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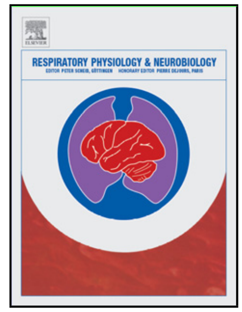

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Highlights

- ・The trapezius muscle (Traps) is considered one of the accessory muscles
- ・Even in the supine position, Traps had a unique EMG activity
- ・Traps and other accessory muscles did not have the same EMG activity
- ・There was no difference in the EMG activity of Traps between men and women
- ・The unique activity of Traps might be helpful in assessing forceful inspiration

Abstract

The activity of the trapezius muscle is reportedly higher than that of other neck accessory muscles under a condition of increased inspiratory pressure in the standing position. The present study aimed to compare the activity of the trapezius muscle with those of the scalene and sternocleidomastoid muscles under a condition of increased inspiratory pressure in the supine position. This study included 40 subjects, and the muscle activity was measured using surface electromyography. Regarding the results, there was a significant difference in the muscle activity between the trapezius muscle and the scalene and sternocleidomastoid muscles ($p = 0.003$) in both men and women. Post-hoc analysis showed significant differences between trapezius and the other muscles. Moreover, there was no difference between the scalene and sternocleidomastoid muscles ($p = 0.596$). The increase in the change in electromyography activity of the muscle is greater in the trapezius muscle than in other muscles when the level of inspiratory pressure increases in the supine position.

Keywords: supine position, trapezius muscle, accessory muscles, inspiratory resistive loading, surface electromyography

1. Introduction

During quiet breathing, the diaphragm performs most of the work. When the activity of the diaphragm increases with forceful breathing, the accessory breathing muscles are recruited to maintain forceful breathing (Celli, 1998; DeTroyer and Boriek, 2011). The accessory muscles of inspiration include various muscles in the neck, chest, and upper back. The trapezius muscle is one of these muscles (Agostoni, 1964), and it is a prominent muscle of the neck, thoracic, and shoulder regions. It extends along the midline from the occiput to the lower thoracic region and extends laterally as far as the acromion. The role of the trapezius muscle is to draw the scapula and clavicle backward or to raise the scapula by rotating the clavicle about the sternoclavicular joint (Johnson et al., 1994). A previous study reported that the activity of the trapezius muscle increases during forceful inspiration to help brace the head and to allow the sternocleidomastoid muscles to raise the thorax (DeTroyer and Boriek, 2011). With increasing inspiratory resistive loading during forceful inspiration, the trapezius muscle has been reported to have different activity levels or characteristics of muscle contraction compared with those of other accessory inspiratory muscles (Yokoba et al., 2003). In these previous studies, the activity of the trapezius muscle was measured with subjects in the standing position. The effect of an increase in inspiratory resistive loading on the activity of the trapezius muscle in the supine position has not been reported (Segizbaeva et al., 2013). Additionally, because differences in maximum inspiratory pressure have been reported between men and women with different heights, weights, and respiratory functions, it is not known whether there are differences in the effect of an increase in inspiratory resistive loading on the activity of the trapezius muscle in the supine position between men and women (Aslan et al., 2019; White et al., 1983; Aitken et al., 1986; Chen and Kuo, 1989).

Unlike the standing position in the previous study (Yokoba et al., 2003), the role of the trapezius during inspiration may be different in the supine position where the scapula is fixed. Therefore, the present study aimed to analyze the activity difference between the trapezius muscle and the scalene and sternocleidomastoid muscles with regard to activity changes in response to increased inspiratory pressure among subjects in the supine position, using surface electromyography (EMG). In addition, we compared the activity of the trapezius muscle in response to an increase in inspiratory pressure between males and females.

2. Material and methods

2.1. Design and subjects characteristics

This was an experimental cross-sectional study. The study included 40 nonsmoking subjects (20 male and 20 female subjects) that did not have daily exercise habits. Their ages ranged from the 20s to the 40s. Each subject was confirmed by interview to be free of cardiorespiratory diseases, such as pulmonary emphysema, bronchial asthma, pneumothorax, hyperventilation syndrome, angina, and myocardial infarction. In addition, pulmonary function tests involving a spirometer (Graham et al., 2019) at the sitting position revealed no abnormalities, such as obstructive, restrictive, and mixed pulmonary diseases. The subject characteristics, such as age, height, weight, vital capacity (VC), percentage vital capacity (%VC), forced vital capacity (FVC), forced expiratory volume in 1 second (FEV1), ratio of forced expiratory volume in 1 second to forced vital capacity (FEV1/FVC) and body mass index (BMI), were recorded. This study was approved by the appropriate Ethics Committee and was performed according to the ethical standards of the Helsinki Declaration for Human Experimentation. Each subject provided written informed consent after receiving a thorough explanation of the study.

2.2. Measurements

2.2.1. Experimental device

Resistance during inspiration was measured using the Threshold IMT inspiratory resistive loading device (Respironics Medical Products, Shenzhen, China), which can be used with the subject in any body position. The internal spring is expanded and contracted by turning the control knob, and the magnitude of resistance during inspiration can be measured from 9 to 40 cm H_2O (De Andrade et al., 2005). The maximal inspiratory mouth pressure (PIm_{max}) was measured by Müller's maneuver (Segizbaeva et al., 2013), using the maximal inspiratory pressure (MIP) function of the Vela™ Ventilator (Care Fusion, San Diego, CA, USA).

2.2.2. Surface EMG recordings

EMG signals from the scalene, sternocleidomastoid, and trapezius muscles were measured using pairs of transcutaneously applied bipolar surface EMG electrodes (20-mm diameter, silver/silver chloride, Natus®; Natus Neurology, Middleton, WI, USA) connected to a Viking Quest version 12 recording system (Care Fusion). Interelectrode impedance was minimized by abrading the skin with an abrasive powder applied using alcohol-treated cotton. With regard to EMG signal measurement, the electrode is applied in the direction of the muscle fiber of the scalene muscle, which are located in the posterior triangle lateral to the sternocleidomastoid muscle, was placed on the skin above the right middle scalene muscle under ultrasonographic observation (7.5-MHz linear probe) (Usui et al., 2010; Schmidt et al., 2013). Additionally, the electrode for the sternocleidomastoid muscle was placed on the skin 5 cm medially at the thyroid cartilage level (Sekiguchi et al., 2018).

The electrode for the trapezius muscle was placed in the center of a straight line between the acromion and the seventh cervical vertebra (Holtermann et al., 2008). The electrodes were attached to the skin with vinyl tape 2 cm apart. The reference electrode was solidly attached to the right acromion. Before the experiment, the baseline noise of the surface EMG wave was assessed. If considerable noise was detected, additional skin abrasion was performed before electrode reattachment. The input impedance of the amplifier was set to 200 MΩ, and the common mode rejection ratio was 110 dB. The Ham filter was turned off, and the band-pass filter was set between 5 Hz and 1.5 kHz. Analog EMG signals were digitized at 16 bits and a sampling rate of 100 kHz. The digitized signals were stored on a portable computer. Signal strength was quantified by Integrated-EMG (Basmajian and DeLuca, 1985; Moritani and Yoshitake, 1998; Fischer et al., 2015) for period of 3 seconds (mV·s). After attaching the electrodes, the subject was placed in the supine position on a bed in the physiology laboratory.

2.2.3. Data acquisition and processing

Maximum voluntary contraction (MVC) techniques of the scalene, sternocleidomastoid (Hislop et al., 2014), and trapezius (Hislop et al., 2014) muscles were directly applied by a physical therapist, and the EMG signals of each muscle were recorded. MVC was maintained for 3 s.

The PIm_{max} was measured with the subject holding a mouthpiece attached to the ventilator circuit and performing inspiration for 3 s while wearing a nose clip. Inspiratory resistive loadings of 10, 20, 30, and 40 cm H_2O were measured randomly for 3 s with the subject breathing on a mouthpiece connected to Threshold IMT. Both arms of the subject were placed beside the trunk, and the mouthpiece was retained by the experimental assistant to prevent artifacts on EMG caused by the subject moving the arms. During measurement of the PIm_{max} and each inspiratory resistive loading, the subject's occipital region of the head and back was grounded to the bed surface. The subject was instructed to perform inspiration for 3 s for each measurement by following a metronome. The PIm_{max} and each inspiratory pressure from 10 to 40 cm H_2O were measured thrice and the maximum value of each measurement was recorded for use in this study. The target muscle activity for period of 3 seconds was evaluated using I-EMG. A rest interval of 3 min was allowed between measurement tasks (MVC, PIm_{max}, and each inspiratory resistive loading).

2.3. Statistical analysis

Subject characteristics, such as age, height, and VC, are presented as mean ± standard deviation. Differences in age, height, weight, and lung capacity, %VC, FVC, FEV1, FEV1/FVC, PIm_{max} and BMI between male and female subjects were analyzed using the unpaired *t*-test. Integrated EMG values of PIm_{max}, 10 cm H_2O, 20 cm H_2O, 30 cm H_2O, and 40 cm H_2O were calculated as %EMG compare with the integrated EMG values of the MVCs of the three targeted muscles, respectively.

The %EMG values of the muscles are expressed as mean ± standard deviation for all subject, male and female subjects, respectively. The change in %EMG with increase in PIm, with values from 10 to 20 cm H_2O, 20 to 30 cm H_2O, 30 to 40 cm H_2O, and 40 cm H_2O to PIm_{max}, were calculated respectively, using the following formula:

$$\Delta \%EMG(\%)/\Delta P\mathrm{Im}(cmH_2O)$$

The factor 1 was the difference in %EMG change between the scalene, sternocleidomastoid, and trapezius muscles with increase in inspiratory pressure. The factor 2 was the difference in %EMG change within each muscle with increase in inspiratory pressure. They were analyzed by two-way analysis of variance (ANOVA) repeated in all subjects, male and female subjects, respectively. If there was a significant difference in the %EMG of the three targeted muscles, the post-hoc test used the honestly significant difference test of Tukey–Kramer.

As subanalysis, we analyzed the %EMG with increase in each PIm of the trapezius muscle in the male and female subjects using two-way repeated measures analysis of variance (ANOVA) using both sex and %EMG change with increase in inspiratory pressure as factors.

For all statistical analyses in this study, $p < 0.05$ was considered to indicate statistical significance. All statistical analyses were performed using JMP® statistical package (version 14.1.0; SAS Institute, Cary, NC, USA).

3. Results

3.1. Subject characteristics and EMG data

All subjects completed the experimental procedure. The subject characteristics are shown in Table 1 (insert Table 1 here). Height, weight, VC, FVC, FEV_1, PIm_{max}, and BMI were significantly greater in male subjects than in female subjects.

The %EMG values based on integrated EMG values against MVCs of the three targeted muscles in all subjects, male and female subjects are shown in Tables 2, respectively. (insert Table 2 here). The measured values from 10 to 40 cm H_2O showed an increasing trend with increasing inspiratory pressure.

Figure 1 shows the raw EMG data in a male subject (insert Figure 1 here). Figure 2 indicates the percent electromyogram (%EMG) of each muscle with increase in inspiratory pressure from 10 to 20, 20 to 30, 30 to 40 cm H_2O, and 40 cm H_2O to PIm_{max} in all subjects (N = 40) (insert Figure 2 here).

3.2. The difference in %EMG change among the scalene, sternocleidomastoid, and trapezius muscles with increase in the inspiratory pressure.

There were differences in the size of the %EMG changes among the three muscles as across all conditions of inspiratory pressure ($p = 0.003$). Post-hoc analysis showed that the differences were between the trapezius and the scalene and sternocleidomastoid muscles, $p < 0.001$ and $p = 0.001$ respectively. There was no difference in the EMG change between scalene and sternocleidomastoid muscles ($p = 0.596$). Figure 3 indicates change in percent electromyogram (%EMG) of each muscle with increase in inspiratory pressure from 10 to 20, 20 to 30, 30 to 40 cm H_2O, and 40 cm H_2O to PIm_{max} in male and female subjects (N = 20, respectively). In male subjects, as the upper panel in figure 3 indicates, the result of the difference in the %EMG change among the scalene, sternocleidomastoid, and trapezius muscles with increase in inspiratory pressure was $p = 0.023$. The Tukey–Kramer test showed $P = 0.661$ for the scalene and sternocleidomastoid muscles, $p = 0.011$ for the scalene and trapezius muscles, and $p = 0.030$ for the sternocleidomastoid and trapezius muscles. In female subjects, as the bottom panel in figure 3 shows, the result of the difference in %EMG change among the scalene, sternocleidomastoid, and trapezius muscles with increase in the inspiratory pressure was $P < 0.0001$. The Tukey–Kramer test showed $p = 0.744$ for the scalene and sternocleidomastoid muscles, $p < 0.0001$ for the scalene and trapezius muscles, and $p < 0.0001$ for the sternocleidomastoid and trapezius muscles. There were statistically significant differences among the scalene, sternocleidomastoid, and trapezius muscles in the amount of change in %EMG under an increase in inspiratory pressure both male and female, respectively. The increase in %EMG with changes in inspiratory pressure in the trapezius muscles in both of male and female were different from those in the scalene and sternocleidomastoid muscles in each sex (insert Figure 3 here).

3.3. The difference in the %EMG change within each muscle with increase in inspiratory pressure

The difference in the %EMG change within each muscle with an increase in the inspiratory pressure in all subjects was significant ($P < 0.0001$). The results differed significantly between male and female subjects ($P < 0.0001$).

3.4. The change in %EMG with increase in each PIm of the trapezius muscle in male and female subjects

Figure 4 shows the comparisons of the amount of change in %EMG with increase in inspiratory pressure of the trapezius muscle in male and female subjects. The difference in %EMG change of the trapezius muscles between male and female with increase in inspiratory pressure was $P = 0.81$. The difference in %EMG change in each muscle with increase in inspiratory pressure was $P <0.0001$. There were no statistically significant differences between the trapezius muscles both of male and female in the amount of change in %EMG with an increase in inspiratory pressure. Furthermore, the Figure 4 showed that trapezius muscles tended to have higher EMG action potentials at higher inspiratory pressures. (insert Figure 4 here).

4. Discussion

Although this was an experimental cross-sectional study with a limited number of participants and a limited range of ages, this study showed that when the level of inspiratory pressure increased with the subject in the supine position, the change in the characteristics of the contraction of the trapezius muscle, based on surface EMG, was significantly different (say greater or less) from that of other neck muscles (i.e., the scalene and sternocleidomastoid muscles). Furthermore, the activity of the trapezius muscle that appeared under high inspiratory pressure did not differ between male and female subjects. From the perspective of respiratory physiology, the trapezius muscle is considered as one of the accessory muscles of inspiration, and its function is interpreted to enlarge the rib cage and facilitate the action of the inspiratory muscles (Agostoni, 1964). However, interestingly, according to a study by Johnson et al. (1994) involving the detailed anatomy of adult human cadavers, the essentially transverse orientation of the upper and middle fibers of the trapezius precludes any action as an elevator of the scapula, as commonly depicted. In fact, the action of these fibers is to draw the scapula and clavicle backward or to raise the scapula by rotating the clavicle about the sternoclavicular joint. Holtermann et al. (2008) confirmed the conclusion of the study by Johnson et al. (1994) regarding the function of the trapezius muscle on EMG studies. According to Fishman et al. (2017), during forceful inspiration, the trapezius muscle becomes more active to help brace the head and to allow the sternocleidomastoid muscle to raise the thorax. Another study, in which inspiratory resistive loading was continuously increased, reported that the activity of the trapezius muscle was markedly higher than the activities of the scalene and sternocleidomastoid muscles at high inspiratory resistive loading (Yokoba et al., 2003). In this study, the subjects were standing during measurements. We believed that the activity pattern of the trapezius muscle differs between the supine and standing positions. Because, as the back is fixed on the bed in the supine position and the movements of the scapula are restricted, there is a possibility that the role of the trapezius muscle accompanying inspiratory movements, as described in previous studies, might not be clear. However, surprisingly and contrary to our expectations, we found that the activity of the trapezius muscle increased at high inspiratory pressure, even with subjects in the supine position, similar to the findings in subjects in the standing position. With regard to future research on the interpretation of this result, we believe that it is important to clarify the interaction or influence between the diaphragm activity (or including other respiratory accessory muscles activity) and the trapezius muscle when changing the body position of the subject because this study did not assess the diaphragm (Hudson et al. 2016).

Moreover, contrary to our pre-experiment predictions, despite the differences in physical status and respiratory physiological functions, such as height, weight, VC, and MIP, there was no difference in the activity pattern of the trapezius muscle between the male and female subjects. Therefore, on the basis of this result, we may be able to apply the characteristics of the trapezius muscle exhibiting prominent activity at a relatively high inspiratory pressure to the assessment of respiration of both male and female patients. For example, if the trapezius and other accessory respiratory muscles are simultaneously evaluated using surface electromyography, the estimation method of "prominent accessory muscles use," which was earlier based on subjective visual observation (Steinborn et al., 2001), may be objectively used by determining the prominent recruitment of trapezius muscle.

The present study has several limitations. First, the study included only 40 subjects. In the future, it will be necessary to verify the results in a larger number of subjects. Second, although the methods in this study were based on those in previous experimental studies, we used an inspiratory resistive loading device (De Andrade et al., 2005) that can maintain a constant inspiratory resistive pressure regardless of the inspiratory flow. The inspiratory time was controlled using a metronome; however, the tidal volume was not measured. It will be necessary to verify the experimental results with a controlled tidal volume in the future. Third, although the study showed the unique activity of the trapezius muscle under high inspiratory pressure, we could not show the anatomical and physiological mechanisms of the results. Fourth, Surface EMG was used in this study; therefore, it is necessary to recognize that contamination of the action potential from other adjacent muscles cannot be completely prevented. Finally, all the subjects were relatively young, healthy males and females. In the clinical setting, patients facing long-term inactivity in bed with long-term mechanical ventilator support might be of different ages and might have different muscle conditions (Mantilla and Sieck, 2013; Powers et al., 2013). Therefore, the clinical application mentioned previously in the Discussion is speculative, and verification in a real clinical setting is necessary in the future.

5. Conclusions

The increase in the amount of change in activity of the muscle is greater in the trapezius muscle than in the scalene and sternocleidomastoid muscles when the level of inspiratory pressure increase in the supine position. Additionally, the characteristic activity pattern of the trapezius muscle does not differ between males and females. It is possible that the specific activity of the trapezius muscle under high inspiratory pressure might be helpful to assess the threshold of forceful inspiration with prominent accessory muscle activities in the fields of clinical medicine and respiratory rehabilitation medicine in the future.

Author contributions

Hiroshi Sekiguchi: Conceptualization, Methodology, Writing-Original Draft. **Akira Minei:** Investigation. **Masako Noborikawa:** Data Curation. **Yutaka Kondo:** Validation, Supervision. **Yuichiro Tamaki:** Validation, Writing-Review & Editing. **Tatsuma Fukuda:** Validation, Supervision. **Kazuhiko Hanashiro:** Formal analysis. **Ichiro Kukita:** Supervision.

Conflict of interest statement

None.

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Fig. 1. Raw electromyography (EMG) data. Representative raw EMG data of the scalene, sternocleidomastoid and Trapezius muscles. The top rows of the traces are scalene and the second and third rows are sternocleidomastoid and Trapezius EMGs, respectively. The interval between vertical lines 1 (L1) and 2 (L2) are 3 seconds, respectively. The number (μV) at the right end of the figure represents the scale of the electromyogram display, respectively.

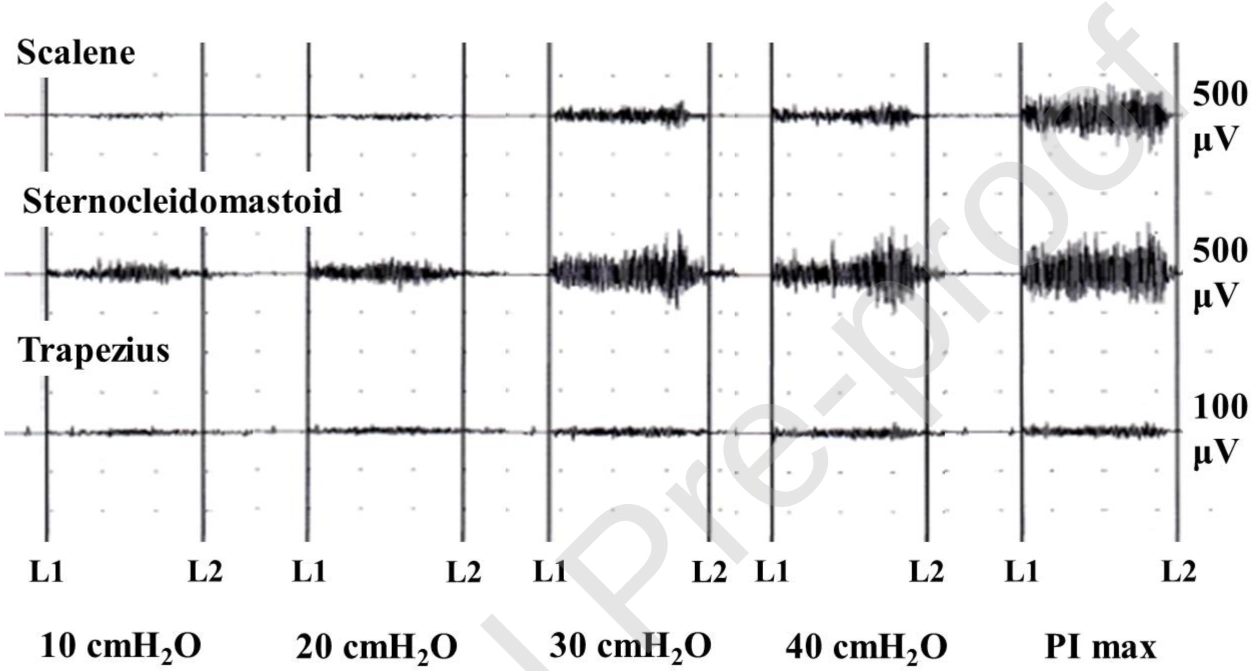


Fig. 2. Change in percent electromyogram (%EMG) with increase in inspiratory mouth pressure in all subjects. The small dotted line graph indicate the scalene muscle, the big dotted line graph indicate sternocleidomastoid muscle, and the solid line graph indicate trapezius muscle. The black points on the line graph are the average value, and the error bars indicate the standard deviation. The vertical axis indicates the percent electromyogram (%EMG) with increase in inspiratory pressure per one cmH_2O. The horizontal axis indicates change in the inspiratory pressure. N = 40.

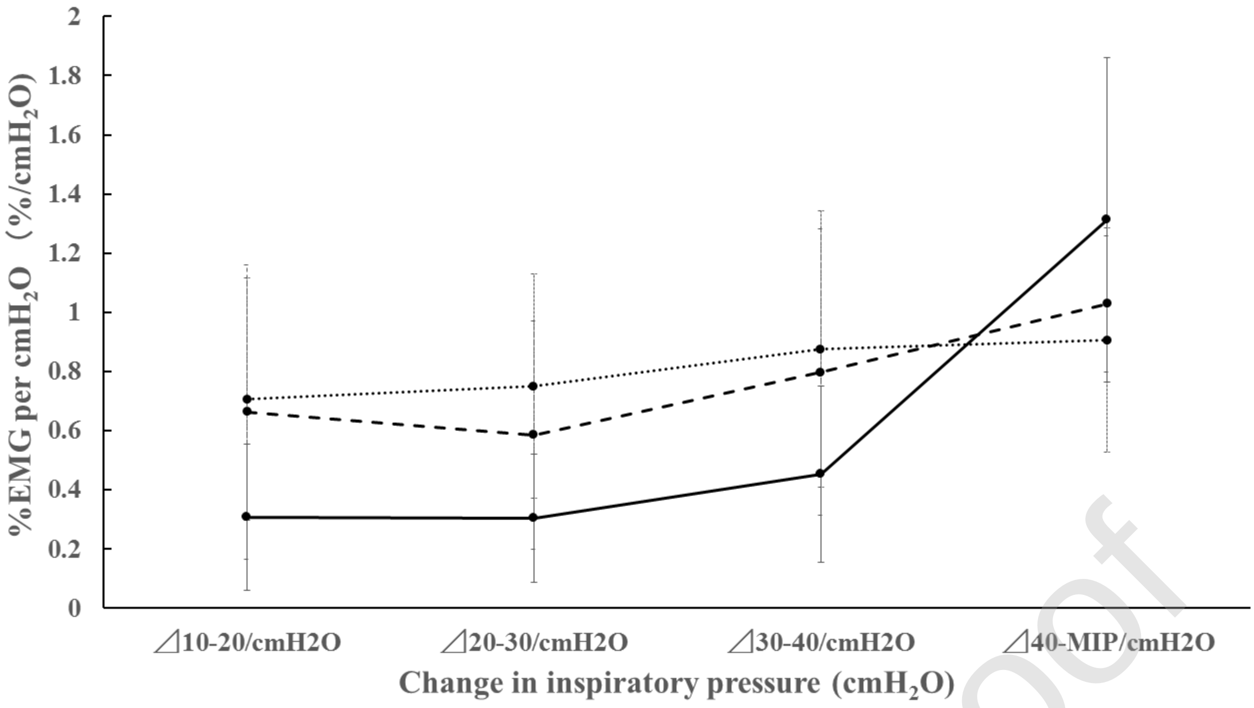
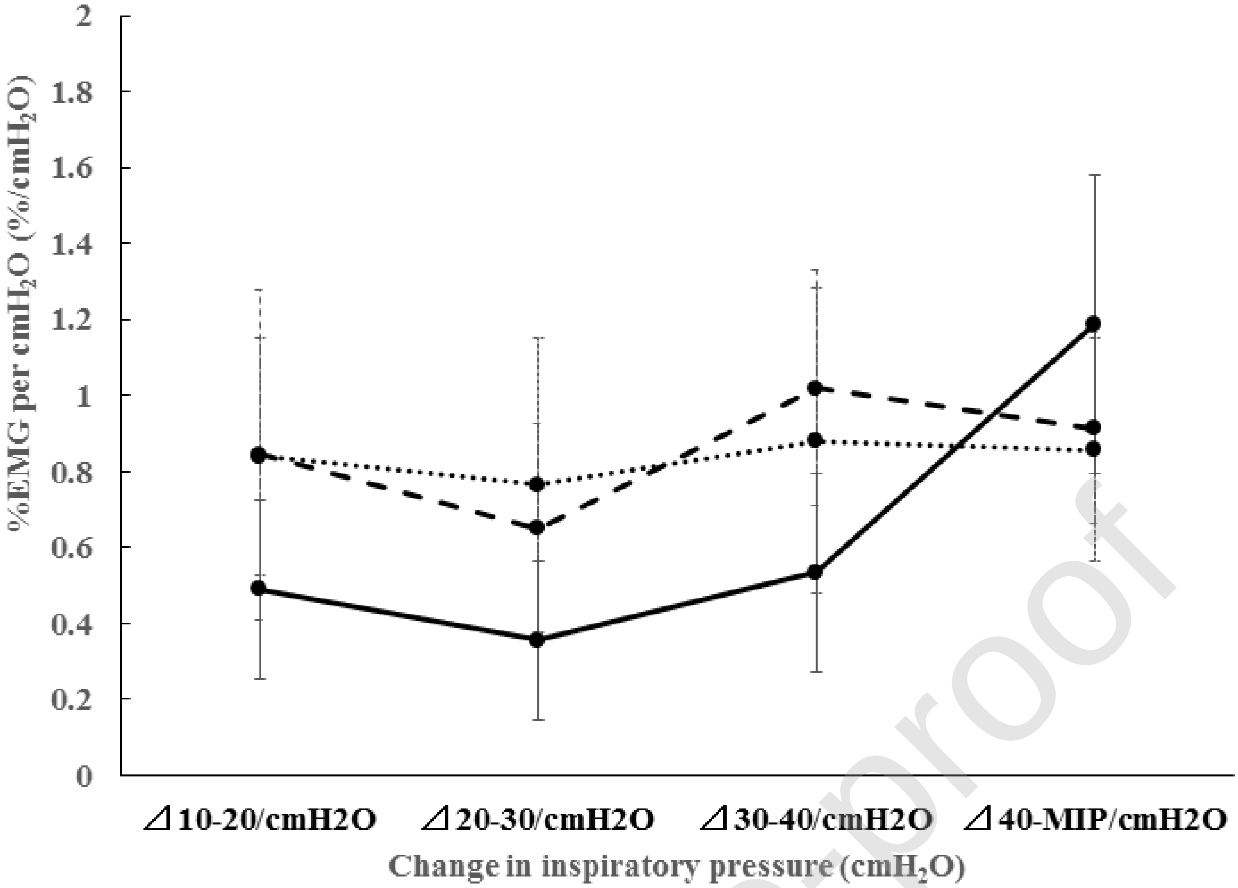


Fig. 3. Change in percent electromyogram (%EMG) with increase in inspiratory mouth pressure in male and female subjects. The upper panel is male subject, the bottom one indicates female subjects. The small dotted line graph indicate the scalene muscle, the big dotted line graph indicate sternocleidomastoid muscle, and the solid line graph indicate trapezius muscle. The black points on the line graph are the average value, and the error bars indicate the standard deviation. The vertical axis indicates the percent electromyogram (%EMG) with increase in inspiratory pressure per one cmH_2O. The horizontal axis indicates change in the inspiratory pressure, respectively. The number of subject is 20 each.


2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
%EMG per cmH2O (%/cmH2O)
⊿10-20/cmH2O
⊿20-30/cmH2O
⊿30-40/cmH2O
⊿40-MIP/cmH2O
Change in inspiratory pressure (cmH2O)

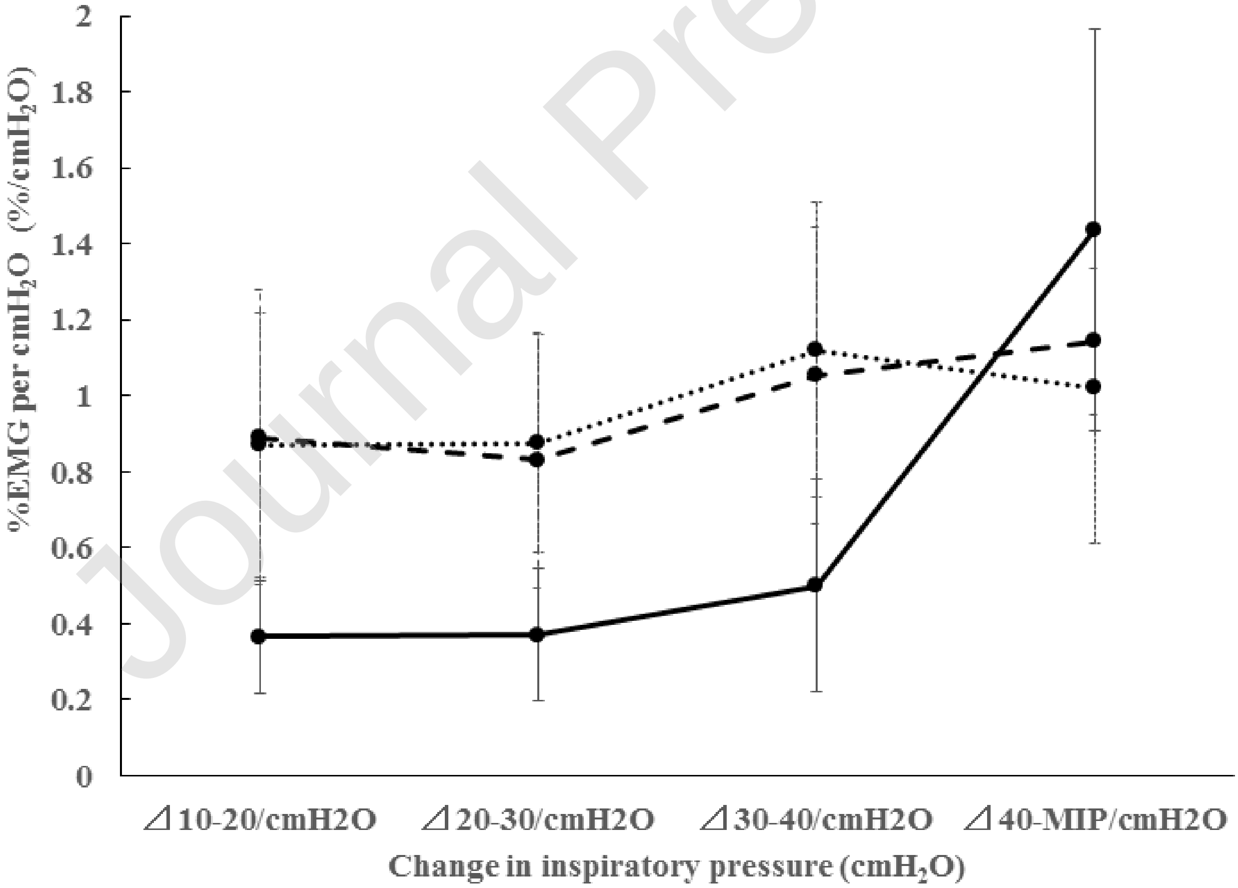

2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
%EMG per cmH2O (%/cmH2O)
⊿10-20/cmH2O
⊿20-30/cmH2O
⊿30-40/cmH2O
⊿40-MIP/cmH2O
Change in inspiratory pressure (cmH2O)

Fig. 4. Comparison of the percent electromyogram (%EMG) of trapezius muscle with increase in inspiratory mouth pressure between male and female subject. The dotted line graph is male subject, the solid line graph is female subject. The black points on the line graph are the average value, and the error bars indicate the standard deviation. The vertical axis indicates the percent electromyogram (%EMG) with increase in inspiratory pressure per one cmH_2O. The horizontal axis indicates change in the inspiratory pressure. The number of subject is 20, respectively.

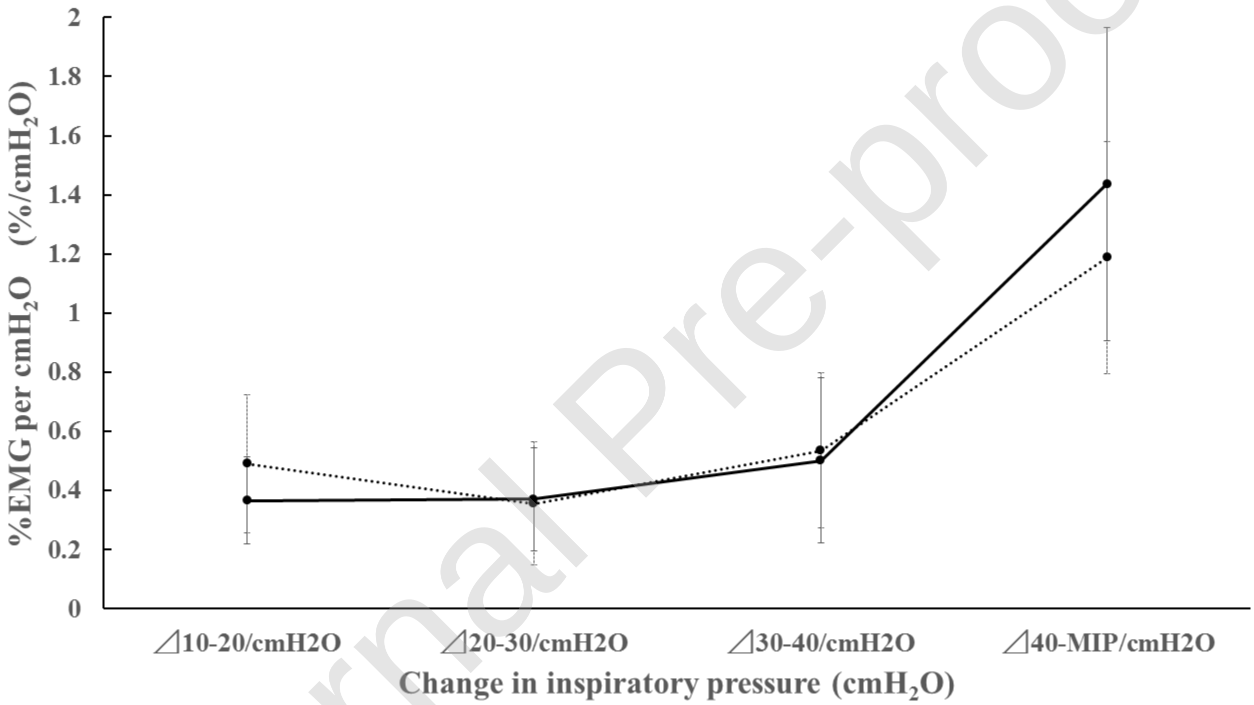


Table 1 The characteristics of subjects

Characteristics	Male	Female	P-value
Age (y)	29 ± 5	30 ± 6	0.36
Height (cm)	171 ± 3	157 ± 6	< 0.0001
Weight (kg)	68 ± 8	52 ± 7	< 0.0001
VC (ml)	4637 ± 399	3330 ± 608	< 0.0001
%VC	111.8 ± 8.5	112.2 ± 18.2	0.46
FVC (ml)	4610 ± 377	3311 ± 513	< 0.0001
FEV_1	4098 ± 358	2980 ± 534	< 0.0001
FEV_1/FVC	88.9 ± 6.1	89.4 ± 5.9	0.39
PI m_{max} (cmH_2O)	79 ± 12	58 ± 11	< 0.0001
BMI	27.2 ± 2.1	25.6 ± 2.5	< 0.0001

n = 40. Results are presented as mean ± SD.

VC, vital capacity; %VC, percent vital capacity; FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, forced expiratory volume one second percent; PI m_{max}, maximal inspiratory mouth pressure. BMI, body mass index. Statistical analysis was performed using unpaired *t*-test. Significant p value at $P < 0.05$.

Table 2 %EMG at MVC in all subjects

Inspiratory mouth pressure	Scalene	Sternocleidomastoid	Trapezius
PIm_{max}	75±16	65±16	47±22
40cmH_2O	64±15	52±16	30±14
30cmH_2O	55±15	44±13	25±12
20cmH_2O	48±13	38±12	22±10
10cmH_2O	41±12	31±11	19±11

%EMG at MVC in male subjects

Inspiratory mouth pressure	Scalene	Sternocleidomastoid	Trapezius
PIm_{max}	69±15	63±15	45±22
40cmH_2O	57±14	50±18	29±12
30cmH_2O	49±14	43±15	24±10
20cmH_2O	41±10	36±12	22±9
10cmH_2O	35±10	30±11	19±12

%EMG max at MVC in female subjects

Inspiratory mouth pressure	Scalene	Sternocleidomastoid	Trapezius
PIm_{max}	82±15	67±16	48±23
40cmH_2O	70±14	53±15	32±15
30cmH_2O	62±12	45±11	27±13
20cmH_2O	54±12	40±12	23±12
10cmH_2O	47±10	33±10	20±10

n = 40 (male = 20, female = 20). Results were presented as mean ± SD (%).

%EMG, percent electromyogram; MVC, maximum voluntary contraction; PImmax, maximal inspiratory mouth pressure. The upper table shows the results for all subjects. The middle table shows the results for male subjects, and the lower table shows the results for female subjects.