Comparative articulatory modelling of the tongue in speech and feeding

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Abstract

Two of the majo fu tio s of the huma o al t a t a e feedi a d s ea i . to e eti ally a d hylo e eti ally feedi tas s e ede s ea i tas s a d it has ee hy othesised that s ea i mo eme ts o stitute a su set of feedi mo eme ts. om Ele t oMa eti ti ulo a hy data we ha e ext a ted two estimates of the de ees of f eedom of the to ue, o e f om a s ee h tas a d o e f om a feedi tas . These ha e ee used to uild two o es o di a ti ulato y models. o oth tas s, a out 9 of the to ue a ia e a e ex lai ed y a amete s. Co t a y to the a e ted eha iou fo s ee h, fo feedi tas s, the ti , mid a d a e io s of the to ue a ea to e o t olled i de e de tly. The e o st u tio e o s of s ee h a d feedi a ti ulatio s y the two models show sli htly ette effi ie y fo the feedi model, su esti that the s ee h mo eme ts mi ht ealisti ally e o side ed a su set of the feedi mo eme ts.

1 ntroduction

In the framework of speech evolution, the study of the point at which speech movements emerged in the vocal tract raises a number of questions. A current hypothesis is that during evolution, humans developed articulatory movements for speech by borrowing skills related to other tasks such as chewing or swallowing [3, 4]. Three main functions can be ascribed to the vocal tract: breathing, feeding and speaking. W hilst breathing does not require complex vocal tract articulation, we know that both ontogenetically and phylogenetically feeding tasks precede speaking tasks. Based on this observation and relying on the frame-content theory [4], [2, 3] have hypothesized that the geometrical and articulatory spaces covered by the articulators while speaking might be a subset of the spaces covered while feeding. In the present study, we have considered this hypothesis in terms of degrees of freedom of the jaw and tongue. Our method involves recording articulatory measurements during speaking and feeding tasks using an ElectroMagnetic Articulograph (EMA) and building the associated articulatory models [1]. Although some comparative articulatory studies between speech and feeding have already been conducted [3,], our study aims to provide the first articulatory model of the vocal tract for feeding tasks. The linear modelling relies on Principal omponent Analysis (P A) and linear regression to extract the degrees of freedom of the jaw and the tongue from the measurements, as described in [1].

2 Data

2.1 Subject and corpora

To model the feeding mechanism using EMA, a French subject already used in another articulatory modelling study [1] was recorded.

The speech corpus consisted of (1) a set of artificially sustained articulations representative of the range of French articulations (44 phonemes including oral and nasal vowels, and consonants in three contexts [a i u], see [1]), and (2) a set of 9

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French continuous, phonetically balanced sentences. The feeding corpus was designed according to the clinical protocol for swallowing disorder assessment. The food was divided into three categories covering a wide range of food textures: liquids (saliva, water, single cream, custard), solid food (Angel Delight, eetabix softened in milk) and hard food (Rice W rispies in single cream, shortbread biscuits). The subject fed himself by means of a plastic teaspoon from a container in front of him, performing between 3 and 6 swallows for each type of food. The water was drunk from a glass by 3 different methods: (1) using a plastic teaspoon, (2) continuously using a plastic straw and (3) continuously directly from the glass.

2.2 Articulatory data

Eight EMA sensors were glued on the subject's articulators in the midsagittal plane: upper incisors and top of the nose (used as references for the head), lower incisors, upper and lower lips, and tip, mid and back regions of the tongue (about 1 cm, 4 cm and 6 cm from the tip point respectively). The EMA data used in this study consist of the coordinates of the jaw and tongue sensors centres.

The middle instant of each sustained phoneme was manually labelled and chosen as representative of the phoneme articulation. For the sentences, all the samples between the beginning and the end of each utterance have been used. For the feeding data, each sequence represents the entire process of swallowing, from the opening of the mouth for placing the food through to the final swallowing of the bolus. Note however that for the water drunk from the glass or from the straw, the sequence is considered to run from the beginning of the first swallow to the end of the last swallow, considering the movement as continuous rather than as succession of elementary swallows. In summary, with repetitions during the recordings, we obtained 82 sequences for the sustained phonemes, 12 for the sentences and 34 for the entire food corpus.

3 Articulatory model of the tongue in speech

The speech data used for the articulatory modelling of the tongue consist of 82 articulations of 8 variables (3 locations on the tongue 1 on the jaw each with 2 coordinates).

It is generally agreed that the jaw constitutes the primary articulator that impacts on the tongue position. Around 95% of the variance of the jaw position can be explained by a single articulatory parameter, *Jaw Height* (JH), obtained by PCA on the lower teeth sensor coordinates. A linear regression of the 82×6 tongue coordinate measurements on the JH parameter allows to determine the contribution of JH to the tongue (see Fig 1a) and to remove its contribution from the data. A PCA is then applied to the

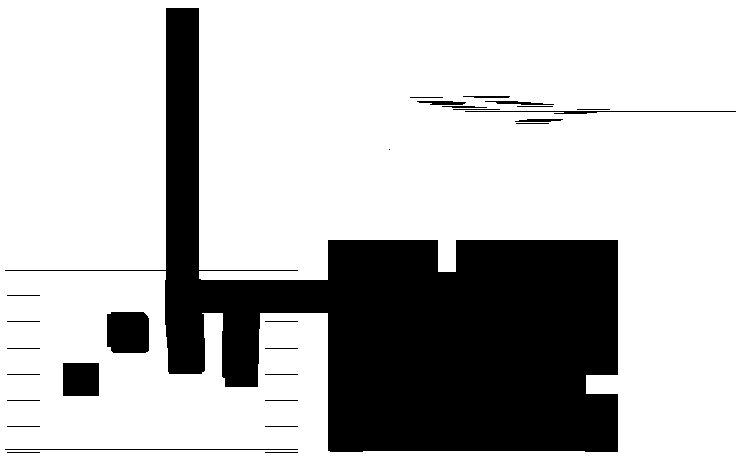


Table 1. *Ex lai ed a ia e, umulati e ex lai ed a ia e a d umulati e M e o st u tio e o fo the to ue y ea h of the a ti ulato y a amete s*

	Var.	um.Var.	RMS
Speech model parameters			
JH	19 %	19 %	0.55 cm
TB	48 %	67 %	0.35 cm
TD	20 %	87 %	0.22 cm
TT	7 %	94 %	0.15 cm
Feeding model parameters			
JH	65 %	65 %	0.46 cm
Tbck	11 %	76 %	0.35 cm
Tmid	8 %	84 %	0.28 cm
Ttip	13 %	97 %	0.13 cm
TtipV	2 %	99 %	0.08 cm

4 Articulatory model of the tongue in feeding

The model presented in this section constitutes a first attempt to extract the degrees of freedom for feeding tasks. Recall that unlike speech data, the feeding sequences used here consist of EMA trajectories, each sequence being a succession of positions of the sensors.

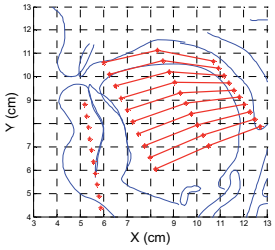
Again, the jaw is the principal influence on tongue position. The parameter JH is thus extracted from the jaw sensor coordinates on the full feeding corpus (see it contribution to tongue in Fig 2a). The range of variation of the jaw and thus of the tongue is greater for feeding than for speech. The movement of the tongue differs from that during speech: the back of the tongue follows a downward-backward movement where the movement is simply backward for speaking.

We make the assumption that the EMA sequence for water drunk from a glass is typical of swallow patterns for feeding. This sequence shows a cyclic, continuous movement of the tongue, from the front of the mouth to collect the liquid to the back of the mouth to swallow it, without any discontinuity or break. The model described next has thus been extracted from this sequence only.

A study of the cross-correlations of the residues of the tongue variables on this sequence has shown very little correlation suggesting that, unlike speech, the three points of the tongue act quite independently. Three articulatory parameters are thus extracted corresponding to the three tongue points, starting with the back point and finishing with the front, in order of decreasing variance. First *To ue Ba* (Tbck), was obtained by P A on the back sensor coordinates and its contribution to the 6 tongue variables assessed and removed by linear regression. The same procedure was then applied to the mid sensor coordinates to extract *To ue Mid* (Tmid) and finally to the front sensor coordinates to extract *To ue Ti* (Ttip). The nomograms of these parameters are shown in Fig 2b to 2d. The contribution of each articulatory parameter to the full feeding corpus is summarized in Table 1.

We observe that Tbck corresponds mainly to a vertical movement of the back of the tongue acting as an opening-closing connection with the pharyngeal cavity. Tmid corresponds mainly to a vertical movement of the mid of the tongue, the two extremities remaining fixed. This movement appears related to the creation of a puddle in the middle of the mouth to gather the liquid before lifting the tongue up to the hard palate to pass the liquid to the pharynx. Finally Ttip corresponds to a global front-back movement of the tongue associated with an up-down movement of the front of the tongue, so as to collect the liquid arriving in the mouth.

We observe that the four parameters JH, Tbck, Tmid and Ttip explain 97 % of the full feeding corpus variance, although three of them have been extracted on a restricted version of this corpus. However some tongue variability may have been missed by this approach, as only jaw movements and liquid swallowing have been considered for the model. A more precise study of the residue of the feeding data unexplained by the model shows a large variability for the front point of the tongue. P A on the residue of the front point coordinates allows a *To ue Ti Ve ti al* parameter (TtipV) to emerge, whose contribution to the tongue obtained by linear regression is displayed in Fig 2e. TtipV corresponds to an upward-backward movement of the front of the tongue which might be ascribed to a residue of mastication or a complementary action to move food from the front to the middle of the mouth. Although TtipV has a relatively low impact on the variance explanation, it corresponds to a plausible movement and it reduces significantly the RMS reconstruction errors found articulation by articulation.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