Coarticulation magnitude in German children

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The present study investigated the development of coarticulation in German children, aged 3 to 7 year-old. Coarticulation is generally defined as the articulatory overlapping for neighboring phonemes. It involves multiple articulators (e.g., the tongue) whose actions must be finely coordinated to produce intelligible speech. From a developmental point of view, acquisition of coarticulation is essential to fluent language production. However, contrary to other important language-related capabilities emerging concomitantly with coarticulation in the first years of life, the development of spatial and temporal organization of speech gestures is not completely understood (e.g., Barbier et al., 2015; Noiray et al., 2013; Zharkova et al., 2011). Previous studies in the domain have reported contradictory results regarding the magnitude of coarticulation in syllables (CVs) and therefore generated diverging theories on the units of speech production. To date, it is still unclear whether children initially coarticulate more than adults and progressively develop from a syllabic representation associated with immature articulatory routines to a more segmental organization accompanied with more differentiated control over articulators (Nittrouer et al., 1996) or if the opposite occurs (Green et al., 2002). The present study examined developmental differences in coarticulation magnitude with a theoretical and methodological approach different from those mostly reported in the literature. First, it measures movement from the tongue using ultrasound imaging to directly track the spatial and temporal organization of lingual gestures for consecutive phonemes. Second, it examines the role of phonetic (articulatory) characteristics of the produced sequences to assess how much consonants and vowels can interact with one another in a target sequence. Finally, it uses a cross-sectional design to investigate how these characteristics change with age as the child gains more experience speaking his native language.

METHODS

Three cohorts of ten German children (age 3-4-5) as well as fifteen adults were tested at LOLA Lab (Germany). Stimuli were elicited in a repetition task, which for children, was embedded in a game setting. The prerecorded acoustic stimuli consisted of disyllabic C1 V1 C2 V2 pseudo words preceded by the carrier word “eine”. Within the stressed first syllable (C1 V1), C1= /b/, /d/, /g/, or /z/ and V1 one of the tense vowels /i/, /y/, /u/, /a/, /e/, and /o/. The second CV syllable consisting of the same consonant set as C1 plus the neutral vowel /ə/ is added to the syllable of interest such that C2 is never equal to C1, resulting in three different contexts per C1 V1. In total, there are 72 different pseudo words. During the recordings, children were comfortably seated in an adjustable car seat. Movement from the tongue was recorded with an ultrasound system synchronized with audio speech signal. The probe was fixed on a custom-made probe holder positioned below the participant’s chin to record the tongue on the midsagittal plane. Video assisted tracking of the head and probe motion allowed for expressing the data from a jaw-based to a head-based coordinate system. Tongue contours were computed via a custom Matlab platform (SollarContours) and sampled as 100 points. For each point, xy coordinates providing spatial information along the front back and height dimensions were extracted for subsequent analyses.

To assess developmental differences in CV coarticulation, we employed 1) Locus Equation measures (LE) which test differences of coarticulation magnitude and resistance as a function of consonant place of articulation and 2) Mutual Information (MI), a method used to quantify the articulatory dependence versus independence between phonemes (Iskarous et al., 2013). While LE metric has been widely employed in the acoustic domain and more recently applied to articulation (adults: Iskarous et al. 2010; children: Noiray et al. 2013), MI had only been used to characterize adults’ coarticulation cross-linguistically using EMA corpora. This study therefore extends previous investigations, testing the potential of MI to a different form of articulatory data quantification, i.e. ultrasound as well as a more challenging population, i.e., children. As MI analysis is less dependent on data distribution than standard LE measures, it is a particularly promising method to be employed in the developmental field considering 1) the difficulty of child data collection, 2) the large overall variability obtained in child speech. Also, while LE tests linear relationships between adjacent phonemes (slope and correlation coefficient), MI allows for measuring the amount of physical information shared between phonemes. Both methods therefore complement each other.
In our study, we extended standard acoustic LE to the articulatory domain as previously done with colleagues. For each CV sequence, both LE and MI were computed over three time points: consonant midpoint, vowel onset and its midpoint. For each corresponding tongue contour, the x coordinate of the highest point on the tongue dorsum was used to describe its motion along the front-back dimension. We focused on the tongue dorsum that is the main lingual functional subpart involved in vowel constrictions. LE regression lines as well as MI value were calculated between C midpoint or V onset in relation to V midpoint.

RESULTS & Discussion
Results in German adults corroborate those reported in English (Iskarous et al., 2010). LE slope varied across C’s place of articulation as a result of differences in articulatory constraints and compatibility of tongue gestures between C and V with the following slope hierarchy: b>g>d). In the case of labial coarticulation, the tongue position for C was largely influenced by the neighboring vowel. It was not the case for /d/ for which vowels’ influence was not exerted over the syllable as much as in labial context. MI results are in agreement with LE. Low MI for /d/ indicates that in alveolar context, the position of tongue dorsum along the front-back dimension was independent for each segment. On the contrary, greater MI was observed between vowels and the labial C as an indication of large articulatory dependence between both segments. Finally, velar /g/ was characterized by an intermediate MI as it exhibit a more flexible articulation depending on its immediate vocalic context.

Regarding children, data for the 3 year-old cohort is currently being analyzed. For the 4 and 5 year-old cohorts, LE slopes showed overall more coarticulation for all three consonant types than adults but with similar trends (b>g>d). Interestingly, vowel influence was already present during consonant closure and to a greater extent than adults. In alveolar context, less coarticulatory resistance was observed in children, which manifested by higher slopes than found in adults. However, more variability was observed with lower correlation coefficients. This suggests children age 4 and 5 have not yet acquired precise articulatory realizations for target phonemes within syllables.

Taken together, results suggest that (developmental) differences in coarticulation require more fine-grained measures than those traditionally employed in the literature. Both methods tested in this study provide opportunities to depart from categorical descriptions of coarticulation magnitude and envision coarticulation as a continuum which magnitude depends on the articulatory characteristics for contiguous phonemes. Regarding whether measure of coarticulation magnitude can reveal age differences in speech organization (i.e., segmental versus syllabic), our results indicate that the temporal organization of children’s speech as well as those of adults’ is tightly related to the articulatory properties of the phonemes coarticulated. Important differences already appear in the young age as a function of the consonants and vowels combined. Further analyses are currently conducted to extend evidence in this direction.


