

Development of Lingual Displacement Independence at Babbling Stage

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Abstract

In this study, we recorded jaw movements and the acoustic signal of 15 babies of 8 to 12 months of age during babbling in order to assess the hypothesis whereby tongue gestures would be more independent from mandibular ones with age.

Results corroborate our expectations. We have shown that increase in the amplitude of tongue gestures in the anterior/posterior dimension, in relation to vertical jaw movement, is noticeable in older babies. This reveals emergence of articulatory control in babies throughout the babbling stage

1. Introduction

Babbling (6-12 months) is a language development stage which is achieved in spite of relatively poor motor control abilities. The famous “bababa...” sequences, associated with this period, could be produced by mandibular activation only. This is the hypothesis advocated by MacNeilage in the *Frame then Content* theory [13], which is the theoretical framework of this study.

2. The mandible’s influence on the production system at the babbling stage

The “*Frame then Content*” theory assumes that there could be a natural mandibular movement from which would emerge a specific and complex control for speech function. Speech would then be based on a “syllabic frame”, generated by the alternation of vocal tract open-close phases, the closing phase giving a consonantal configuration and the opening phase a vocalic one. The “content” would in turn be congruent with the emergence of the independent control of any single vocal tract articulator, superimposed on the mandibular cycle. Babbling

productions would result in a frame production, without content, and would depend on the intrinsic rhythm of mandibular oscillations. Accordingly, the jaw would be the only active articulator at this stage [9, 10]. Consistent with this last assumption, Munhall & Jones’s [14] Optotrak measurements showed that the lips are not actively involved in the open/close phase of the vocal tract in babbling. Throughout the closing gesture, lower lip movements were found to be passively carried by the jaw thus pushing the upper lip upwards at contact. Throughout the opening gesture, the lower lip would simply move downwards under the mandible’s influence. Hence, lip displacements seem to be initially a passive consequence of mandibular oscillations.

In this perspective, speech motor control abilities at the babbling stage, characterized by mandibular frame dominance and tongue passivity, have led Davis & MacNeilage [4, *et al.* 5] to assume three associative CV sequences to be limited to three associative patterns: central vowels associated with labial consonants within the “*pure frame*” (like in [ba]); front vowels associated with coronal consonants within the “*fronted frame*” (like in [dɛ]); back vowels with velar consonants within the “*backed frame*” (like in [gu])

3. Articulatory control emergence

Early in the babbling stage, the frame generated by mandibular oscillations is reduplicated. These successive repetitions of jaw phase alternations could in part reflect poor articulatory control. According to MacNeilage’s theory, “content” could increase in a trend called “fronting”, which would correspond to the first form of intercycle variation. Thus, during a bisyllabic sequence, the first syllable

would involve a “pure frame”, which would be followed by a lingual movement implicating a “fronted frame” and giving utterances like /pate/. However, this type of variation cannot alone account for the emergence of content, or more exactly for that of articulatory control.

We assume that entry into mature articulatory patterns involves dissociation of articulatory movements within a single cycle, which means that articulators can follow different trajectories. Our aim is to observe how the independence of articulators, such as the tongue, will evolve with age. It is hypothesized that articulatory control emerges when babies are able to dissociate tongue and jaw movements. In this context, it is assumed that, as babies get older, they their tongue movements become decoupled from jaw oscillations, thus drifting away from typical “pure-frame” movements.

4. Method

4.1 Participants

Fifteen babies from 8 to 12 months of age were recorded. They reported no history of motor or perceptual disorders. Their distribution across the speech acquisition stage was as follows: 3 subjects of 8 months of age, 3 of 9 months, 3 of 10 months, 3 of 11 months and 3 of 12 months. All babies were born in Germany and were living with parents who exclusively spoke German to them.

4.2 Experiment

We observed the evolution of tongue-jaw correlations by simultaneous articulatory and acoustic studies. The kinematic signals were acquired with Optotrak [14], a movement tracking system, which is, according to Green *et al* [11], the only investigation technique available, reliable enough to study mandibular movements before 4 years of age. Optotrak signals allowed the capture of jaw movements in the vertical dimension. Acoustic signals were used to infer tongue displacements during lowering or raising of the mandible. The tongue is an articulator whose position cannot be detected by Optotrak. Its displacements can be indirectly inferred from a spectral analysis of the acoustic signal. Indeed, the second formant (F2) is suggested to be an acoustic indicator to determine lingual movements in the anterior-posterior dimension [6].

4.3 Data processing

Jaw trajectories were segmented into simple movements according to displacements in the raising or lowering dimension. Within each simple jaw movement, F2 variations were segmented into monotonic segments, interpreted as individual tongue movements in the anterior-posterior dimension (see Figure 2).

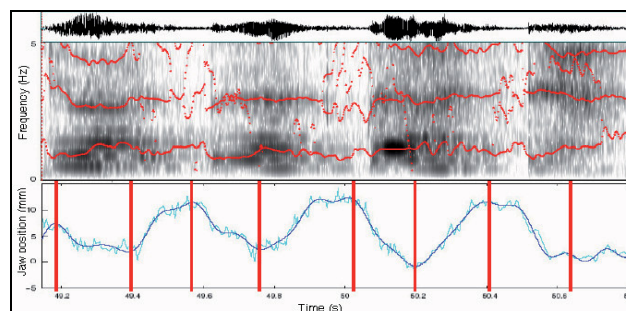


Figure 1: Segmentation of single tongue movements

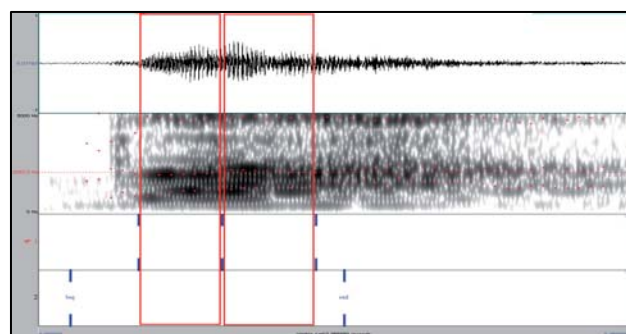


Figure 2: Detection of a change of F2 trajectory within a single jaw movement interval

In order to assess the variation of tongue movement amplitudes, relatively to jaw movement amplitudes, the difference in Hz between F2, at movement onset, and F2 at movement offset ($\Delta F2$) was computed for each simple movement. The distance (in mm), covered by the jaw in the same temporal interval was also measured (Δjaw). Further, we determined the ratio of these two values ($\Delta F2 / \Delta \text{jaw}$). The higher the ratio, the more pronounced the tongue movement would be, relative to the jaw. Inversely, the lower the ratio, the more predominant jaw movement would be. The average ratio was calculated for each subject, and the correlation between this ratio and age was estimated, in order to report on the progression of independence of tongue movement between 8 and 12 months.

5. Results

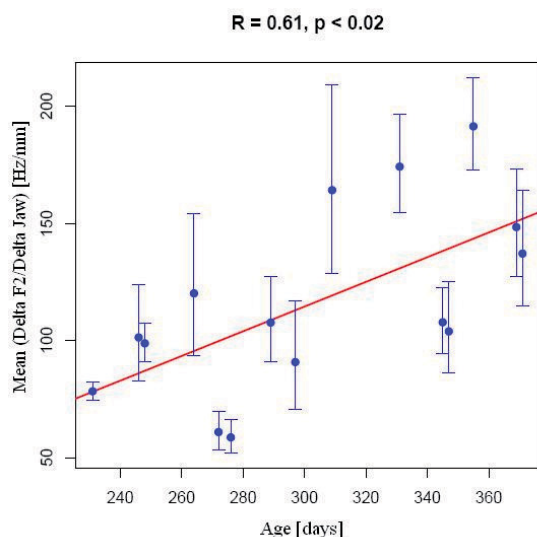


Figure 3: Evolution of $\Delta F2/\Delta \text{Jaw}$ ratio with age

On Figure 3, the mean $\Delta F2/\Delta \text{Jaw}$ ratio for each baby is plotted as a function of age. Vertical bars represent standard errors. The line represents the linear regression of the ratio as a function of age.

Our data concern motor control development of speech during a period going from reduplicated babbling to variegated babbling. Actually, results suggest that there is an increase in tongue movement amplitude in the anterior – posterior dimension of the vocal tract during this period. The $\Delta F2/\Delta \text{Jaw}$ ratio shows a significant progression, with a correlation coefficient of $R = 0.61$ ($p < 0.02$).

This suggests that the amplitude of the tongue movements in respect to the amplitude of jaw movements will increase with age. In addition, more and more lingual movements in the anterior-posterior dimension could be superimposed to the mandible's vertical displacements, with age.

6. Conclusion and discussion

This study aimed at giving an experimental support to MacNeilage's « *Frame then Content* » theory. MacNeilage defines speech as a frame on which content is superimposed. It means that human productions would result from the association of mandibular oscillations (frame) and other articulatory gestures (content). From an ontogenetic point of view, the baby must learn to superimpose this content on the mandibular frame in developing the ability of the other articulators, which, initially, only move under the mandible's influence.

Our results seem to support this hypothesis. Development of motor abilities for mature speech function goes through a phase during which other articulator displacements begin to be spatially

dissociated from displacements imposed by the jaw, in order to associate content to the frame.

With age, babies increase their articulatory capabilities and especially lingual gestures. The amplitude of tongue movements in the anterior/posterior dimension of the vocal tract is quite small for the younger subjects (8 months). Gradually, however, the tongue begins to be more active and its movement patterns become independent of those from the jaw.

Nevertheless, it cannot be concluded that articulatory control has been acquired at this stage. Articulatory patterns must still be refined. A study by Nitttrouer [15], for example, shows that lingual gestures are constrained by external factors such as phonologic context, until the age of 7 years. Other investigations, which looked at lip behaviour in children, pointed out the fact that even if kinematic patterns are in average relatively similar to adult ones at the age of 4 or 5 [18], or even 6 [9, 10], they still show remarkable variability [17]. Thus, in order to achieve mature patterns, articulators like the tongue, the lips or the velum must stabilize their trajectories.

Moreover, a question remains. Would our results be similar if we had chosen babies from languages with other characteristics, like Chinese (tone language) or Gambian Wolof (quantity language)? Actually, linguistic environment could influence the production system. Boysson-Bardies *et al.* [2] have, for example, shown in measuring formant values that differences between linguistic communities already appear in 10 month old babies.

Actually, in spite of possible sociolinguistic variations, babbling productions can be hypothesized, according to MacNeilage, to be generated by universal motor constraints which would involve, for example, the dominance of reduplicated syllables, co-occurrence patterns and a preference for some sounds, regardless of the language: consonants [p, t, k, b, d, g, m, n, w, j] and vowels [a, ae, ε, oe, e] are privileged [8, 12, 19, 20, 3, 1, 21 4, 5, 7...]. Moreover, these predilections would expand until the stage of first words [13, 5]. Furthermore, Boysson Bardies *et al.*'s data [2] show that, at 10 months, F2 mean values are comparable for English and French babies. For our discussion, standard deviation mainly matters, and it is stable between the two communities. This is not consistent with Rvachew *et al.* [16] who present data that show discrepancies for 20 Anglo Canadian babies vs. 23 Franco Canadian babies, from 10 months to 18 months of age. Actually, according to their results standard deviation increases for English and is stable for French, with age. It is then possible that differences found in F2 evolution could be related to

specificities in vocalic inventories. However, these across-language disparities should essentially emerge after 12 months, and our data collection does not go beyond 12 months. Examining such results shows, nonetheless, an F2 variation of different degrees: the standard deviation varies from 130 mels to 245 mels for English, and from 157 mels to 175 mels for French.

Thus, increase in tongue displacements, which stands out in our study, is likely not related to the nature of the target language. We believe that some aspects of motor control would indeed adjust differently to specific linguistic requirements. More exactly, increase in tongue movements, related to the vertical displacements of the mandible, would be systematic, even though this phenomenon could be more or less pronounced as a function of the language.

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