

## Coordination of Tongue Activity During Swallowing in Mouth-breathing Children

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**Abstract** Habitual mouth breathing is often accompanied by habitual anterior tongue thrust, instead of a lip closure, in order to create the anterior seal necessary for the initiation of physiological deglutition. We tested the null hypothesis of no significant influence of oral maneuver and the use of oral screens on tongue coordination and position during deglutition in 29 subjects (age = 6–16; mean = 9.69 years; 13/16 female/male) with habitual open-mouth posture using intraoral polysensography. The target parameters for swallowing were swallowing-associated nasal airflow interruption (NAI) and coordination of tongue–palate contact during NAI. Conventional myofunctional maneuvers could be facilitated and made more efficient, in terms of increasing the numbers of favorable early tongue–palate contacts typical of somatic swallowing, if accompanied by the application of an oral screen. Habitual open-mouth breathing does not necessarily

coincide with distinctively pronounced proportions of late tongue–palate contact.

**Keywords** Deglutition · Deglutition disorders · Tongue position · Mouth-breathing · Oral maneuver · Intraoral polysensography

The function of the human tongue during normal deglutition is a complex, integrated, biomechanical process that includes a series of rapid shape changes intended to contain and then propel the bolus from the oral cavity to the pharynx [1]. Swallowing patterns, which can be either visceral or somatic, are not easy to differentiate clinically [2]. The recently introduced biofunctional orofacial model offers a new approach to defining normal functions as well as dysfunctions of the oral phase of swallowing, and, in particular, the presence or absence of an oral force equilibrium, i.e., the balance of opposing forces that are exerted on the teeth by the tongue, lips, and cheeks [3]. The resting position and dynamics of the tongue are, in this context, a major contributing factor to the oral force equilibrium. Therefore, a key question is whether, after deglutition, the tongue adopts a cranial contact position with the hard palate, which is compatible with a closed rest position, or whether this cranial rest position is lost immediately after completion of the act of swallow. The maintenance of a cranial tongue position is decisive for the effectiveness of orthodontic and myofunctional therapy in mouth-breathing children, as anterior tongue thrusting during deglutition exerts pressure forces on teeth that typically counteract the orthodontic forces that are applied for a closure of open bites. Core parameters of the act of swallowing can be defined by nasal airflow interruption (NAI) during the passage of the bolus and tongue–palate contact (TPC) [4]. With regard to different patterns of swallowing (visceral and somatic), there are

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virtually no valid statements concerning the relationships between therapeutically defined basic conditions, the usefulness of therapeutic commands, and the use of additional aids such as oral screens (i.e., a flexible plate that is incorporated between the lips and the anterior teeth thereby creating an anterior mouth seal in children with habitual open-mouth posture) and their influence on the core parameters of swallowing.

An alternative approach to observing tongue posture is the use of orofacial polysensography, which utilizes optical sensors to detect tongue position in combination with nasal airflow indicator thermistors to acquire detailed data about tongue movements with focus on the frequency and duration of TPC position and simultaneous observation of nasal airflow. The functional principle used is to measure the intensity of LED light reflected by the tongue, which is a further development of the technique used by Chuang and Wang [5]. With the aim of simultaneous collection of data from different sites in the mouth, Ono et al. [6] documented the pattern of contact between the tongue and hard palate when water was swallowed. Using an acrylic appliance fitted with seven pressure sensors, they were able to show that in functionally normal subjects, the order, magnitude, and duration of tongue pressure against each part of the palate were highly coordinated.

However, there is a paucity of information in the literature on tongue position and function in subjects with orofacial dysfunctions, such as the habitual open-mouth posture during the act of swallowing. As habitual mouth-breathing is often accompanied by a habitual tongue thrust, it may be that those cases display a different type of coordination during the act of swallowing. The aim of the present study therefore was to extend our understanding of the patterns of intraoral contact phases of the tongue and the palate during deglutition in a group of habitual mouth-breathing children. In particular, we focused on the differences between individuals in the patterns (frequency and timing of the tongue position during and after NAI) that occur during deglutition. In order to assess the influence of instructing subjects to maintain a tongue–palate posture or having the subjects use an oral screen on the deglutition functional patterns, we tested the null hypothesis that the timing of TPC in relation to the NAI does not vary significantly (1) with different functional conditions and (2) as a function of the additional use of an oral screen.

## Methods

### Subjects

Twenty-nine subjects (age = 6–16 years; mean = 9.69; 13/16 female/male) attending two orthodontic centers in

Santa Fé, Argentina were consecutively selected according to the inclusion criterion of habitual daytime open-mouth posture, but they also possessed the ability to adopt a self-controllable orientation of the tongue in order for us to exclude disabled or syndromal subjects with certainty. Subject eligibility (as well as correctness of anamnestic recordings and experiments) was established by an orthodontist who also advised the subjects to position their tongue at the palate in a position at the papilla incisiva in the open-mouth condition. Those who failed the test were excluded from the study.

The type of swallowing pattern a subject used was clinically checked by advising subjects to swallow with lips held in position; the pattern was verified as “visceral” in 27 of the 29 subjects. All subjects showed the clinical picture of habitual mouth-breathing.

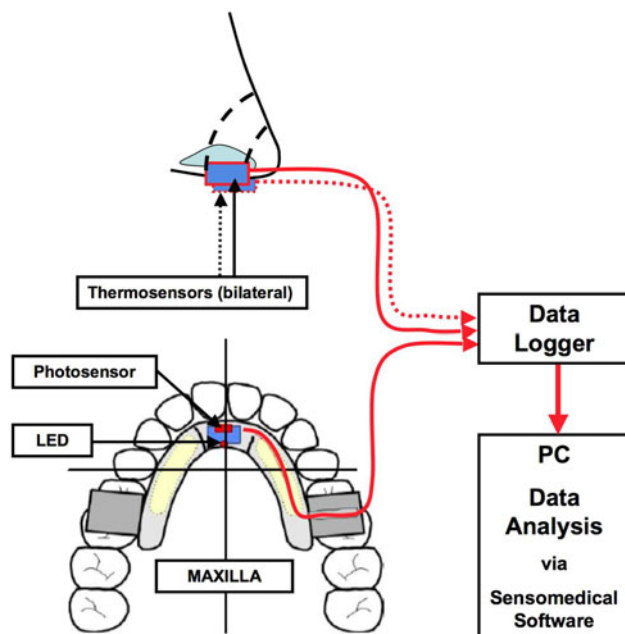
The study received the approval of the local Ethics Commission, and the patients or their guardians, as appropriate, gave informed consent for participation in the study.

### Polysensography

Orofacial polysensography (SensOral III, v1.2, with software OPSG-Lab 3.0; Sensomedical, Göttingen, Germany) using an LED light source and intraoral sensors on individual palate splints was used for making simultaneous optical distance measurements between the tongue and palate and an optometric assessment of the degree of mouth-opening. Nasal airstream was assessed at the nostrils by using two thermistors (thermosensors, 1 mm × 2 mm × 3 mm), separately for each side (Fig. 1). Measurements were made with the subject in the upright position in a fully air-conditioned room with an ambient temperature of 22°C. Intraoral sensors were located at the raphe palatina level with the first premolars. Increasing tongue–palate distance resulted in a decrease in reflected light intensity. In order to assess the cranial tongue posture with the greatest degree of precision, a measuring range of the upper 1/8 of the full scale was designated as TPC, whereas the lower 7/8 of the scale indicated caudal tongue position.

### System Calibration

In order to assign the recorded light impulses unambiguously to different degrees of mouth-opening and vertical tongue positions, a biological system calibration was performed prior to each trial assessment, including maximum mouth-opening, closure, and intercuspitation during maintenance of TPC, in order to unambiguously assign the recorded light signals to different degrees of mouth-opening and tongue positions. Accordingly, maximum mouth closure with the tongue at the palate was defined as 100% scale deflection, maximum mouth-opening as 0%, and a



**Fig. 1** The experimental setup

cranial tongue position as  $>87.5\%$  (7/8 of maximum amplitude).

#### Functional Conditions and Data Analysis

The trials consisted of five functional intervals of 8 min each: F1, respiration at rest (RR); F2, respiration at rest with an oral screen [RROS; oral screen (OS): Akkuphon, Unna, Germany]; F3, swallowing with the use of an OS and the instruction to keep the TPC throughout the measurement interval (TPCOS); F4, instruction to collect saliva and swallow (tongue-repositioning maneuver according to Engelke et al. [3] with OS) (TRMOS); and F5, swallowing with the instruction to maintain TPC after swallowing throughout the measurement interval without OS (TPC).

Acts of swallowing were identified by an interruption of the nasal airflow followed by expiration [7, 8] combined with vertically oriented tongue activity. [1]. NAI has a physiological range from 200 to 1000 ms and can be observed in the exhalation curve of the respiration amplitude [7, 9–11]. Acts of swallowing were differentiated into those with early and those with late cranial tongue movement with respect to NAI. Duration and frequency of deglutition based on NAI and cranial tongue position after swallowing were assessed separately for the five conditions. The identification of single swallowing acts is illustrated in Fig. 2a, b.

#### Statistical Analysis

Frequencies of early and late TPC related to the functional condition (RR, RROS, TPCOS, TRMOS, TPC) were

compared using  $\chi^2$  tests. After global significance was determined ( $p = 0.04$ ), pairwise comparisons between functional conditions were made relative to the control conditions RR and RROS. These analyses were performed using the statistical software R v2.9.2 ([www.r-project.org](http://www.r-project.org)).

The occurrence of early or late TCP, in terms of frequency and duration and dependent on the presence or absence of an oral screen and the functional condition (F1–F5), was analyzed using descriptive statistics as well as ANOVA and subsequent multiple comparisons, at an  $\alpha$  level of 5% using Tukey's method. These analyses were performed using SPSS software (SPSS, Inc., Chicago, IL, USA).

## Results

### Identification of Swallowing Acts During Functional Conditions F1–F5 and Duration of NAI

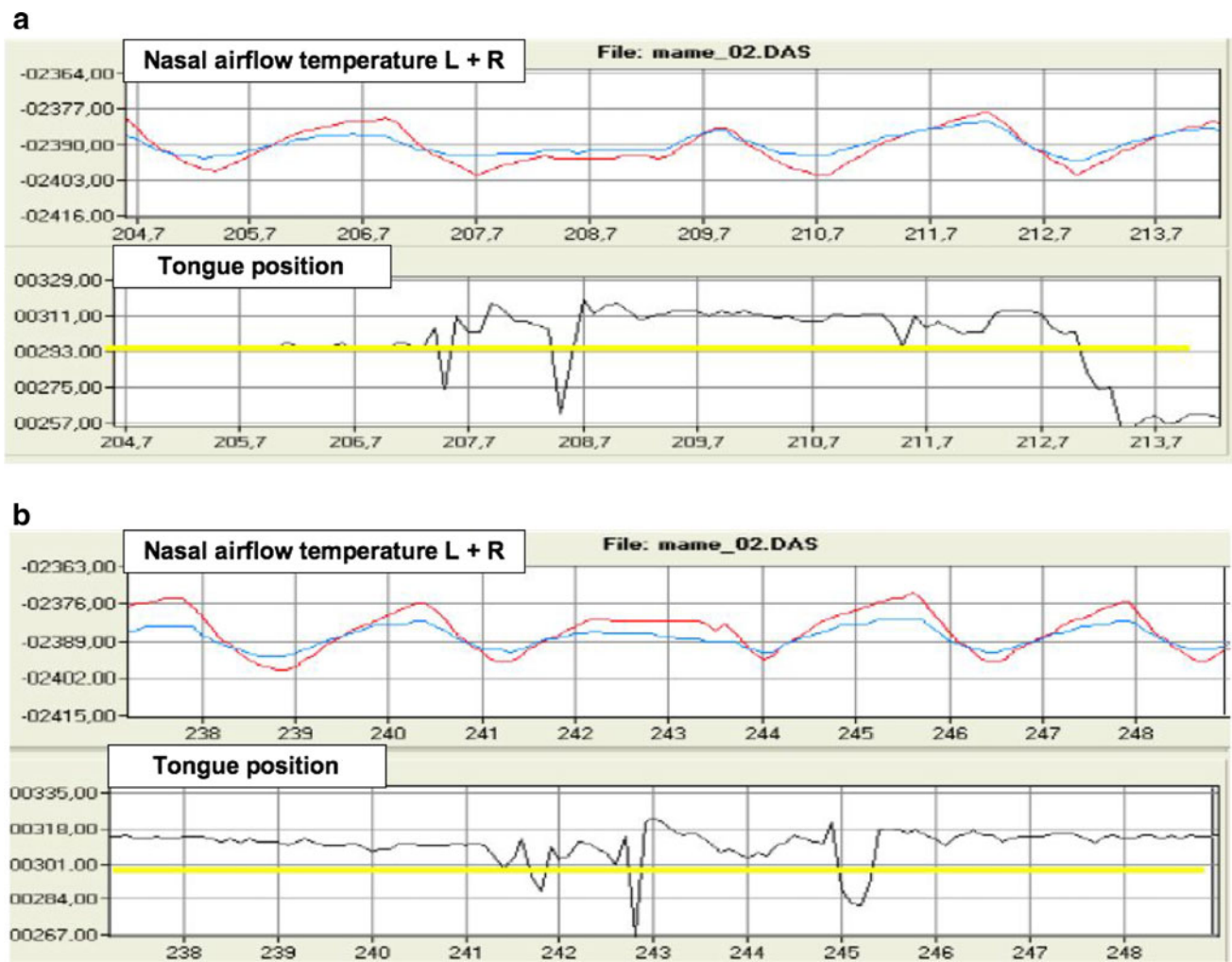
A total number of 542 single swallowing acts were identified, with similar numbers ( $n = 109$ – $128$ ) of swallowing acts for conditions F1–F4 but a smaller number for F5 (Table 1). Mean durations of NAI were very similar for all conditions (Table 2).

### Coordination of Tongue Posture During NAI Under Different Functional Conditions

The variation in tongue posture change (which starts with TPC and ends with a caudal relapse of the tongue) can be divided into two tongue dynamics categories: (1) an early TPC during NAI, i.e., at the beginning of the NAI the tongue is already located cranially at the palate; or (2) a late TPC during NAI, i.e., the tongue moves during NAI cranially to the palate. Figure 2 gives examples of an early and a late TPC.

Absolute and relative numbers of early and late TPC are given in Table 1. The significance levels of the difference between functional conditions in terms of frequencies of early/late TPC are given in Table 3. Accordingly, the OS significantly raises the frequency of the favorable early TPC, but only in combination with the maneuver TPCOS or TRMOS; i.e., the null hypothesis that the timing of the TPC in relation to the NAI does not vary significantly as a function of the functional conditions and as a function of the use of an oral screen was rejected for the functional conditions TRMOS and TPCOS compared to resting respiration (RR) (Table 3).

Although there was a similar tendency during resting respiration and in the absence of additional maneuvers



**Fig. 2 a** Resting respiration with oral screen (RRS, F2). The NAI starts in this case at second 209 with an early TPC. The subsequent TPC lasts for 4 s. The threshold of the maximal cranial tongue rest position is 296 digital units. **b** Resting respiration with oral screen (RRS, F2). The NAI starts in this case at second 242.3 with a late

TPC. The threshold of the maximal cranial tongue rest position of 296 digital units is reached only at second 242.8. The total duration of the post-deglutition cranial tongue rest position is only 2 s, half the duration of that in **a**

**Table 1** Frequencies and proportions of early and late tongue–palate contacts (TPC) in terms of functional condition

Functional condition	Swallowing acts [ <i>n</i> (%)]	Early TPC ( <i>n</i> )	Late TPC ( <i>n</i> )	Early TPC (%)	Late TPC (%)
F1 (RR)	114 (21%)	52	62	45.61	54.39
F2 (RRS)	109 (20.1%)	64	45	58.72	41.28
F3 (TPCOS)	128 (23.6%)	78	50	60.94	39.06
F4 (TRMOS)	119 (21.9%)	74	45	62.18	37.82
F5 (TPC)	72 (13.28%)	35	37	48.61	51.39

Total number of swallowing acts was  $n = 542$

(RRS vs. RR: 64 vs. 45;  $p = 0.068$ ), wearing the OS during normal respiration did not significantly raise the numbers of early TPC, i.e., without the OS there was no increase in the favorable early TPC.

## Discussion

The act of swallowing is characterized by the interruption of the nasal airflow (NAI) and simultaneous cranial

**Table 2** Mean duration of NAI

	RR, F1	RROS, F2	TPCOS, F3	TRMOS, F4	TPC, F5
Mean duration (s)	0.38	0.37	0.39	0.37	0.38
SD	0.096	0.073	0.086	0.098	0.092

**Table 3** Significance levels between functional conditions in terms of frequencies of early/late tongue–palate contacts

Comparison	<i>p</i> Values
RR RROS	0.0682
RR TPCOS	<b>0.0240</b>
RR TRMOS	<b>0.0161</b>
RR TPC	0.8040
RROS TPCOS	0.8299
RROS TRMOS	0.6894
RROS TPC	0.2364

Bold values are significant. Significance level is 0.05

movement of the tongue [8, 12, 13]. The 542 single acts of swallowing identified in this study were comparably distributed among the functional conditions F1–F4 (range = 20.1–23.6% each,  $n = 109$ – $128$ ), but reduced in the TPC group F5 (13.28%,  $n = 72$ ).

### Pattern of Deglutition

Two different patterns of motion of the tongue were identified in the present study. An early TPC is characterized by an already existing maximal palate contact at the beginning of the NAI, whereas a late TPC develops during the time course of the NAI (Fig. 2). An early TPC during deglutition is considered to be a normal swallowing pattern [14–16], whereas a late TPC seems to be associated with a visceral swallowing pattern. In the research presented here, it is notable that the functional intervals that included the oral screen (F2–F4) showed a distinct tendency to an early TPC (58.72–62.18% early TPC), whereas those without the OS (F1 and F5) were balanced in proportions or more frequently tended to display a late TPC (51.39–54.39% late TPC; Table 1). It is also worth noting that 27 of the 29 cases in this study were verified from their anamneses as having a “visceral” swallowing pattern, whereas all had a clinical picture of habitual mouth-breathing. This implies, on the one hand, that during normal respiration, subjects with a clinically diagnosed visceral deglutition pattern do indeed also show balanced proportions of early and late TPC. This, in turn, implies that the clinical observation of a visceral swallowing pattern, which is normally performed

at open lips, is questionable. It also implies that habitual open-mouth breathing does not necessarily coincide with a distinctively pronounced proportion of late TPC. Moreover, in these subjects, wearing an oral screen seems to have been beneficial in terms of increasing the numbers of favorable early TPC.

### Duration of NAI

NAI occurs as a reflex response to the commencement of deglutition. Its purpose is to prevent aspiration [12]. Nasal airflow interruption may vary in timing with respect to respiratory activity, i.e., there are different patterns of respiration and NAI coordination considered as normal [8]. However, this is not relevant in the context of our evaluation, as the NAI in our study merely served as an indicator for the velopharyngeal closure during deglutition, without further impact on the interpretation of tongue-positioning. It has previously been shown that there is a high degree of interindividual variation, ranging from 200 ms to about 1 s [8–10, 12, 13, 17]. The present study found NAI durations of  $370 \pm 20$  ms (Table 2), which is in agreement with the results of previous research. NAI durations were almost identical for all assessment intervals and therefore do not seem to be a subject of intraindividual variation in terms of the functional condition.

### Oral Screen and Maneuver Impact

During physiological deglutition, the oral cavity can be described as being a cylinder [18], with the lips forming an anterior seal and the velopharyngeal sphincter a cranial seal in the direction of the nose [19, 20]. The tongue has the function of a plunger pressing against the palate [18], thereby creating a separate compartment between the palate and the tongue dorsum, with negative pressure created after passive lowering of the tongue [3]. It is widely accepted that the tongue has the ability to adapt passively and functionally to the features of the anterior oral cavity in order to create an anterior seal during swallowing [21]. In open-bite cases, for example, the tongue often contributes to a deterioration in malocclusion by thrusting between the anterior teeth during every act of swallowing. By incorporating an oral screen, the condition in habitual mouth breathers, whose anterior seal is not provided by the lips most of the time, can be favorably changed, as the OS takes on the role of the anterior seal and enables the negative intraoral pressure needed for normal deglutition to be created [3, 20]. Even after the swallowing act has been completed, mouth-breathing is hindered by the OS and the negative pressure created by the act of deglutition needs to escape slowly in the posterior direction and this, in turn, has a positive effect on the duration of the post-deglutition cranial tongue rest position [3].

The clinical relevance of an enduring cranial tongue rest position is substantiated by previous research on predominantly mouth-breathing subjects who have a tendency to exhibit enhanced muscular activities of the *M. mentalis* and other mimic muscles [22], but decreased activity of the temporal and masseter muscles [23] at rest and during swallowing compared to predominantly nose-breathing subjects. Training of myofunctional maneuvers is therefore considered a valuable contribution to normalization of masseter, temporal, and mimic muscle tones. In a continuation of our research, we are planning to answer the question of the persistence of myofunctional therapy effects by use of a long-term manometric screening of intra-oral compartment formation.

The maintenance of the cranial tongue rest position is considered to be crucial for normal dentofacial development and for prevention of open-bite formation [24]. Accordingly, previous research on the stability of orthodontic treatment of open bites indicates a higher effectiveness in maintaining closure of anterior open bites in conjunction with orofacial myofunctional training in comparison to orthodontic treatment alone [25]. Accordingly, the maneuvers proposed by this study may be seen as helpful additions to orthodontic treatment of anterior open bites.

The aim of performing the additional oral maneuver TPCOS while wearing the oral screen is to create a posterior seal of the oral cavity to prolong the favorable tongue-palate contact after deglutition. This is done by supporting the tongue posture via the typically negative intraoral pressure generated during swallowing. In this condition, the oral cavity can be compared to a closed hydraulic system. The nasal airflow passes this functional closed system without disturbing the hydraulic system. However, if the velolingual seal is released, internal mouth-breathing (airflow from pharynx to mouth) will result [20].

In sum, deglutition in the functional conditions that include the OS has the following scheme: The tip of the tongue contacts the palate prior to the commencement of NAI and it remains at the palate during NAI and maintains contact afterwards. This type of deglutition pattern is comparable to the somatic swallowing pattern. In subjects who exhibit habitual open-mouth breathing and who do not wear an OS during resting respiration have a greater tendency for the tongue tip to make contact with the palate after commencement of NAI and relapse immediately to the floor of the oral cavity after deglutition. This pattern of deglutition resembles the visceral type of swallowing.

## Conclusions

We conclude that the conventional myofunctional maneuver shown following the instruction to put the tongue on the palate before, during, and after swallowing could be

facilitated and be more efficient in terms of raising the number of the favorable early TPC if these exercises were accompanied by the wearing of an oral screen. Functional intervals that include the oral screen (F2–F4) showed a distinct tendency toward an early TPC, whereas those without OS (F1 and F5) had balanced proportions of early and late TPC or tended to display a late TPC.

The value of the clinical diagnosis of a visceral deglutition pattern seen with open lips is questionable and can be deceptive, given that our trial subjects were overwhelmingly initially diagnosed as having such a manifestation but showed balanced proportions of early and late TPC on polysensography.

Habitual open-mouth breathing does not necessarily coincide with distinctively pronounced proportions of late TPC. Future research will address the timing of the tongue movement and NAI in relation to intraoral pressures.

**Disclosure** The authors have no conflicts of interest to disclose.

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