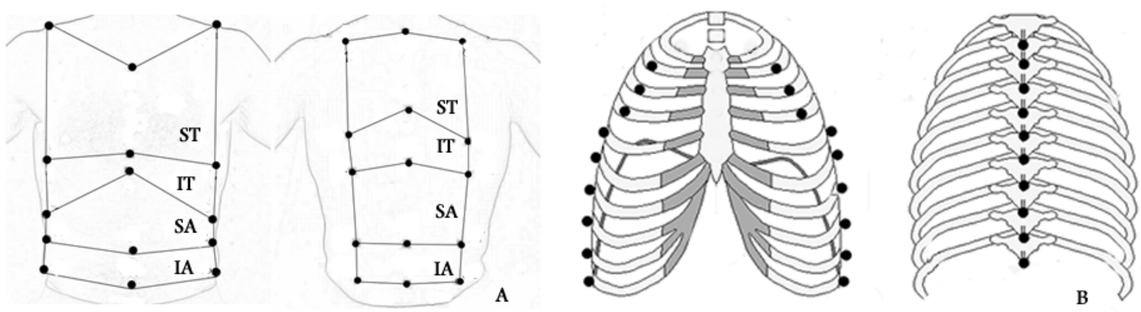

Figure 1: Representation of the trunk using external markers: model used to calculate the separate trunk volumes (A): ST = superior thorax, IT = inferior thorax, SA = superior abdomen, IA = inferior abdomen; and markers used to calculate the coordinate systems of the ribs (B).

The trunk was divided into 4 compartments: superior thorax (ST); inferior thorax (IT); superior abdomen (SA); and inferior abdomen (IA) (figure 1-A). Each compartment was geometrically defined as the sum of two irregular dodecahedrons with 8 vertices, defined by the markers. The sum of all the compartments defined the total volume of the trunk (Tk) (Ferrigno et al., 1994).
After the volumes calculation, a rib coordinate system was obtained for each pair of ribs using the markers positioned at the lateral extremity of the right and left ribs and at the spinous process of the correspondent thoracic vertebra (figure 1-B). A trunk coordinate system was calculated using the markers at the posterior superior iliac spines and the 1st thoracic vertebra. Then the rotation angle around the quasi-transversal axis was calculated, between the coordinate system associated to each pair of ribs and the coordinate system associated to the trunk (Sarro et al., 2005).
The correlation coefficient was used to measure the association between the curves of the ribs rotation angle and the curves of the separate volumes. Each rib (2nd to 10th) was correlated with each compartment and with the Tk in all the subjects. The means over the subjects were calculated. The distribution of the mean values of the correlation coefficient obtained for each compartment was compared between the groups.

Data Analysis: The 3D coordinates were smoothed with a zero-phase forward and reverse Butterworth digital filter of 5th order (cutoff 1 Hz). Considering that the correlation coefficient did not present a normal distribution, a transformation was applied according to Fisher, z-transformed correlation coefficient (Brownlee, 1960). In order to verify the statistical difference between the groups, t-test ($p<0.05$) was performed with the z transformed coefficient correlation. In the data without normal distribution (Lilliefors test, $p<0.05$), differences were tested with the Kruskal-Wallis nonparametric one-way analysis of variance.

RESULTS: Figure 2 shows an example of the ribs rotation angles around their quasi-transversal axes and the variation of the separate volumes of the trunk presented by one subject of the SG during VC manoeuvers. The ascendent phase corresponds to an inspiration and the descendent phase corresponds to an expiration; another point to be noticed is the phase agreement among the curves. These curves were obtained simultaneously from the 3D coordinate of the markers.

Figure 3 shows the distribution of the mean values of the correlation coefficients between the separate trunk volumes and the ribs rotation angles presented by the CG and the SG during VC maneuvers in a boxplot representation. The results show that there is a high correlation between the ribs rotation angles and the separate volumes of the trunk in both groups. Comparing the distribution of the mean values of the correlation coefficient between the groups, differences were found for all the compartments ($p<0.05$). CG presented higher values correlating the volume of the ST with the ribs angles, while SG presented higher values (above 0.9) for all the other compartments. The highest difference was found in the IA, where the CG presented the smallest correlation values. The highest values were found in the SG related to the IT.

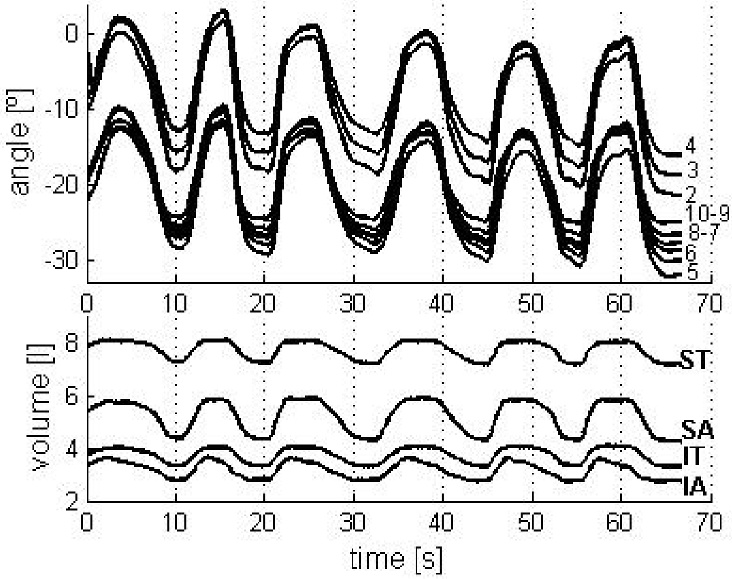

Figure 2: Rotation of the ribs (2nd to the 10th) around the quasi-transversal axis and the 4 separate volumes of the trunk of one subject of the swimmers group: ST = superior thorax, IT = inferior thorax, SA = superior abdomen, IA = inferior abdomen.

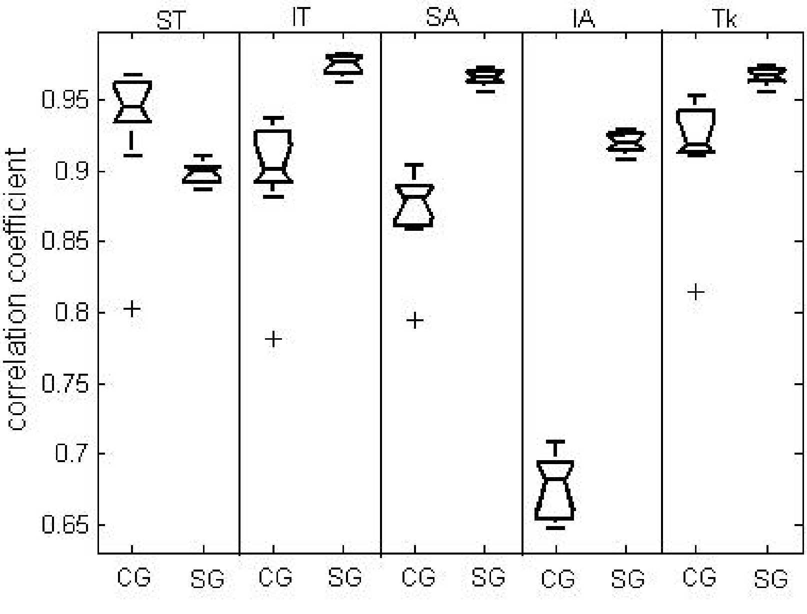

Figure 3: Distribution of the mean values of the correlation coefficient between the ribs angles and the volumes of each compartment of the trunk presented by the control group (CG) and swimmer group (SG) during vital capacity maneuvers (VC). ST = superior thorax, IT = inferior thorax, SA = superior abdomen, IA = inferior abdomen, Tk = trunk.

DISCUSSION: According to the concepts adopted in the methodology, the high positive correlation values indicate a pattern of phase agreement between each rib rotation angle and the compartment volume. The results showed that CG presented higher values only when the ST was considered, showing that ribs motion is more associated with the volume variation of the ST. Higher correlations were found in the SG, which presented higher values between ribs motion and IT, SA and IA, pointing a better coordination of these compartments with the ribs motion. Since the diaphragm is responsible for the displacement of the abdomen during inspiration and IT represents the region of apposition between the diaphragm and the rib cage, these results could be explained by the coordinated use of the swimmer's diaphragm during VC manoeuvers. These results indicate a coordinative optimization of the diaphragm action displacing the thorax and the abdomen when the respiratory system is submitted to higher efforts like maximal breathings, as used by swimmers during training.

This optimized breathing pattern found in the SG reinforces the idea that practicing swimming can promote positive changes in the thoracoabdominal motion. The intense requirement of the respiratory system during regular swimming training might lead to a better control of the ribs motion, suggesting that a higher coordination of the ribs motion and thoracoabdominal volumes is necessary for the increment in breathing performance. The same optimization was found by Barros *et al.* (2003) in yoga practitioners, correlating the variation of the thoracic and abdominal areas during VC maneuvers.

The major contribution of this work was the identification of this optimized breathing pattern in swimmers, not yet reported in literature. The significance of this finding is the fact that this optimized pattern can partially explain the higher lung volumes found in these athletes as reported in literature.

CONCLUSION: The results of this study showed that there is a high correlation between the volume variation of the trunk and the ribs motion. This correlation is better in the swimmers, suggesting that swimming practice might lead to the formation of an optimized breathing pattern when larger efforts are required from the respiratory system, increasing the coordination between the separate volumes of the trunk and the ribs motion. Based on these findings, we believe that the introduction of breathing exercises in the training program could increase the coordination of the ribs motion and separate trunk volumes even more, improving the swimmer's performance.

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