

Effect of upper costal and costo-diaphragmatic breathing types on electromyographic activity of respiratory muscles

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Aim: To compare electromyographic (EMG) activity in young–adult subjects with different breathing types. **Methodology:** This study included 50 healthy male subjects with complete natural dentition, and no history of orofacial pain or craniomandibular-cervical-spinal disorders. Subjects were classified into two groups: upper costal breathing type, and costo-diaphragmatic breathing. Bipolar surface electrodes were located on sternocleidomastoid, diaphragm, external intercostal, and latissimus dorsi muscles. Electromyographic activity was recorded during the following tasks: (1) normal quiet breathing; (2) speaking the word ‘Mississippi’; (3) swallowing saliva; and (4) forced deep breathing.

Results: Sternocleidomastoid and latissimus dorsi EMG activity was not significantly different between breathing types, whereas diaphragm and external intercostal EMG activity was significantly higher in the upper costal than costo-diaphragmatic breathing type in all tasks ($P < 0.05$; Wilcoxon signed rank-sum test).

Conclusion: Diaphragm and external intercostal EMG activity suggests that there could be differences in motor unit recruitment strategies depending on the breathing type.

Keywords: Breathing types, Electromyography, Normal quiet breathing, Speech, Swallowing, Forced deep breathing

Introduction

Some skeletal muscles are termed ‘respiratory’ muscles as they alter the dimensions of the thorax and bring about inspiration or expiration. The muscles that contract in every breath during quiet breathing are ‘obligatory’ muscles of respiration,¹ for example, the diaphragm, scalene, parasternal and external intercostal muscles. The diaphragm is the main muscle of inspiration, and is responsible for generating the majority of inspiratory airflow,² but other muscles that act on the chest wall, for example the external and parasternal intercostal muscles and the scalene muscles, also contract with every breath. Diaphragmatic electromyography has been used to describe respiratory effort in patients with moderately severe chronic obstructive pulmonary disease.³

The discharge of the inspiratory motoneurons in the external and parasternal intercostal muscles has been described in detail in humans during quiet breathing.^{4,5} Drive to the respiratory muscles in voluntary breaths activates the intercostal motoneurons in the same manner as for quiet breathing.⁶ Additional muscles contract when demand on the respiratory system changes, for example in deep breaths, and these muscles are termed ‘accessory’ respiratory muscles,¹ e.g. sternocleidomastoid and trapezius muscles. Several proximal muscles contract as accessory muscles in forced breathing.⁷ In addition, the latissimus dorsi muscle appears to have an inspiratory action in patients with hyperpnea, emphysema, and asthma.^{8,9}

Several breathing types have been defined, depending on the expansion of the abdomino-thoracic region during inspiration at rest:^{10–12}

1. Costo-diaphragmatic breathing type is observed when the abdominal and lateral costal expansion is

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predominant over the superior thoracic expansion, during inspiration at rest. This is considered the optimum breathing type because it allows maximal lung expansion, and therefore, maximum lung capacity and gas exchange

2. Upper costal breathing type takes place when superior thoracic expansion exceeds the abdominal and lateral costal expansion during inspiration at rest. This breathing type produces a smaller expansion of the rib cage and therefore, smaller lung capacity and gas exchange. Hence, the use of accessory muscles may be required in order to breathe properly
3. Mixed breathing type is observed when there is no clear predominance of superior thoracic expansion or abdominal and lateral costal expansion.

In order to increase the diameter of the thorax, it could be assumed that the diaphragm, external intercostal and sternocleidomastoid muscles are more activated in subjects with an upper costal breathing pattern than in costo-diaphragmatic breathing pattern. To the best of the authors' knowledge, the effect of breathing type on the latissimus dorsi muscle activity has not been studied until now. In addition, there is no evidence of a different electromyographic (EMG) pattern of these muscles during non-respiratory activities, i.e. speech or swallowing, in subjects with different breathing types. Therefore, in order to better understand the human EMG pattern of 'obligatory' muscles of respiration and 'accessory' respiratory muscles,¹ this study evaluated EMG activity of the sternocleidomastoid, diaphragm, external intercostal, and latissimus dorsi muscles between subjects with costo-diaphragmatic and upper costal breathing type, during normal quiet breathing, speaking the word 'Mississippi', swallowing saliva, and forced deep breathing. The null hypothesis was that the EMG activity would be higher in subjects with upper costal breathing type. This may have a significant impact on the basic physiological aspect in human breathing function.

Material and Methods

Subjects

This study included 50 healthy male subjects, with complete natural dentition (excluding the third molars), no history of orthodontic treatment in the last 12 months,¹³ and no history of orofacial pain or craniomandibular-cervical-spinal disorders. None of the subjects were on a therapeutic medication that could have influenced muscle activity. EMG recordings were not performed in cold or environmental allergies subjects. Participants were students enrolled at the Dental and Medicine School of the University of Chile. Each of them gave informed written consent

before participating in the study. A protocol based on ethical principles that have their origin in the Declaration of Helsinki was used.

Determination of the breathing type

Subjects were classified according to their breathing type in two groups of 25 each: costo-diaphragmatic breathing type and upper costal breathing type. They were asked to remain standing, look straight ahead, with their feet 10 cm apart, and to breathe normally for 2 minutes as a baseline. A calibrated physical therapist clinician determined the breathing type as follows: first, she placed their left hand on the upper chest and their right hand on the upper back; next, she placed their left hand on the lower right costal region and their right hand on the upper abdomen. After checking 10 inspirations on each step of the clinical examination, the subject was classified to be of the upper costal breathing type if, during inspiration at rest, the superior thoracic expansion was predominant, and the costo-diaphragmatic breathing type when the abdominal and lateral costal expansion was predominant.^{11,12} Those subjects who did not show a clear predominance of superior thoracic expansion or abdominal and lateral costal expansion (mixed breathing type), were excluded from the study.

The upper costal breathing type group included 25 male subjects, ranging in age from 18 to 28 years with a mean age of 21.7 years. The costo-diaphragmatic breathing type group included 25 male subjects, ranging in age from 18 to 26 years with a mean age of 21.9 years. The period during which the examiner selected the sample studied was continuous and lasted 12 weeks.

Electromyography

Bipolar surface electrodes (BioFLEX, BioResearch Associates, Inc., Brown Deer, WI, USA) were used on the sternocleidomastoid, diaphragm, external intercostal, and latissimus dorsi muscles. The skin area was cleaned with alcohol to reduce skin impedance and to enhance signal conductivity. The electrodes were placed on the sternocleidomastoid muscle in the anterior border (middle portion), 1 cm above and below the motor point.¹⁴ The electrodes were placed on the diaphragm 1 cm below the xiphoid process (lower part of the sternum). The electrodes were placed on the external intercostal muscles between the 6th and 7th rib, following an imaginary vertical line projected from the nipple of the breast. The electrodes were placed on the latissimus dorsi muscle in the projection of the 12th rib or lumbar vertebra L1, following thoracolumbar

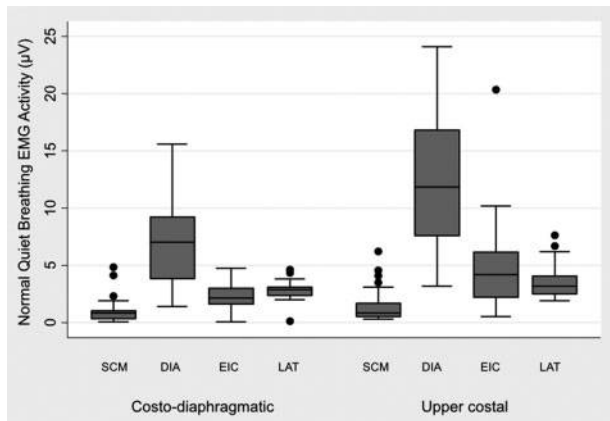


Figure 1 Box plot graph showing EMG activity recorded in the sternocleidomastoid (SCM), diaphragm (DIA), external intercostal (EIC), and latissimus dorsi (LAT) muscles, during normal quiet breathing, in subjects with costo-diaphragmatic and upper costal breathing types.

fascia edge. A surface ground electrode was attached to the forehead. The EMG signals were amplified (Model 7P5B preamplifier, Grass Instrument Co., Quincy, MA, USA) rectified and then integrated (time constant of 0.1 second) and then recorded online in a computer exclusively for the acquisition and processing of EMG signals. The system was calibrated before each record.

Electromyographic activity was recorded while the subject was in a standing position, maintaining their stance with feet at 10 cm apart, with their eyes open, looking straight ahead. The self-balanced position was obtained by having each subject standing with his visual axis horizontal, with no external intervention or modification of his posture. The standing position was chosen to register EMG activity because it allows researchers a better standardization of the subject position during the recordings.

Each subject underwent three unilateral EMG recordings of the sternocleidomastoid, diaphragm, external intercostal, and latissimus dorsi muscles in the following experimental conditions:

- Task 1: normal quiet breathing
- Task 2: speaking the word ‘Mississippi’
- Task 3: swallowing saliva
- Task 4: forced deep breathing.

Before the EMG recording tasks, an examiner explained the four conditions to each subject so they would be able to repeat each one correctly.

During the deep inspiration (task 4) each subject was asked to breathe in total lung capacity, holding the breath for 10 seconds. This period was decided to ensure maximum and sustained muscle activity without producing a respiratory function disorder. Tasks 1, 2 and 3 also lasted 10 seconds based on the

duration of task 4. A 20 second resting period was allowed between each EMG recording in each task.

To obtain the average value of each curve, measurements were taken every 0.1 second from the initial to the end of the recording using a computer program. The mean value of the three curves obtained at each task and for each subject was used. Task-to-task variability in the sternocleidomastoid muscle was $\leq 28.2\%$; in the diaphragm muscle it was $\leq 8.2\%$; in the external intercostal muscle it was $\leq 15.2\%$; and in the latissimus dorsi muscle it was $\leq 13.7\%$.

A body mass index (BMI) was obtained for each subject, dividing the weight (in kilograms) by the square of the height (in meters). Age and BMI variables were used to check for possible influence on the muscle activity recorded in each muscle.

Statistical analysis

The data were analyzed using the SYSTAT 13 program (Systat Software Inc. (SSI), San José, CA, USA). Electromyographic activity recorded presented a non-normal distribution of data ($P < 0.05$; Shapiro Wilk test); therefore, the paired comparison of the tasks in each muscle between subjects with costo-diaphragmatic and upper costal was made by the non-parametric Wilcoxon signed rank-sum test. A value of $P < 0.05$ was considered statistically significant.

Regression analysis for repeated measures between EMG activity and age, and BMI was performed for each muscle (mixed model with an unstructured covariance matrix), using STATA, Release 12.0 (StataCorp, College Station, TX, USA).

Results

Figure 1 shows normal quiet breathing EMG activity recorded in the sternocleidomastoid, diaphragm, external intercostal, and latissimus dorsi muscles, in subjects with costo-diaphragmatic and upper costal breathing types. Table 1 shows that sternocleidomastoid and latissimus dorsi EMG activity was not significantly different between breathing types ($P > 0.05$), whereas diaphragm and external intercostal EMG activity was significantly higher in the upper costal than in costo-diaphragmatic breathing type ($P < 0.01$; Wilcoxon signed rank-sum test).

Figure 2 shows EMG activity while speaking the word ‘Mississippi’ recorded in the sternocleidomastoid, diaphragm, external intercostal, and latissimus dorsi muscles, in subjects with costo-diaphragmatic and upper costal breathing types. Table 2 shows that sternocleidomastoid and latissimus dorsi EMG activity was not significantly different between breathing

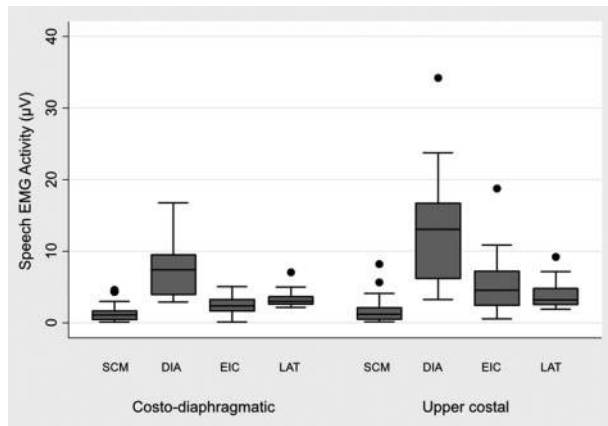


Figure 2 Box plot graph showing EMG activity recorded in the sternocleidomastoid (SCM), diaphragm (DIA), external intercostal (EIC), and latissimus dorsi (LAT) muscles, during speech the word 'Mississippi', in subjects with costo-diaphragmatic and upper costal breathing types.

types ($P>0.05$), whereas diaphragm and external intercostal EMG activity was significantly higher in the upper costal than costo-diaphragmatic breathing type ($P<0.01$).

Figure 3 shows swallowing of saliva EMG activity recorded in the sternocleidomastoid, diaphragm, external intercostal, and latissimus dorsi muscles, in subjects

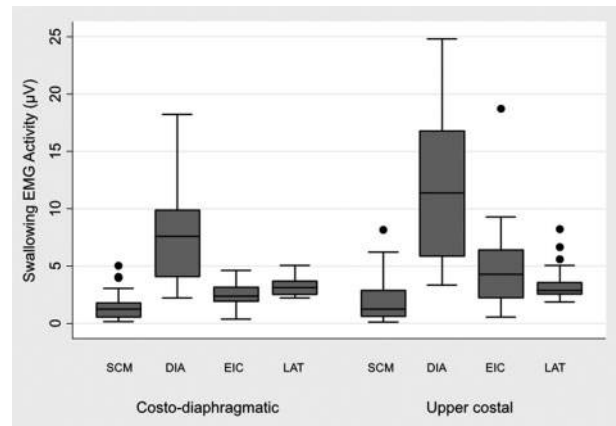


Figure 3 Box plot graph showing EMG activity recorded in the sternocleidomastoid (E SCM), diaphragm (DIA), external intercostal (EIC), and latissimus dorsi (LAT) muscles, during swallowing of saliva, in subjects with costo-diaphragmatic and upper costal breathing types.

with costo-diaphragmatic and upper costal breathing types. Table 3 shows that sternocleidomastoid and latissimus dorsi EMG activity was not significantly different between breathing types ($P>0.05$), whereas diaphragm and external intercostal EMG activity was significantly higher in the upper costal than costo-diaphragmatic breathing type ($P<0.05$).

Table 1 Comparison of EMG activity recorded in subjects with costo-diaphragmatic and upper costal breathing types during normal quiet breathing (Wilcoxon signed rank-sum test)

Muscles	Breathing type	P value
Sternocleidomastoid	Costo-diaphragmatic vs upper costal	0.2003 NS
Diaphragm	Costo-diaphragmatic vs upper costal	0.0024 **
External intercostal	Costo-diaphragmatic vs upper costal	0.0029 **
Latissimus dorsi	Costo-diaphragmatic vs upper costal	0.1802 NS

Note: ** $P<0.01$; NS: not significant.

Table 2 Comparison of EMG activity recorded in subjects with costo-diaphragmatic and upper costal breathing types during speech the word 'Mississippi' (Wilcoxon signed rank-sum test)

Muscles	Breathing type	P value
Sternocleidomastoid	Costo-diaphragmatic vs upper costal	0.7269 NS
Diaphragm	Costo-diaphragmatic vs upper costal	0.0013 **
External intercostal	Costo-diaphragmatic vs upper costal	0.0016 **
Latissimus dorsi	Costo-diaphragmatic vs upper costal	0.6071 NS

Note: ** $P<0.01$; NS: not significant.

Table 3 Comparison of EMG Activity recorded in subjects with costo-diaphragmatic and upper costal breathing types during swallowing of saliva (Wilcoxon signed rank-sum test)

Muscles	Breathing type	p-value
Sternocleidomastoid	Costo-diaphragmatic vs upper costal	0.6071 NS
Diaphragm	Costo-diaphragmatic vs upper costal	0.0101 *
External intercostal	Costo-diaphragmatic vs upper costal	0.0141 *
Latissimus dorsi	Costo-diaphragmatic vs upper costal	0.8843 NS

Note: * $P<0.05$; NS: not significant.

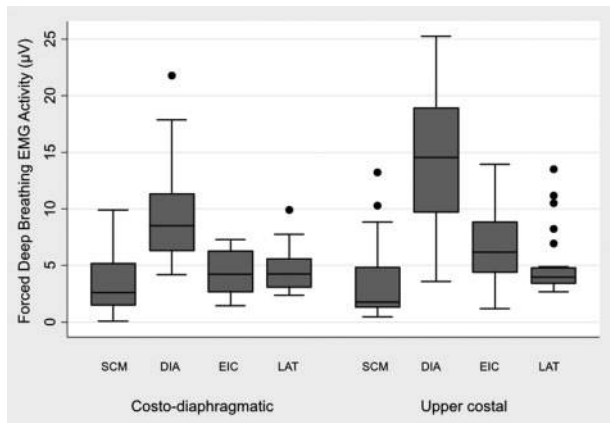


Figure 4 Box plot graph showing EMG activity recorded in the sternocleidomastoid (SCM), diaphragm (DIA), external intercostal (EIC), and latissimus dorsi (LAT) muscles, during forced deep breathing, in subjects with costo-diaphragmatic and upper costal breathing types.

Figure 4 shows forced deep breathing EMG activity recorded in the sternocleidomastoid, diaphragm, external intercostal, and latissimus dorsi muscles, in subjects with costo-diaphragmatic and upper costal breathing types. Table 4 shows that sternocleidomastoid and latissimus dorsi EMG activity was not significantly different between breathing types ($P>0.05$), whereas diaphragm and external intercostal EMG activity was significantly higher in the upper costal than costo-diaphragmatic breathing type ($P<0.01$).

Table 5 shows a significant negative correlation between BMI and diaphragm EMG activity. Subjects

with lower BMI presented higher EMG activity (** $P<0.01$; mixed model with an unstructured covariance matrix). Age did not present a significant correlation with the diaphragm EMG activity ($P>0.05$).

Table 6 shows a significant positive correlation between age and external intercostal EMG activity; the older the subjects higher the EMG activity (** $P<0.01$). Body mass index did not present a significant correlation with the external intercostal EMG activity ($P>0.05$).

Age and BMI did not present a significant correlation with the sternocleidomastoid and latissimus dorsi EMG activity ($P>0.05$).

Discussion

The null hypothesis that EMG activity would be higher in subjects with upper costal than costo-diaphragmatic breathing type must be rejected because this was only observed in the diaphragm and external intercostal muscles.

Sternocleidomastoid EMG activity did not present significant differences between subjects with different breathing types in any of the tasks studied. This agrees with the result observed in a previous study¹¹ in which no significant differences were found at rest and during swallowing EMG activity between both breathing types. The absence of significant differences observed during speaking the word ‘Mississippi’ and forced deep breathing is a new finding in the EMG behavior of this muscle in subjects with different breathing types.

Table 4 Comparison of EMG activity recorded in subjects with costo-diaphragmatic and upper costal breathing types during forced deep breathing (Wilcoxon signed rank-sum test)

Muscles	Breathing type	P value
Sternocleidomastoid	Costo-diaphragmatic vs upper costal	0.7196 NS
Diaphragm	Costo-diaphragmatic vs upper costal	0.0045 **
External intercostal	Costo-diaphragmatic vs upper costal	0.0076 **
Latissimus dorsi	Costo-diaphragmatic vs upper costal	0.7415 NS

Note: ** $P<0.01$; NS: not significant.

Table 5 Diaphragm EMG activity in subjects with different breathing type adjusted by age and body mass index (mixed model with unstructured covariance matrix)

EMG activity	I	z	$P> z $	[95% Conf. Interval]	
Age		0.23	0.817 NS	-0.4396667	0.5570408
Body mass index		-2.66	0.008 **	-1.298278	-0.1974566
Costo-diaphragmatic		4.05	0.000 **	2.686959	7.7297180
Value reference		2.82	0.005	7.231397	40.086380

Note: Reference breathing type: upper costal
 Reference task: 1
 Reference task: 2
 Reference task: 3
 Reference task: 4
 ** $P<0.01$; NS= not significant.

Table 6 External intercostal EMG activity in subjects with different breathing type adjusted by age and body mass index (mixed model with unstructured covariance matrix)

EMG activity	I	z	P> z	[95% Conf. Interval]	
Age	I	2.90	0.004 **	0.1254811	0.6468587
Body mass index	I	-0.88	0.380 NS	-0.4167787	0.1590608
Costo-diaphragmatic	I	3.94	0.000 **	1.330946	3.9688130
Value reference	I	-0.70	0.483	-11.66996	5.5170550

Note: Reference breathing type: upper costal

Reference task: 1

Reference task: 2

Reference task: 3

Reference task: 4

**P<0.01; NS= not significant.

The significant difference observed in diaphragm and external intercostal EMG activity during normal quiet and forced deep breathing in subjects with different breathing types is in agreement with the suggestions that they are 'obligatory' muscles of respiration.¹

The EMG pattern observed in the diaphragm muscle in both breathing types supports the concept that it is the main muscle of inspiration and is responsible for generating the majority of inspiratory airflow,^{2,3} but it also participates during speech and the swallowing of saliva.

Higher EMG activity observed in the external intercostal muscle in subjects with upper costal breathing than in subjects with costo-diaphragmatic breathing type, during normal quiet and forced deep breathing is in agreement with previous work that found that, drive to the respiratory muscles in voluntary breaths, activates the intercostal motoneurons in the same manner as for quiet breathing.⁶ In addition, the authors suggest that it also happens during speech and the swallowing of saliva.

The significantly higher diaphragm and external intercostal EMG activity observed in subjects with upper costal breathing than in subjects with costo-diaphragmatic breathing type suggests that there could be differences in motor unit recruitment strategies depending on the breathing type. This may be an expression of the adaptive capacity of muscle chains in subjects who clinically have a different prevalence of thoraco-abdominal expansion during normal quiet breathing. This pattern of increased EMG activity observed in each of the tasks studied in subjects with upper costal breathing type could be a determinant factor of its adaptability capacity. This may have significant impact on the basic physiological aspect not only in the normal quiet and forced deep breathing, but also during speech and swallowing functions. It could be interesting to compare EMG activity of these muscles in the standing upright position with those in

the supine and lateral decubitus body positions in subjects with different breathing types, which will be the subject of the authors' next study.

Latissimus dorsi muscle EMG activity did not present significant differences between subjects with different breathing types in any of the tasks studied. Its activity could probably be more relevant during longer disturbances and/or in a critical condition, based on previous studies that have found the latissimus dorsi muscle appear to have an inspiratory action in patients with hyperpnea, emphysema, and asthma.^{8,9}

In the present study, a significant negative correlation was found between diaphragm EMG activity and BMI; however BMI did not allow the discrimination between muscle mass and fat layer. This is relevant because it has been observed that an increase in a fatty tissue layer causes a decrease in the values of EMG signal amplitude.¹⁵ Farina and Rainoldi¹⁶ and Bartuzi *et al.*¹⁷ have suggested that the subcutaneous tissue layers attenuate the potential distribution present at the muscle surface.

The authors did not measure muscular and fat weight separately; therefore, it is not possible to assess that subjects with upper costal breathing had lower fat amounts than subjects with costo-diaphragmatic breathing. The authors could speculate that the higher EMG activity observed in subjects with upper costal breathing type is due to a higher respiratory effort during the studied tasks, rather than by the effect of BMI.

Significant positive correlation between external intercostal EMG activity and age was observed. The older the subject, the higher the EMG activity was. The age range of the subjects studied in both groups was narrow (18 to 28 years in the upper costal and 18 to 26 years in the costo-diaphragmatic), so it is probable that the positive correlation observed could be related to a higher thoraco-abdominal muscular volume in the older subjects.

From an overall point of view, this study showed that ‘obligatory’ muscles of respiration, as well as ‘accessory’ respiratory muscles participate not only during normal quiet and forced deep breathing, but also during speech and swallowing functions. This reinforces the concept of the existence of an intimate relationship between different muscle chains that make up the body and work in an integrated way in health or disease. However, further studies are required, in order to have a better understanding of the mechanisms underlying the relationships between EMG activity and breathing type.

The present study has at least two limitations. First, subjects were only male and were recruited at the Dental and Medicine school of the University of Chile. This was to avoid difficulties with breast size, asymmetry of breasts and the use of a bra in the female students during the EMG recording. This may limit the ability to extrapolate these findings to the general population. Second, other factors that could also affect breathing type were not considered in this study (e.g. nasal and/or oral breathing, cervical alignment, body biomechanics). In spite of these limitations, this is the first study that showed significant differences in the diaphragm and external intercostal muscles between subjects with costo-diaphragmatic and upper costal breathing.

Conclusions

- Diaphragm and external intercostal EMG activity was significantly higher in subjects with upper costal breathing type than in subjects with costo-diaphragmatic breathing type.
- This EMG pattern observed in subjects with upper costal breathing type could be a determinant factor of its adaptive capacity.

Disclaimer statements

Contributors IC: Performed the experiments, wrote the manuscript, and contributed substantially to the discussion. RC: Performed the experiments, wrote the manuscript, proofread the manuscript, and contributed substantially to discussion. RM: Idea, experimental design, wrote the manuscript, contributed substantially to the discussion, proofread the manuscript, consulted on and performed the statistical evaluation. FM: Performed the experiments, and wrote the manuscript. PE: Performed the experiments, and wrote manuscript. CB: Performed the experiments, and wrote manuscript. SV: Performed the experiments, wrote the manuscript, proofread the

manuscript, and contributed substantially to the discussion.

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Conflicts of interest The authors have no conflicts of interest in this study.

Ethics approval A protocol based on ethical principles that have their origin in the Declaration of Helsinki was used.

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