

## Changes in respiratory activity induced by mastication during oral breathing in humans

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**Daimon S, Yamaguchi K.** Changes in respiratory activity induced by mastication during oral breathing in humans. *J Appl Physiol* 116: 1365–1370, 2014. First published April 17, 2014; doi:10.1152/jappphysiol.01236.2013.—We examined the effect of oral breathing on respiratory movements, including the number of respirations and the movement of the thoracic wall at rest and while chewing gum. Forty normal nose breathers were selected by detecting expiratory airflow from the mouth using a CO<sub>2</sub> sensor. Chest measurements were recorded using a Piezo respiratory belt transducer, and electromyographic (EMG) activity of the masseter and trapezius muscles were recorded at rest and while chewing gum during nasal or oral breathing. Oral breathing was introduced by completely occluding the nostrils with a nose clip. During oral breathing, the respiration rate was significantly lower while chewing gum than while at rest ( $P < 0.05$ ). While chewing gum, the respiration rate was significantly lower during oral breathing than during nasal breathing ( $P < 0.05$ ). During oral breathing, thoracic movement was significantly higher while chewing gum than while at rest ( $P < 0.05$ ). Thoracic movement was significantly greater during oral breathing than during nasal breathing ( $P < 0.05$ ). The trapezius muscle exhibited significant EMG activity when chewing gum during oral breathing. The activity of the trapezius muscle coincided with increased movement of the thoracic wall. Chewing food while breathing through the mouth interferes with and decreases the respiratory cycle and promotes unusual respiratory movement of the thoracic wall, which is directed by the activity of accessory muscles of respiration.

oral breathing; mastication; thoracic wall movement

NORMAL SWALLOWING in humans is depicted as a four-stage sequential process. The four stages, based primarily on the location of the bolus in the food pathway, are the oral preparatory, oral propulsive, pharyngeal, and esophageal stages (4, 11). In this four-stage sequential model, mastication is regarded as part of the oral preparatory stage. During the oral preparatory stage, food is thought to be retained in the oral cavity by closure of the lips anteriorly and the oropharyngeal isthmus posteriorly. Firm contact between the soft palate and the posterior surface of the tongue is believed necessary to prevent premature leakage of the food into the pharynx and prevent aspiration prior to swallowing (13). Respiration and mastication must be controlled to prevent aspiration during this period of bolus aggregation, given the overlapping anatomy of the esophagus and the trachea (13). These are normal phenomena during nasal breathing. The respiration rate is said to increase and the movement of the thoracic wall to decrease during mastication while breathing through the nose (6, 14–15,

24); however, nasal breathing never disturbs the masticatory function (13, 14, 23).

In contrast, the respiratory and masticatory functions cannot help but compete with the oral tract when breathing through the mouth in cases of nasal obstruction. Oral breathing reportedly interferes with chewing activity and decreases the duration of tooth contact and degree of tooth contact force (8, 9). The decreased vertical effect of chewing on the posterior teeth extrudes the posterior teeth, resulting in clockwise rotation of the mandible (12, 25). These results indicate how oral breathing induces the vertical deformity of the face as an etiological factor. Other experimental studies have described the mechanism through which nasal obstruction induces horizontal or anteroposterior deformities of the face (16, 26).

By the same token, mastication during oral breathing might interfere with breathing when the two functions compete with each other. However, the influence of oral breathing on respiration when chewing food has not been well studied.

During normal ventilation, the chest is magnified by shrinkage of inspiratory muscles (e.g., the intercostal external muscle or the diaphragm). Respiratory activity is controlled and adjusted by several mechanisms. For example, the carotid body senses changes in the partial pressure of carbon dioxide in the blood, and chemical adjustment from the chemoreceptor in the carotid body stimulates the respiratory center and regulates respiratory movement (1, 5, 18, 20, 22). In addition, mechanical stimuli such as tension or negative pressure in the lung and respiratory muscles induce respiratory reflexes to magnify the inspiratory muscles (28). In these mechanisms, a labored breath is made by expanding the thoracic and abdominal walls to increase the tidal volume. Unusual activity of the accessory respiratory muscles (e.g., the anterior scalenus, trapezius, and sternocleidomastoid muscles) is required in addition to the usual respiratory muscle activity at rest (2, 3, 10, 21, 29).

We postulated that mastication during oral breathing will decrease the respiratory rate, and that impeded respiratory function would introduce extraordinary movement of the thoracic wall by the accessory respiratory muscles through several mechanisms, including the central nervous system.

To test this hypothesis, in this study we examined the effect of oral breathing on respiratory functions, including the respiratory rate and thoracic wall movement accompanying accessory respiratory muscle activity at rest and while chewing gum.

### METHODS

**Participants.** Forty adult men were categorized as normal nasal breathers by detecting expiratory airflow from the mouth for 5 min using a CO<sub>2</sub> sensor (Nihon Kohden, Tokyo, Japan) according to Fujimoto et al. (7). For these participants, we recorded respiratory exhalation, chest measurements, and the electromyographic (EMG) activity of the masseter and trapezius muscles at rest and while chewing gum during nasal or oral breathing.

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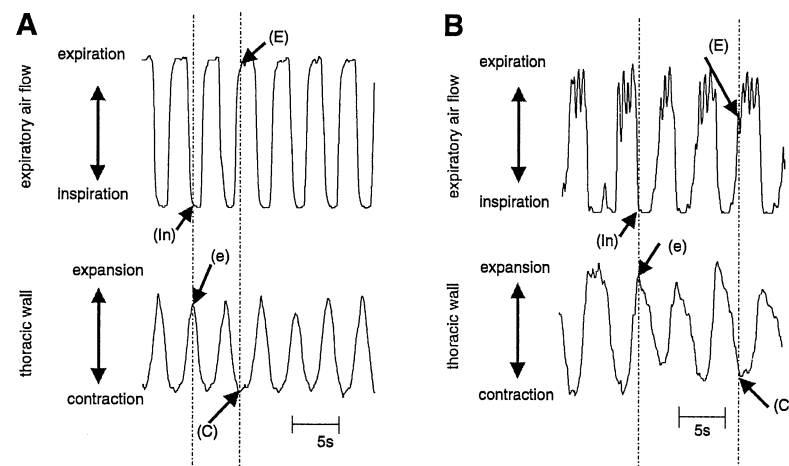


Fig. 1. Coordination of oral or nasal airflow with thoracic wall movements. The maximum inspiration (In) and expiration (E) coincide with the maximum expansion (e) and contraction (C) of the thoracic wall during nasal breathing (A) and oral breathing (B). Therefore, the respiratory variables were estimated using the measurement of thoracic movement during respiration.

The study protocol was approved by the institutional ethics committee of research. The protocols were performed under a license obtained from the committee. After we explained the purpose of this study, informed consent was obtained from all participants.

**Recording respiratory airflow at rest and during gum chewing.** Respiratory exhalations from the nose during nasal breathing, and from the mouth during oral breathing, were recorded with a CO<sub>2</sub> sensor at rest and while chewing gum (tooth brushing gum, Cracie Food Research Institute, Osaka, Japan) for 60 s. Oral breathing was introduced by completely occluding the nostrils with a nose clip.

**Measurement of chest movement with piezo-electricity sensors.** First, each study participant sat in a dental chair in an upright position. We fixed piezo-electricity sensors (Piezo respiratory belt transducer, MLT1132, ADInstruments) to each participant's chest at the height of the bilateral nipple when the individual stopped his breath at maximal exhalation. For each participant, the actual measurement (mm) of the chest circumference was measured using a measuring tape at the height of the bilateral nipple during maximal inspiration and exhalation. Then the maximum and minimum chest measurements recorded with the piezo-electricity sensors were calibrated with the actual maximal and minimal chest circumference measurements.

Next, we recorded thoracic wall movement using piezo-electricity sensors for 60 s, and calculated chest movement as the difference between the maximum and minimum chest measurements while each participant was at rest, as well as while chewing gum during nasal or oral breathing. Figure 1 depicts the coordination of thoracic wall movements with oral and nasal airflow. The maximum inspiration (In)

and expiration (E) coincided with the maximum thoracic wall expansion (e) and contraction (C) during nasal or oral breathing. Therefore, the respiratory movement of the thoracic wall was used to estimate the respiratory rate and variation of the respiratory rhythm.

**Measurement of EMG activity of the trapezius and masseter muscles.** The skin over the masseter and trapezius muscles was wiped with alcohol, and surface electrodes (Blue sensor, type N-00-S Medicotest) were placed on the skin perpendicular to their orientation. The sternocleidomastoid muscle was used as the ground. The accessory muscles of respiration (e.g., the trapezius, scalenus, and sternocleidomastoid muscles) assist in the thoracic movement to increase the inspiratory volume according to demand. Because the scalenus and sternocleidomastoid muscles exhibited EMG activity during gum chewing, in this study we selected only the trapezius muscle as an accessory muscle of respiration.

Muscle activity was recorded by EMG at a sampling frequency of 1 kHz and rectified using a biological data analysis system (Labchart, ADInstruments) through an amplifier (MEG-5200, Nihon Kohden, Tokyo) while at rest and while chewing gum. The integrated EMG activity of the masseter muscle was obtained during 60 s at rest or while chewing gum, and the root mean square (RMS) of EMG signals was obtained to calculate the chewing stroke.

**Reproducibility and reliability of measurements.** To prevent unexpected movement of the thoracic wall, first we obstructed the nostrils with a clip and recorded the respiratory movements at rest and while chewing gum during oral breathing. Next, we removed the clip and recorded measurements during nasal breathing. The recording during

Table 1. Reliability of measurements on respiratory frequency and thoracic movement

	1st	2nd	3rd	4th	5th	Mean ± SD	F	P
<i>Respiratory rate</i>								
Rest								
Nose breathing	15.0 ± 3.60	15.9 ± 4.02	15.8 ± 3.24	15.5 ± 3.65	14.9 ± 4.14	15.4 ± 3.72	0.422	0.7919
Oral breathing	16.6 ± 2.40	15.7 ± 2.28	15.9 ± 2.64	16.2 ± 2.22	16.4 ± 2.10	16.1 ± 2.28	0.499	0.7366
Gum chewing								
Nose breathing	14.5 ± 3.84	15.9 ± 2.94	16.2 ± 2.46	14.9 ± 3.30	15.2 ± 3.06	15.3 ± 3.12	1.397	0.2507
Oral breathing	13.2 ± 2.76	12.7 ± 2.64	13.0 ± 2.63	13.9 ± 2.16	14.0 ± 3.60	13.4 ± 2.76	0.813	0.5235
<i>Thoracic movement</i>								
Rest								
Nose breathing	16.80 ± 13.3	16.45 ± 9.72	17.12 ± 9.92	13.30 ± 9.12	15.47 ± 10.49	15.82 ± 10.37	1.105	0.3662
Oral breathing	17.75 ± 9.92	17.44 ± 10.84	16.99 ± 11.88	17.38 ± 14.42	15.52 ± 9.68	16.81 ± 11.22	1.248	0.3049
Gum chewing								
Nose breathing	16.41 ± 12.42	17.17 ± 11.66	16.75 ± 11.93	15.34 ± 10.75	15.28 ± 11.73	16.28 ± 11.07	1.683	0.1694
Oral breathing	22.40 ± 12.60	23.69 ± 13.46	24.61 ± 18.75	21.13 ± 12.96	20.67 ± 14.76	22.47 ± 14.70	0.791	0.5367

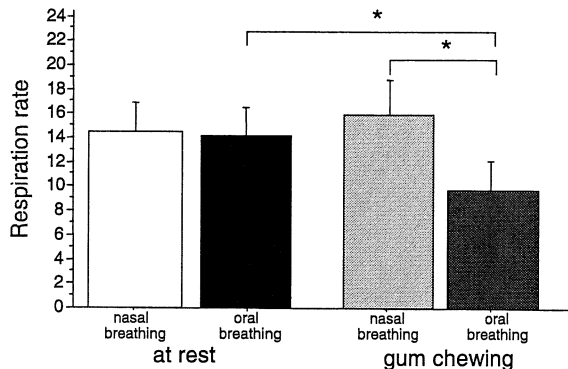


Fig. 2. Respiration rate at rest and during gum chewing. The respiration rate at rest did not differ significantly between nasal and oral breathing, and also did not differ significantly between while at rest and while chewing gum during nasal breathing. However, the respiration rate during oral breathing was significantly lower when chewing gum than at rest. Additionally, the respiratory rate was significantly lower during oral breathing than nasal breathing while chewing gum. \* $P < 0.05$ .

nasal breathing followed oral breathing at rest. Variables to be statistically compared were recorded in a single session. For example, variables were recorded 1) at rest and while chewing gum during nasal breathing; 2) at rest and while chewing gum during oral breathing; and 3) during nasal and oral breathing while chewing gum.

For seven additional study participants that were categorized as normal nasal breathers, we recorded the respiration rate and respiratory movement of the thoracic wall as variables five times while at rest and while chewing gum during nasal or oral breathing. The five recordings were repeated for each variable and examined by repeated analysis of variance. The five recordings did not differ significantly regarding the two variables (respiratory rate and respiratory movement of the thoracic wall) during nasal or oral breathing (Table 1). Variables were compared using a paired  $t$ -test; the critical value for rejecting the hypothesis was  $P > 0.05$ .

## RESULTS

**Respiratory rate.** The respiration rate at rest did not differ during nasal vs. oral breathing (Fig. 2). There was also no significant difference in the respiration rate during nasal breathing while at rest vs. while chewing gum (Figs. 2 and 3A). However, during oral breathing the respiration rate was significantly lower when chewing gum than while at rest ( $P < 0.05$ ; Figs. 2 and 3B). The respiration rate was also significantly lower during oral breathing than during nasal breathing while chewing gum ( $P < 0.05$ ; Figs. 2 and 4).

**Thoracic movement while at rest and during gum chewing.** At rest, the thoracic movements did not differ significantly between breathing modes (Fig. 5). During nasal breathing, there were no significant differences in the thoracic movements while at rest vs. while chewing gum (Figs. 3A and 5). During oral breathing, thoracic movement was significantly increased during gum chewing vs. while at rest ( $P < 0.05$ ; Figs. 3B and 5). During chewing gum, thoracic movement was significantly increased while oral breathing vs. nasal breathing ( $P < 0.05$ ; Figs. 4 and 5).

**EMG activity of thoracic movements while at rest and while chewing gum.** The trapezius muscle exhibited significant EMG activity when study participants took deep breaths (Fig. 6). The trapezius muscle exhibited no EMG activity while at rest during oral or nasal breathing and during gum chewing with nasal breathing; however, there was significant EMG activity during gum chewing with oral breathing (Fig. 7). Increased movement of the thoracic wall coincided with activity of the trapezius muscle and nonactivity of the masseter muscle during gum chewing with oral breathing (Fig. 7).

**EMG activity of the masseter muscles and chewing stroke while chewing gum.** Integrated EMG activity of the masseter muscle while chewing gum for 60 s was significantly lower during oral breathing than during nasal breathing ( $P < 0.05$ ; Fig. 8). Chewing stroke while chewing gum for 60 s was significantly reduced during oral breathing compared with during nasal breathing ( $P < 0.05$ ; Fig. 9).

## DISCUSSION

**Decreased respiratory rate during gum chewing with oral breathing.** Mastication and breathing occur in different areas during nasal breathing, and the pathways for air and food cross in the pharynx. This setup is made possible by the mechanism whereby the pharynx (passage) is separated from the lower airway and nasal cavity during pharyngeal swallowing to prevent aspiration of foreign materials into the trachea before or during swallowing (13). During nasal breathing, the soft palate is lowered and apposed to the tongue (13). Therefore, mastication occurs in the oral cavity, while respiration continues through the nasal cavity and pharynx with no interruption or obstruction of respiratory movement (13).

Fontana et al. (6) reported that the frequency of respiration increased and ribcage movement tended to decrease during mastication (6, 14, 15). It was thought that the metabolic demand incurred by contracting the muscles of mastication was accounted for by the increased respiratory frequency (6, 14,

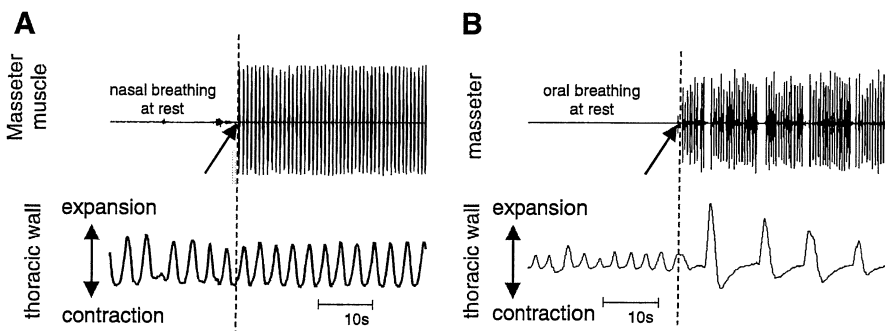
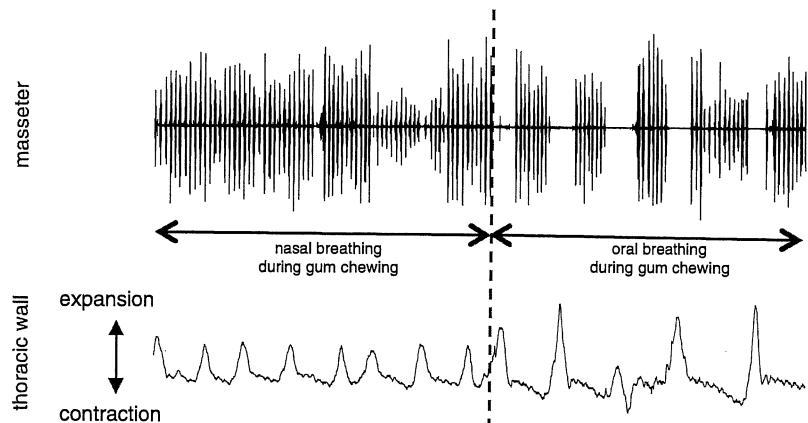


Fig. 3. Movement of the thoracic wall at rest and while chewing gum during nasal or oral breathing. A: nasal breathing. There was no obvious change in respiration rate or extent of thoracic wall movement upon starting to chew gum (arrow) during nasal breathing. B: oral breathing. The respiration rate decreased and the extent of thoracic wall movement increased upon starting to chew gum (arrow) during oral breathing.

Fig. 4. Thoracic movement during gum chewing. The respiration rate decreased and movement of the thoracic wall increased when participants began oral breathing during gum chewing.



15). The metabolic and ventilator demands increase during the work of mastication; therefore, gas exchange is maintained. Fontana et al. measured the respiratory cycle as the change in nasal pressure during aspiration. In our study, we recorded airflow from the nose or mouth and recorded the movement of the thoracic wall. We found that aspiratory airflow coincided with the movement of the thoracic wall. During nasal breathing, we did not observe significant differences in respiratory frequency at rest vs. during gum chewing. In contrast, during oral breathing the soft palate elevates to open the fauces, separating the nasal cavity from the pharyngeal airway (23). Oral breathing reportedly impedes masticatory functions, such as the duration of the occlusal contact and degree of occlusal contact force (8, 9). In this study, integrated EMG activity of the masseter muscle and chewing stroke were each reduced while chewing gum during oral breathing. These findings were supported by previous studies (8, 9, 14), and EMG activity of the masseter muscle is inhibited through the governance of mastication and respiration by the central nervous system (19).

In contrast, the respiratory rate during oral breathing was significantly decreased when chewing gum vs. while at rest,

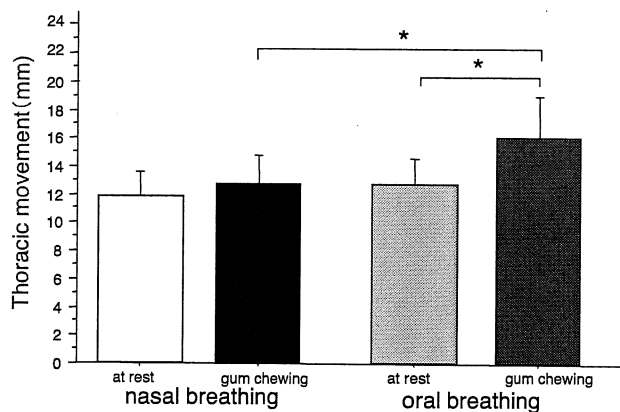


Fig. 5. Thoracic movement while at rest and during gum chewing. At rest, there were no significant differences in thoracic movements between breathing modes. During nasal breathing, thoracic movements did not differ between at rest and while chewing gum. During oral breathing, thoracic movement increased significantly during gum chewing vs. while at rest. \* $P < 0.05$ . During chewing gum, thoracic movement was significantly increased while oral breathing vs. nasal breathing. \* $P < 0.05$ .

and respiratory rate was significantly decreased during oral vs. nasal breathing when chewing gum. The respiratory rate decreased during gum chewing concomitant with oral breathing because oral breathing ceased during gum chewing (Fig. 3). These results indicate that chewing function restricts oral breathing when mastication and breathing occur in the same area.

**Decreased ventilation and regulation of respiratory movement.** Minute ventilation is determined by respiratory frequency and tidal volume. The intake of oxygen into the lung depends on the tidal volume and the minute ventilation. Usually, 75% of the resting rate of respiration is caused by diaphragmatic work. When the respiratory rate decreases, minute ventilation and the supply of oxygen in the lung both decrease. The oxygen deficiency in the lung reduces the quantity of oxygen in the blood. This appears to be a basic regulatory mechanism in which increased carbon dioxide in the blood stimulates the respiratory center through chemoreceptors, and increases the minute ventilation by increasing the respiratory rate and enlarging the movement of the thoracic or abdominal wall (1, 20, 22). Increased thoracic wall movement coincides with apparent EMG activity of the respiratory accessory muscles when individuals take a deep or labored breath (3, 10, 29). In this study, the respiratory rate during oral breathing significantly decreased when participants started to chew gum, and the movement of the thoracic wall simultaneously increased (Fig. 3). This movement was coincident with the EMG activity of the trapezius muscle (Fig. 7). Therefore, it is thought that the increased thoracic movement coincident with accessory respi-

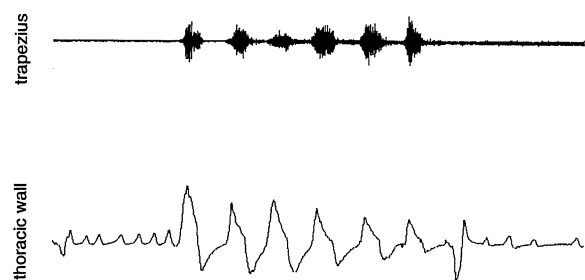


Fig. 6. Movement of thoracic wall and EMG activity of the trapezius muscle during deep breathing. The trapezius muscle showed apparent EMG activity when study participants took deep breaths according to the thoracic movement.

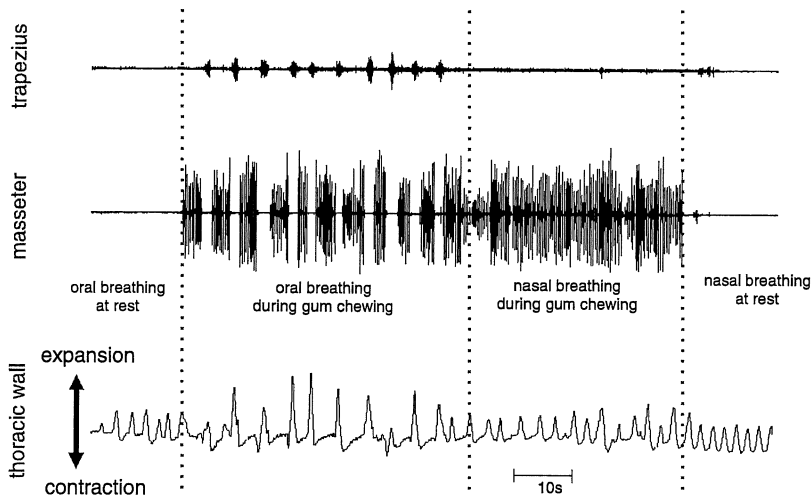


Fig. 7. EMG activity of the trapezius and masseter muscles during gum chewing. The trapezius muscle exhibited no EMG activity at rest during oral or nasal breathing, or while chewing gum during nasal breathing; however, significant EMG activity was observed when the study participants chewed gum during oral breathing. Increased movement of the thoracic wall coincided with activity of the trapezius muscle during gum chewing concomitant with oral breathing.

ratory activity during oral breathing when an individual starts to chew gum is accomplished by regulatory mechanisms through the respiratory center. To discuss a possible regulatory mechanism in which decreased oxide in the blood stimulates the respiratory center through chemoreceptors and increases movement of the thoracic wall, we also measured oxygen saturation (Handheld SpO<sub>2</sub> monitor, OGS-2002, Nihon Kohden, Yokohama) in blood in several participants during breath-holding and while chewing gum during oral breathing (Fig. 10). Oxygen saturation fell to 94% after holding the breath for 40 s, and decreased to 97% in 30–40 s after starting gum chewing during oral breathing. Resting SpO<sub>2</sub>  $\leq$ 95% is defined as abnormal (27). For these reasons, the regulatory mechanism through which decreased oxygen in the blood stimulates the respiratory center is not a major factor for the instant increase of thoracic movement after starting gum chewing during oral breathing in this study. It might be induced by a different mechanism, such as mechanical stimuli in the lung and respiratory muscles inducing respiratory reflexes to magnify the inspiratory muscles (28).

**Oral breathing and gum chewing.** Oral breathing interfered with breathing activity and reduced the respiratory rate. Ac-

ording to the previously described physiological mechanism, a decreased respiration rate during oral breathing while chewing gum was presumed to change the respiratory movement of the thoracic wall. Therefore, we recorded thoracic wall movements and the EMG activity of the accessory muscles of respiration while chewing gum during oral breathing. We found that the movement of the thoracic wall increased and EMG activity of the trapezius muscle significantly and clearly increased while chewing gum with oral breathing. This means that habitual mouth breathers experience difficulty in breathing while chewing food, and indicates that extraordinary activity of the accessory muscles of respiration also occurs, expanding the thoracic wall to increase inspiration. Unusual movement of the thoracic wall due to the decreased respiration rate should be studied in future examinations of growing children and adults.

**Conclusions.** Although oral breathing is an oral problem, chewing while breathing through the mouth might affect the respiratory cycle and result in systemic effects. Chewing foods during oral breathing interferes with the respiratory cycle. Decreased respiratory cycles promote respiratory movement of the thoracic wall, which is directed by the activity of the accessory muscles of respiration.

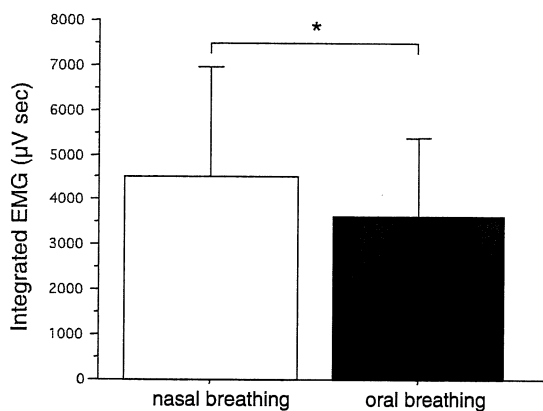


Fig. 8. EMG activity of the masseter muscles while chewing gum. Integrated EMG activity of the masseter muscle while chewing gum for 60 s was significantly lower during oral breathing than during nasal breathing ( $*P < 0.05$ ).

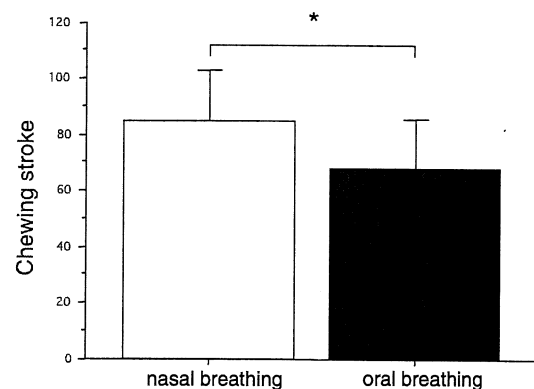
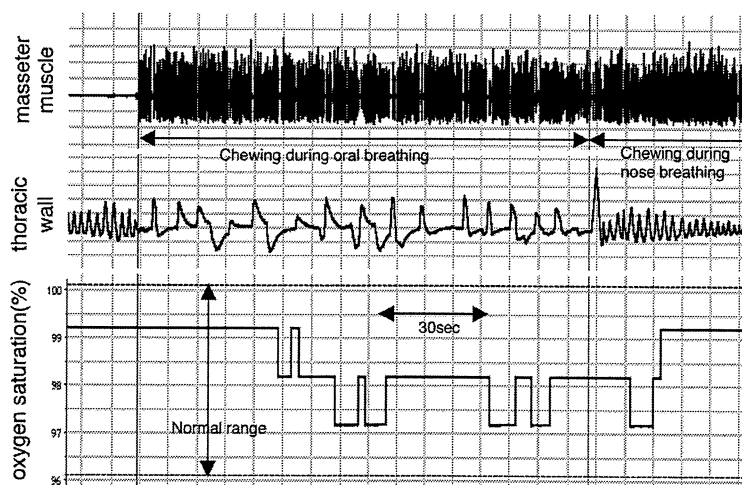


Fig. 9. Chewing stroke while chewing gum. Chewing stroke while chewing gum for 60 s was significantly reduced during oral breathing compared with during nasal breathing ( $*P < 0.05$ ).

Fig. 10. Oxygen saturation while chewing gum during oral breathing. Oxygen saturation in the blood decreased to 97% only 30–40 s after starting to chew gum during oral breathing. Resting SpO<sub>2</sub>  $\leq$ 95% is defined as abnormal. Thoracic movement increased immediately after participants began to chew gum during oral breathing, and instantly recovered to normal after nasal breathing was initiated. Decreased oxygen saturation in the blood remained after nasal breathing was initiated.



## DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

## AUTHOR CONTRIBUTIONS

Author contributions: S.D. performed experiments; S.D. and K.Y. analyzed data; S.D. prepared figures; S.D. and K.Y. drafted manuscript; K.Y. conception and design of research; K.Y. interpreted results of experiments; K.Y. edited and revised manuscript; K.Y. approved final version of manuscript.

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