Technology and Health Care 21 (2013) 511–520
DOI 10.3233/THC-130749
IOS Press

Analysis of facial and inspiratory muscles performance during breastfeeding

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Received 12 August 2013
Accepted 28 August 2013

Abstract.
BACKGROUND: Breastfeeding is a dynamic process in which the infant recruits several muscle groups in his face, head and throat.
OBJECTIVE: The objective of this study was to explore the relative role of the submental muscle group, the orbicularis oris and the sternocleidomastoid muscles to breastfeeding process and to the relatively high intra-oral vacuum measured during this process.
METHODS: Electromyography (EMG) measurements were conducted on 11 infants (mean age 1.91 ± 1.0 days, mean weight 3364 ± 328 g) using surface electrodes. The EMG data were filtered with a low pass filter to yield the linear envelopes (IEMG). The maximal and mean value and the area under each linear envelope curve were examined.
RESULTS: During active suckling significantly higher activity ($P < 0.05$) of the submental muscle group were measured compared with the orbicularis oris and sternocleidomastoid muscles (mean ± SE values of the maximal linear envelope were 24.4 ± 1 μV, 9.6 ± 0.6 μV and 14 ± 0.7 μV, respectively).
CONCLUSION: These results confirmed that jaw movements have the primary role during breastfeeding, but also revealed that the inspiratory muscles have a substantial contribution to this process and probably have an important role in the generation of intra oral vacuum measured during breastfeeding.

Keywords: Breastfeeding, electromyography (EMG), infant development, signal processing

1. Introduction

Breastfeeding is a dynamic process, which requires synchronization of the cycling motion of the infant's jaws, the rhythmic pulsation of the infant's tongue, and the mother's milk ejection reflex that delivers milk from the alveoli into the lactiferous ducts. The precise mechanism responsible for milk delivery during breastfeeding is still debatable [1,2]. It is generally believed that the infant latches on to the breast and nipple whereupon the nipple extends 2–3 times its resting length [2,3]. Then, cyclic motions of the infant's mandible compress the areola in a suckling process that extracts milk into the

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mouth [4]. When the volume of milk is sufficient to trigger swallowing, the back of the infant's tongue elevates and presses against the posterior pharyngeal wall. The soft palate then rises, closing off the nasal passageways, while the larynx moves up and forward to close off the trachea, allowing milk to flow into the esophagus [2,5].

Performance of breastfeeding depends on recruitment of the infant's orofacial muscles. The major groups are: (i) the submentals (SBM), especially the mylohyoideus, which depresses the mandible; (ii) the masseter and temporal muscles, which are situated at the side of the face and move the jaw; (iii) the orbicularis oris (OBO), which is a complex of muscles in the lip area that encircle the mouth and are associated with the closure of the lips; (iv) the buccinator at the side of the face, which is responsible for cheek compression and air expulsion; and, (v) the tongue which is involved in swallowing. The activity of these muscles during breastfeeding is also important for oral maturation since their stimulation is a major determinant of craniofacial growth [6]. The cyclic compression of the areola region during breastfeeding by the infant's mandible stimulates its perioral musculature [7]. Recently, it has been suggested that breastfeeding seems to prevent early developmental problems of malocclusion, particularly posterior crossbites in the primary dentition, which is rarely self-corrected [8,9].

Noninvasive studies on the role of infant's muscles in the sucking and swallowing mechanisms during breastfeeding utilized surface electromyography (EMG) [10]. Measurements of EMG signals from the masseter muscle of breastfeeding infants (i.e., 2–6-months old) revealed mean 0- to peak amplitude activity of 50 μV [11,12]. Comparable results were also found for the masseter, temporal and buccinator muscles in a group of 20 infants (i.e., 2–3 months old) during breastfeeding. The median values of each muscle contraction were determined by a nonparametric analysis of variance with non-normal distributions. The activity of the temporalis and masseter were higher (e.g., median values of 111 μV and 80 μV, respectively) than that of the buccinator (e.g., 42 μV) [6].

Analysis of EMG signals of the suprahyoid, temporalis, masseter and orbicularis oris muscles was also employed in studies of the development of the sucking function during breastfeeding [13]. The duration between the onset of one EMG burst to the onset of the next one was considered as a suckle cycle. The maximal and mean amplitudes of the EMG signal during 10 suckle cycles were evaluated. The mean amplitude was used as the active potential for each muscle. Significant increase in the mean activity was found in the suprahyoid muscles in 1–5 months old infants. On the other hand, the activity of the temporalis, masseter and orbicularis oris, remained unchanged [13]. Analysis of EMG signals from above the upper lip, under the chin, and the pharynx area in preterm infants revealed stronger signals from above the upper lip [13].

During breastfeeding, the infant generates negative pressures in his mouth. Recent studies during breastfeeding reported peak and mean intra-oral vacuum of -145 ± 58 mmHg and 114 ± 50 mmHg, respectively [1]. Whether the vacuum s role is to seal the extended nipple within the mouth or to remove milk from the breast is still debatable [1,2]. It is well known from respiratory physiology that contraction of the inspiratory muscles generates negative pressures within the mouth during inspiration [14,15]. Male and female adults can generate maximal inspiratory mouth pressures of -93 ± 20 mmHg and -67 ± 19 mmHg, respectively, while inspiring against occluded airway [14], while boys and girls generated -55 ± 17 and -45 ± 17 mmHg, respectively [16]. It has been shown that contraction of the inspiratory accessory muscles is required in addition to that of the diaphragm and external intercostal muscles in order to generate maximal inspiratory efforts [15,17].

Presently, it is unclear how infants generate the relatively high intra-oral vacuum during breastfeeding. Accordingly, the motivation for the present study was to explore the relative role during breastfeeding of the sternocleidomastoid (SCM), which is an important accessory inspiratory muscle along the side of the neck [18]. For this purpose, we acquired EMG signals from the SBM, the OBO and SCM muscle groups during breastfeeding and analyzed their relative activities.

Table 1
Characteristics data of the participating infants at the time of measurements

Subject	Age [days]	Sex	Weight [grams]	Parity	Gestational age (completed weeks)	Delivery
1	3	Female	3100	2	40	Vaginal
2	1	Male	3600	1	39	Caesarean
3	2	Female	3700	2	38	Caesarean
4	2	Female	2900	2	40	Vaginal
5	1	Female	3530	4	41	Vaginal
6	4	Female	3565	2	41	Vaginal
7	2	Female	3470	3	39	Caesarean
8	2	Male	3780	1	39	Vaginal
9	1	Female	3105	3	39	Vaginal
10	2	Female	2820	1	39	Vaginal
11	1	Female	3440	3	40	Vaginal

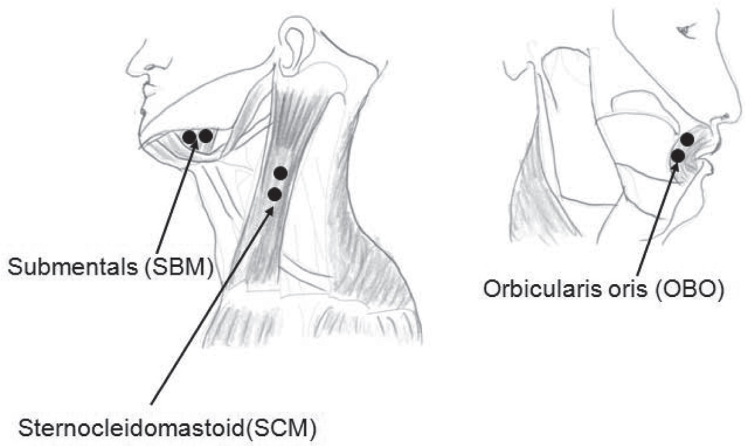

Fig. 1. Schematic illustration of the muscles measured in this study and locations of the surface EMG electrodes.

2. Materials and methods

2.1. Subjects

Eleven healthy, term infants who were free of congenital anomalies and who were receiving all their nutrition through breastfeeding were recruited. Their mean age was 1.91 $\pm$ 1.0 days, and their mean weight on the day they were born was 3364 $\pm$ 328 g. Exclusion criteria included birth weight lower than 2500 g, Apgar lower than 7 in the first 5 minutes and, ischemic episode or sub-Dural hemorrhage. The study was approved by the local ethics committee at the Tel Aviv Sourasky Medical Center and by the Israeli Ministry of Health. The parents were informed about all aspects of the experiment, and they signed an informed consent form. Specific birth and clinical data of the participants in this study are summarized in Table 1.

2.2. Study design

Assessments of the relative contribution of facial and neck muscles to swallowing, suckling and inspiratory activities during breastfeeding were carried out using surface EMG electrodes that allow non-invasive measurements of muscle activity, while minimally interfering with the natural musculoskeletal performance [15]. The three muscle groups chosen for this study were the OBO which is involved in mouth movement, the SBM which is involved in jaw movement, and the SCM which is involved in breathing (Fig. 1). These three muscle groups are relatively easier to locate, for the purpose of electrode positioning, compared to other facial and respiratory muscles.

2.3. Equipment

The EMG signals were acquired using 15 mm diameter disposable surface electrodes for newborns (Kendall Kittycat 1050NPSM small). The signals were amplified by a factor of 2000 or 5000 using three portable amplifiers (Biopac EMG100C), which were operated by two 9V batteries. The signals were sampled at a rate of 1 KHz and displayed on a laptop computer equipped with analog-to-digital converter and sampling software (Labview version 8.0). The signals were recorded for off-line processing and analyses using MATLAB software.

2.4. Experimental protocol

Surface electrodes were attached to the subjects by professional neonatal and premature physicians as follows: two electrodes were placed under the chin, in the upper part of the neck, for measuring the activity of the SBM [13]; two electrodes were placed on the cheek, near the mouth, for measuring the activity of the OBO [13]; two electrodes were placed midway between the angle of the jaw and the clavicle for measuring the activity of the SCM [15]; and, one electrode was placed on the back of the hand for reference (Fig. 1). Each of the two paired electrodes was placed with a center to center distance of about 10 mm apart. The infants were offered the breast while being held by their mothers in a classic nursing position. In this position their heads were supported by the mothers' arm. This position proved to be most comfortable for mothers nursing neonates, and at the same time allowed the infants to suckle without having to move their heads, thus not affecting the data recorded from the SCM. Recording of the EMG data along with real-time display on the laptop started as soon as the infants started suckling, and continued as long as the infants were feeding. The recording was stopped whenever the signals were very noisy, low, absent or without any accordance to the suckling process and the position of the electrodes were corrected. The mothers could stop the measurement at any time during the experiment and withdraw from the study with impunity.

2.5. Data analysis

All signals were displayed and observed prior to processing. The beginning and the end of each recording were manually removed after visual inspection in order to eliminate noises associated with latch-on and latch-off. The EMG signals were then fully rectified to yield the absolute value of the EMG data and filtered with a low pass filter (e.g., Butterworth with a cut-off of 10 Hz) to yield the linear envelopes [15, 19]. This integrated EMG data (IEMG) was used for subsequent analysis. The acquired EMG signal, the corresponding rectified data and linear envelopes (IEMG) of the SBM muscle taken from one baby are demonstrated in Figs 2a-c. A zoom of one linear envelope during one suckling (i.e., between the two lines in Fig. 2c) is depicted in Fig. 2d. The following parameters were examined from each linear envelope: the maximal value of the linear envelope ($IEMG_{max}$), the mean value of the linear envelope ($IEMG_{mean}$) and the area under the linear envelope curve ($IEMG_{AREA}$).

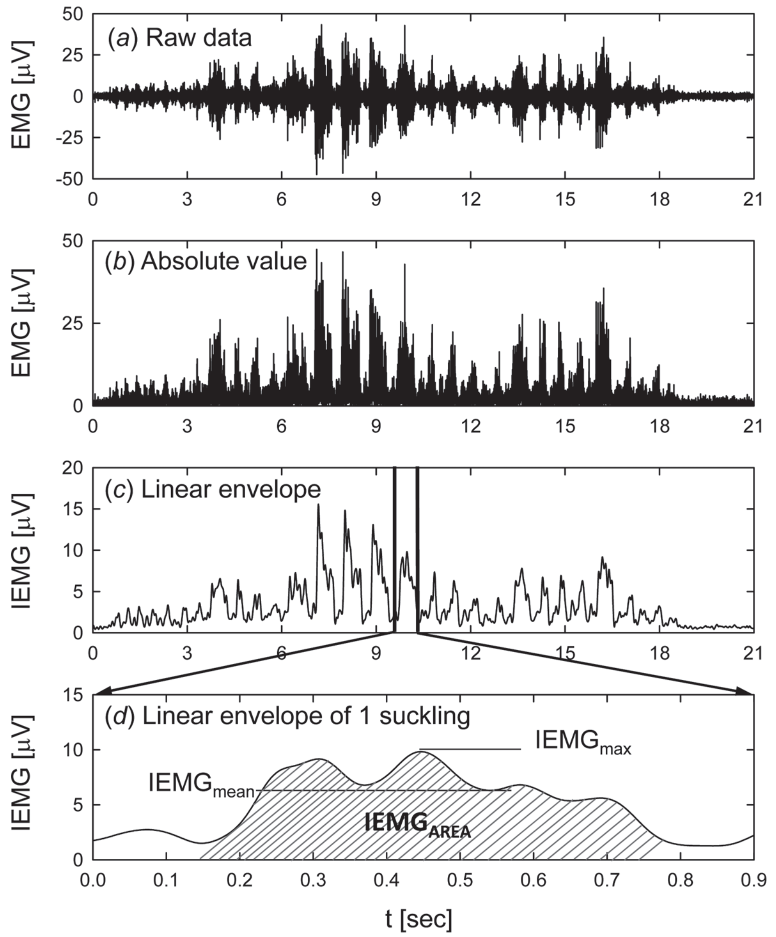

Fig. 2. (a) An example of the EMG signal acquired from the SBM muscle of subject #5 in Table 1 during 21 s of breastfeeding; (b) The corresponding rectified data; (c) The corresponding linear envelopes; and, (d) A zoom on one linear envelope that corresponds to a single nutritive (active) suckle.

The following ratios were defined for evaluation of the relative performance of the different muscles during breastfeeding. The ratio R_1 between the $IEMG_{AREA}$ values of the SBM and OBO muscles,

$$R_1 = \frac{(IEMG_{AREA})_{SBM}}{(IEMG_{AREA})_{OBO}} \tag{1}$$

The ratio R_2 between the $IEMG_{AREA}$ values of the SBM and SCM muscles,

$$R_2 = \frac{(IEMG_{AREA})_{SBM}}{(IEMG_{AREA})_{SCM}} \tag{2}$$

The ratio R_3 between the $IEMG_{AREA}$ values of the OBO and SCM muscles,

$$R_3 = \frac{(IEMG_{AREA})_{OBO}}{(IEMG_{AREA})_{SCM}} \tag{3}$$

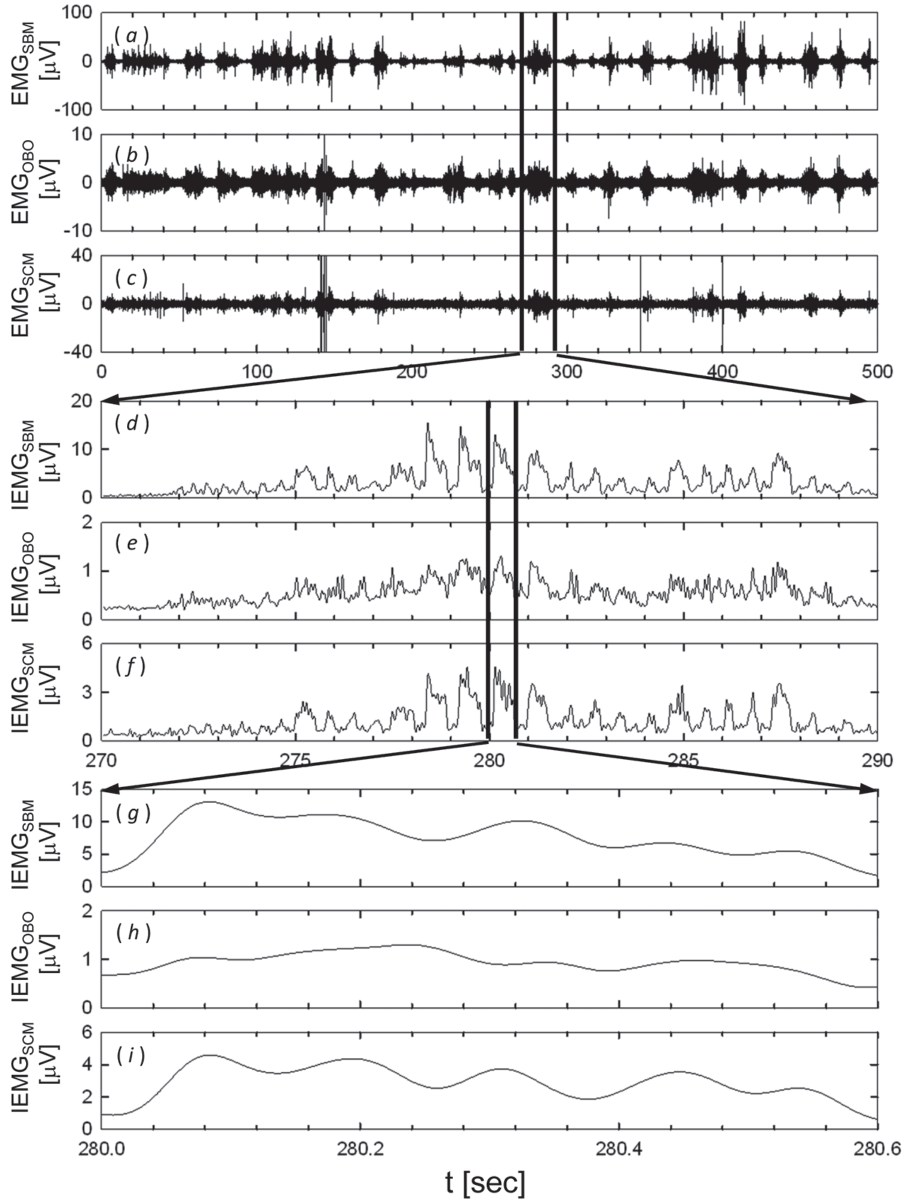

Fig. 3. (a,b,c) An example of the raw data of the EMG signals acquired during 500 s of breastfeeding from the SBM, OBO and SCM muscle groups of subject #5 in Table 1; (d,e,f) a zoom on the corresponding linear envelopes during 20 s where active breastfeeding was observed; (g,h,i) a zoom on the linear envelopes of the 3 muscles during a single suckle.

2.6. Statistical analysis

Descriptive statistics was obtained, in terms of means and standard errors of the $IEMG_{max}$, $IEMG_{mean}$, $IEMG_{area}$, R_1, R_2 and R_3. We further conducted Kruskal-Wallis one-way analysis of variance (ANOVA) on Ranks tests in order to determine whether there is a statistically significant difference between the activities of each of the measured muscles. Differences between groups were declared significant at $p < 0.05$.

3. Results

We acquired EMG signals from 11 infants during breastfeeding. A total of 1192 suckles during active feeding were analyzed for each muscle; an average of about 105 suckles from each baby. An example of raw EMG signals measured from the SBM, OBO and SCM of a representative infant (i.e., subject # 6 in Table 1) during 500 seconds of breastfeeding is shown in Figs 3a-c. A zoom of the corresponding linear envelopes during 20 seconds of active suckling is demonstrated in Fig. 3d-f during which the density of the linear envelopes was high. Each suckle lasted about one second. Electrical activity was found in all the 3 measured muscles, however, significant higher activity ($P < 0.05$) was measured from the SBM compared to that of the OBO and SCM muscles (Fig. 3). The average values of IEMG_{max} were (mean $\pm$ SE) 25 $\pm$ 1 μV, 9.6 $\pm$ 0.6 μV, and 14 $\pm$ 0.7 μV for the SBM, the OBO and the SCM groups, respectively. Similar significant higher values ($P < 0.05$) were also found for IEMG_{mean} of the SBM compared to that of the OBO and SCM (e.g., 10.6 $\pm$ 0.4 μV, 5.6 $\pm$ 0.2 μV, and 7 $\pm$ 0.23 μV for the SBM, OBO and SCM, respectively).

The area under the linear envelope curve represents both the intensity and the period of muscle activity and thus estimates more accurately the performance of the measured muscle. The average area under the curves of $\sim$160 linear envelopes (i.e., IEMG_{AREA}) of the SBM, OBO and SCM and the calculated ratios R_1, R_2 and R_3 from representative infant (e.g., baby #1) are illustrated in Fig. 4. Significant higher values ($P < 0.05$) were obtained from the SBM followed by SCM, the lowest value were obtained from the OBO. Similar results were found for all the subjects. The averaged areas under the curves of a total of 1192 linear envelopes calculated from all 11 subjects were 8.4 $\pm$ 0.36 μV·s, 5.6 $\pm$ 0.23 μV·s and 4.25 $\pm$ 0.16 μV·s for the SBM, SCM and OBO, respectively (Fig. 5a). The averaged ratios R_1, R_2 and R_3 calculated from all the subjects were 2.3 $\pm$ 0.07, 1.4 $\pm$ 0.03, 0.86 $\pm$ 0.011, respectively (Fig. 5b).

4. Discussion

The findings of the present study, clearly demonstrated that all three muscle groups are involved in milk extraction during breastfeeding. It shows that the SBM is the most active group during breastfeeding followed by the SCM and least of them the OBO. This outcome suggested that jaw movement was more dominant than mouth movement and is probably the primary motion during breastfeeding. The present findings corroborated and supported earlier studies that found greater participation of the masseter and temporalis muscles (i.e., responsible for jaw motion) than that of the buccinator muscles (i.e., responsible for cheek compression) during breastfeeding [6].

Evidence of jaw movement dominance in the breastfeeding mechanism can also be observed in video recordings of breastfeeding infants, and there are a few publications, in which breastfeeding has been compared to bottle-feeding from this angle. A review of observations made by health care professionals, as well as clinical studies, revealed that jaw movement is significantly more substantial during breastfeeding compared to bottle-feeding [6,7,12]. In another EMG study, activity of the suprahyoid muscles during suckling in breastfed infants (about 104 μV) was more intense than that of the temporalis, masseter and OBO muscles (about 54 μV, 24 μV and 29 μV, respectively) [13]. This heightened activity of the suprahyoid muscle increased with age, suggesting that the jaw lowering movement plays a primary role in increasing sucking strength during the suckling period. The present results also correlate with recent studies that found a lower rate of posterior crossbite with the increase in breastfeeding duration [8, 9]. The reduction in crossbite occurrence can be attributed to the frequent mechanical stimulation of facial muscles during breastfeeding and thereby their improved development.

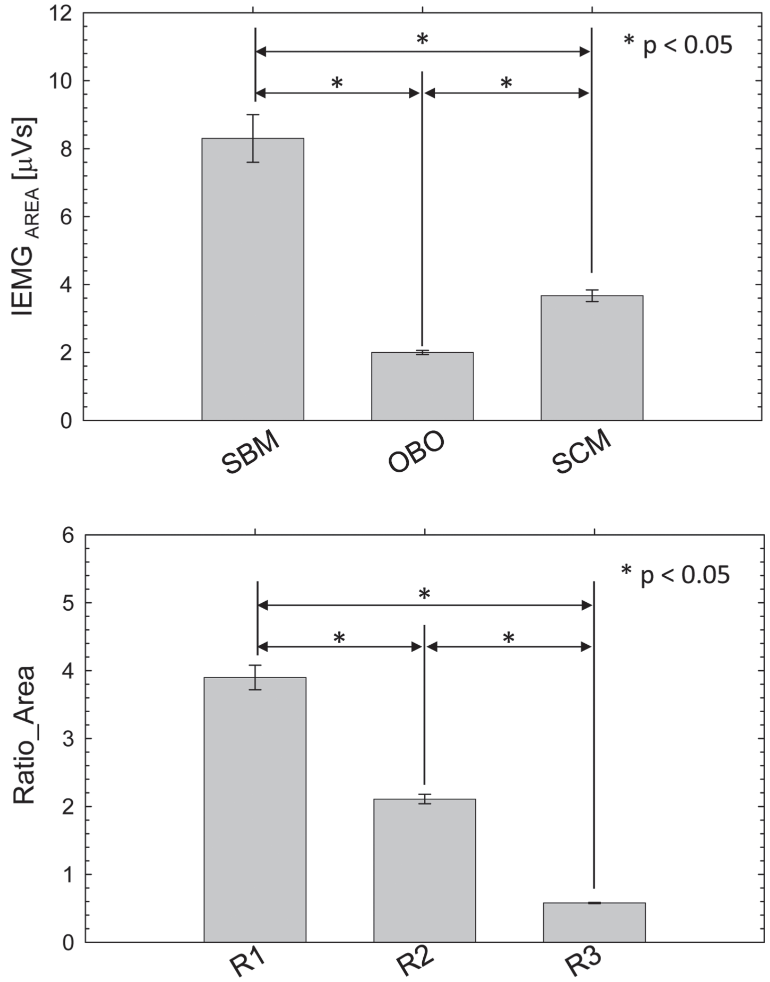

Fig. 4. (a) The average area under the curves of ∼160 linear envelopes ($IEMG_{AREA}$) of the SBM, OBO and SCM; (b) The ratios R_1, R_2 and R_3 from a representative infant (e.g., subject #1 in Table 1). The results are mean ± SE.

The main objective of the present study was to explore the relative contribution of the facial muscles and inspiratory muscles to the breastfeeding process. The present study demonstrated for the first time that the activity of the SCM during breastfeeding was significantly lower as compared to that of the SBM (Figs 3 and 4). However, the mean values for the area under the linear envelopes curves of the SCM reached 66% of that of the SMB (e.g., mean values of 8.4 ± 0.4 and 5.6 ± 0.2 for the SBM and SCM, respectively). The area under the linear envelope can be a good indication for the work done by the muscle since it analyzes both intensity and the period of contraction. Thus, the SCM group of muscles has a substantial role in the forces generated during breastfeeding and most likely contributes to the development of the intra oral vacuum pressure.

The most notable limitation of this study is the population of participants. The muscles of newborns only a few days of age are not fully developed and their feeding pattern is not well established, thus creating problems in obtaining proper signals. It has also been suggested that neonates exert lower vacuums, possibly due to lack of maturity [1]. Other limitations includes lack of video recording of the experiments, the objective weaknesses of surface EMG, such as inaccuracies resulting from adjacent muscle

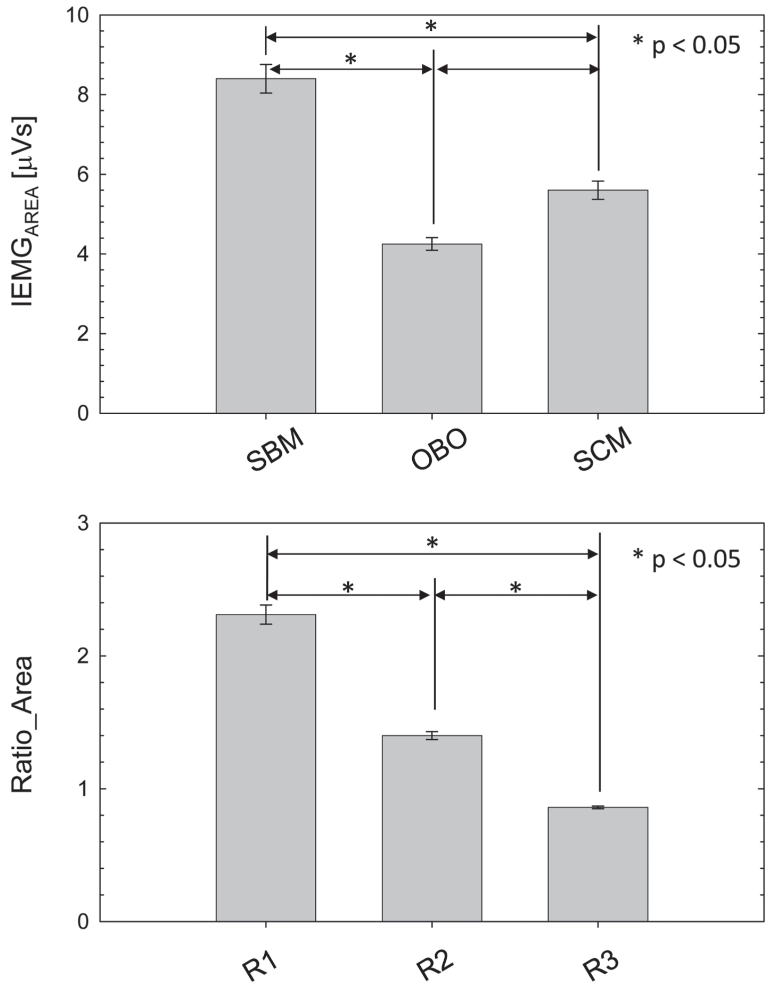

Fig. 5. (a) The average area under the curves of a total of 1192 linear envelopes calculated from all subjects. (b) The average ratios R_1, R_2 and R_3 calculated from all. The results are mean $\pm$ SE.

activity detected by the surface electrodes, and possible noise additives produced by skeleton movement and breathing. In addition, successful EMG measurements on neonates are very difficult to achieve due to their small muscle mass and the difficulties in proper placing of the EMG electrodes. Nevertheless, the muscles measured during this study were specifically chosen for being groups or aggregations of muscles responsible for the motions of interest and working in concert. The coordination between the suckling motion and the on-screen signal confirmed the fact that the correct muscle activity responsible for the motion was being detected.

We speculate that future studies with populations of older breast-fed infants, in whom the jaw, lips and inspiratory muscles are better developed, as well as with infants who are exclusively bottle-fed, may shed more light on the mechanisms and responsible muscles of feeding in newborns.

It is well accepted that a major advantage of breastfeeding is its contribution to the development of facial muscles in terms of preparing them for the future tasks of chewing and speaking. Understanding the biophysical mechanisms responsible for breastfeeding and the role of the different muscles during this process may lead to development of improved artificial nipples that will not obviate the natural motion of the tongue and will dictate activation of the facial muscles during infant feeding. This will provide bottle-fed infants with the same physiological advantages as breastfeeding does and will offer a better alternative for mothers who cannot breastfeed their babies due to personal reasons or pathological conditions.

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