Anticipatory V-to-V Coarticulation in German Preschoolers

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Abstract

This study investigates lingual V-to-V anticipatory coarticulation in German preschoolers and adults using ultrasound measures. In light of conflicting results in the literature, the aim was to study effects in larger cohorts and with a widespread set of vowels. Results provide evidence for V-to-V coarticulation in children as well as adults, independent of the intervocalic consonant. Interestingly, coarticulation degree decreases with age.

Index Terms: Language acquisition, coarticulation, ultrasound, speech production

1. Introduction

Coarticulation, generally defined as the articulatory overlap of speech sounds with one another, provides an opportunity to bridge the gap between phonology and phonetics, as abstract phonemes are assembled to a continuous speech stream. It seems that various mechanisms guide this process: Recasens [1] summarizes that the nature of coarticulatory processes and their magnitude are influenced by mechanical constraints on the one hand and articulatory preprogramming mechanisms on the other hand. More precisely, he found that the extent to which a vowel may overlap with a preceding consonant in CV-syllables highly depends on the articulatory constraints associated with the consonant, i.e. its resistance [2]. However, in anticipatory V-to-V coarticulation in VCV sequences, resistance of C did not show an accordingly large influence ([1], [3]). Recasens interprets this as evidence for V-to-V anticipatory coarticulation to mainly result from articulatory preprogramming.

To become fluent speakers, young children have to both develop a refined control of their speech production system and learn to plan their articulation to achieve their native language's coarticulation patterns. However, albeit studied quite frequently, coarticulation in child speech remains poorly understood because of contradictory results in previous studies (e.g., [4] versus [5]). Due to the lack of non-invasive articulatory measures, child speech has been mostly examined acoustically (except for [6], [7], [8]).

The present study is part of a larger project that aims to track the developmental course of coarticulation mechanisms in German children, investigating multiple age groups and combining traditional acoustic measurements with direct measures of articulation via ultrasound imaging and labial shape tracking.

Here, we more specifically focus on articulatory investigations of lingual anticipatory V-to-V coarticulation in German preschoolers. Some studies on child speech reported a systematic change of the first vowel depending on the second vowel ([9]; [4], [10] for 9;5-year-old child; [11]). Others did not find such effect ([10] for 4;8-year-old child; [12]). Except for [12] all studies only included acoustic measurements. For adults, there is strong evidence for anticipatory V-to-V coarticulation and for this effect to be at least partially modulated by the intervocalic C's resistance ([1], [3], [13], [14]). However, as Recasens [1] emphasizes, the impact of the consonant's resistance is a lot smaller in anticipatory V-to-V coarticulation than it is in CV- and even in carry-over V-to-V coarticulation.

In light of previous literature, our study addresses the following questions: First, do we observe anticipatory V-to-V coarticulation in children as well as adults? If we find that the tongue position during the first vowel varies as a function of tongue position during the second vowel, it will bring evidence for anticipatory V-to-V coarticulation. Second, is the magnitude of V-to-V coarticulation modulated by the degree of resistance of the intervening consonant? If so, we expect smaller V-to-V coarticulation in cases for which consonantal resistance is stronger (i.e. alveolars) than when resistance is minimal (i.e. labials). And finally, does the coarticulatory pattern and magnitude change in the course of development? This hypothesis will be tested by looking at possible differences across cohorts.

2. Method

2.1. Participants

In this study, two cohorts of children including 18 3-year old children (10 females, age range: 3;05 – 3;08 (Y;MM), mean: 3;06), 13 5-year old children (7 females, age range: 5;04 – 5;07, mean: 5;06) and 16 adults (8 females, age range: 19-34 years mean: 25;08) were tested. Participants grew up in a monolingual German environment and none of them reported any language-, hearing, or visual problems.

2.2. Stimulus material

C_1VC_2ə pseudowords were embedded in carrier phrases with the German female article /aɪnə/ such as "eine bide". The set of consonants used consisted of /b/, /d/, and /g/, the vowel set of the tense and long vowels /i/, /y/, /u/, /a/, /e/, and /o/. C_1Vs were designed as a fully crossed set of Cs and Vs while the second C_2ə syllable was added in a way that C_1 was never equal to C_2. Anticipatory V-to-V coarticulation was measured between the vowel and the preceding schwa. Children repeated every word 3 times, resulting in 108 trials per child. Those 108 trials were presented in 6 randomized blocks. For adults the additional consonant /z/ was included but is not analyzed here. With 3 repetitions of each word their data set included 218 trials presented in 9 randomized blocks.

2.3. Experimental procedure

Participants were recorded with SOLLAR (Sonographic and Optical Linguo-Labial Articulation Recording system [15]). This child-friendly platform allows for simultaneous recordings of tongue movement (Sonosite Edge, sr.: 48Hz), lip movement (video camera SONY HDR-CX740VE, sr.: 50Hz) and audio speech signal (microphone Shure, sampling rate: 48kHz). The relatively small ultrasound probe was positioned straight below participants' chin to record the tongue on the midsagittal plane. It was fixed on a custom-made probe holder to be flexible in the vertical dimension allowing for natural jaw movement but prevent motion in lateral and horizontal translations. The acoustic recordings served as a reference to detect the relevant time points in the ultrasound video.

Stimuli were recorded by a German female model speaker beforehand. In the experiment, the task for participants was to repeat the auditorily presented stimuli. For children, the repetition task was presented as a game to stimulate their interest.

2.4. Data processing

First, acoustic data were phonetically labeled using Praat [16]. The time points relevant to our analysis are the temporal midpoint of schwa and the temporal midpoint of the vowel.

These time points were subsequently used to find the corresponding frames in the ultrasound video signal. For each relevant time point, tongue contours were semi-automatically detected with scripts custom-made for MATLAB [17] as part of the SOLLAR platform (see Fig. 1). For each relevant contour, the x-coordinate of the highest point of the tongue dorsum was automatically extracted and used for subsequent coarticulation analyses.

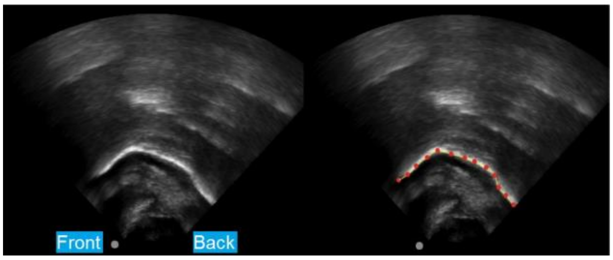

Figure 1. *Midsaggital view of the tongue surface. Left: Tongue contour without labels. Right side: Tongue contour labeled in red.*

3. Results

In line with previous acoustic studies, we first investigated coarticulation using Locus Equations (LE). Most notably, Sussman and colleagues (e.g., [18]) computed linear regressions for the second formant (F2) between the vowel onset and its midpoint to test for linear relationships between consonant and vowels in CV sequences. They found that the slopes of the regressions varied with the amount of CV coarticulation. We transposed LE to the articulatory domain and used the horizontal position of the highest point of the tongue instead of F2. Instead of examining the degree of coarticulation between the consonant and the vowel, we report on the relationship between the schwa and the vowel.

Figure 2-5 display the resulting regression lines. While the slopes for the different consonant contexts are roughly the same within each cohort, slopes are highest for 3-year-old children, intermediate for 5-year-olds and lowest for adults, suggesting less V-to-V coarticulation in older cohorts.

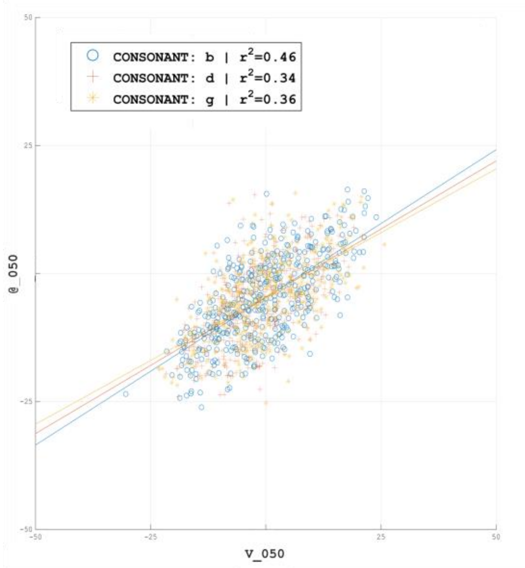

Figure 2. *Linear regressions between schwa midpoint and vowel midpoint for 3-year-olds. Slopes are b: 0.58, d: 0.53, g: 0.5.*

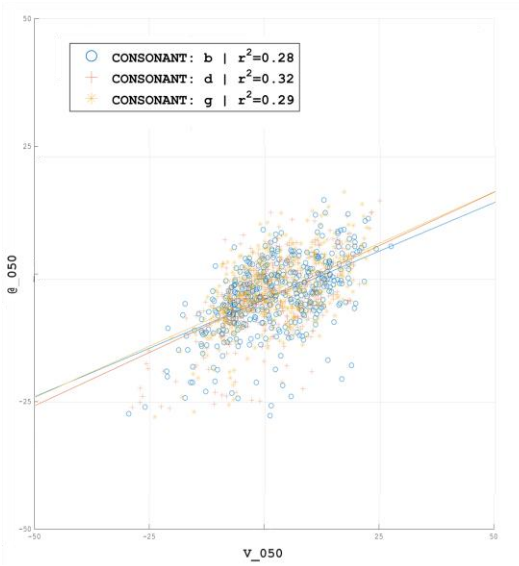

Figure 3. *Linear regressions between schwa midpoint and vowel midpoint for 5-year-olds. Slopes are b: 0.4, d: 0.44, g: 0.42.*

For a more precise analysis we also fit a linear mixed effects model to investigate the relationship between the horizontal position of the highest point of the tongue dorsum during schwa (dependent variable) and during the vowel (independent variable), using R [19] and lme4 [20]. As fixed effects, the horizontal position of the highest point of the tongue at the temporal midpoint of the vowel, cohort, and consonant were included with interaction terms. As random effects, we included intercepts for participants and words, as well as by-word random slopes for the effect of cohort. Residual plots were visually inspected and did not show deviations from homoscedasticity or normality. The goodness of fit was determined using likelihood ratio tests and p-values were obtained with lmerTest [21]. The linear model's output for the main effects and the interactions is dis-

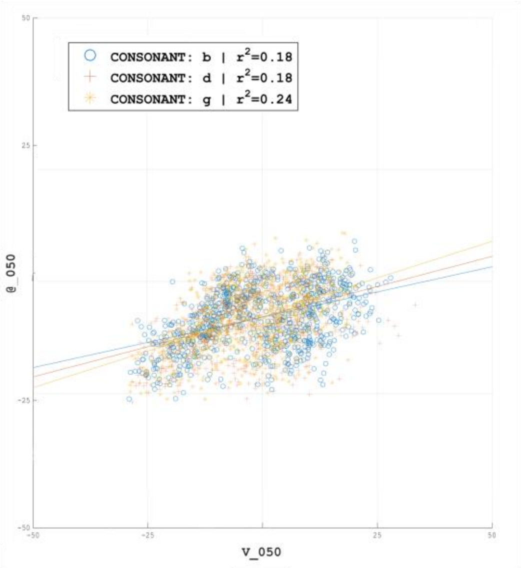

Figure 4. *Linear regressions between schwa midpoint and vowel midpoint for adults. Slopes are b: 0.23, d: 0.27, g: 0.33.*

played in Table 1. The cohort of 5-year-olds and the labial consonant served as the base lines for cohort and consonant respectively.

The position of the tongue (represented by the x-coordinate of the highest point of the tongue dorsum) during the vowel significantly affects its respective position during the schwa. There is not any significant difference in tongue position during schwa between the 3- and the 5-year-olds, but between the 5-year-olds and adults. Neither the consonant /d/ nor /g/ differ significantly from /b/ in their effect on schwa. More interestingly though, the effect of the vowel on the schwa seems to be modulated by age as shown by the significant interactions between the vowel and the cohorts. The effect of the vowel on schwa is not significantly affected by the nature of the intervening consonant as shown by non-significant interactions between vowel and consonants. The interaction between the 3-year old cohort and the consonant /g/ is only marginally significant suggesting that the effect of /g/ on the schwa is different between 3- and 5-year-olds. None of the three-way interactions reached significance.

Table 1. *Output of the linear mixed model.*

Effect	Estimate	SE	t	p
Intercept	-4.714	1.30	-3.61	***
Vowel midpoint	0.56	0.02	20.13	***
3-year-olds	0.27	1.39	0.2	
Adults	-3.35	1.52	-2.21	*
Consonant /d/	1.17	1.16	1.01	
Consonant /g/	0.41	1.12	0.37	
Vowel midpoint: 3-year-olds	0.09	0.03	2.69	**
Vowel midpoint: Adults	-0.43	0.03	-15.01	***
Vowel midpoint: Consonant /d/	0.01	0.04	0.31	
Vowel midpoint: Consonant /g/	0.01	0.04	0.28	
3-year-olds: Consonant /d/	-0.54	0.53	-1.015	
Adults: Consonant /d/	-1.28	0.93	-1.37	
3-year-olds: Consonant /g/	-1.01	0.53	-1.89	.
Adults: Consonant /g/	0.018	0.9	0.02	
Vowel midpoint: 3-year-olds: Consonant /d/	-0.04	0.05	-0.92	
Vowel midpoint: Adults: Consonant /d/	-0.01	0.04	-0.26	
Vowel midpoint: 3-year-olds: Consonant /g/	-0.07	0.05	-1.42	
Vowel midpoint: Adults: Consonant /g/	0.05	0.04	1.28	

Sign. codes: ***: $p < 0.001$, **: $p < 0.01$ *: $p < 0.05$, .: $p < 0.1$

4. Discussion

The significant main effect of tongue position at vowel midpoint in the linear mixed effects analysis suggests an overall effect of the vowel on the schwa, hence, the presence of V-to-V coarticulation. Interestingly, the non-significant interactions between the vowel midpoint and the different consonants negate a dependency of the V-to-V coarticulation magnitude on the identity of the intervening consonant. In our stimuli, the consonants /b/, /d/, and /g/ were used because they vary in coarticulatory resistance with /b/ being least resistant, /g/ intermediate and /d/ most resistant. Results of our earlier CV-coarticulation analysis are neatly in line with this hierarchy. In light of previous literature ([1], [3], [13], [14]), it might then be expected that the effect of V2 on V1 is lower in cases of an intervening /d/, intermediate for an intervening /g/ and highest for an intervening /b/. However, our data suggest that the resistance of the consonant does not significantly affect V-to-V coarticulation. This result might be interpreted as an even stronger case of Recasens' observations [1] that the consonant's effect on coarticulation amount is limited in anticipatory V-to-V coarticulation. In a next step it would be interesting to investigate carry-over coarticulation from V to the final schwa in our data to see whether the consonants' resistance has a larger impact here. Recasens' [1] interpretation of this result, that V-to-V coarticulation is

mainly a question of articulation preprogramming as opposed to CV-coarticulation which is much more a matter of mechanical constraints, suggests that children's task to master V-to-V coarticulation is essentially learning to plan their articulation.
From a developmental perspective, our current results suggest that there are actually changes in the degree but not in the pattern of coarticulation with age. Planning is thus probably not adult-like yet. The significant interactions between age cohorts and vowel midpoint depict that 3-year-olds' V-to-V coarticulation magnitude differs from 5-year-olds' and that 5-year-olds' in turn differs significantly from adults'. Going back to the regression analysis, the pattern of slopes across age cohorts shows a developmental trend towards less coarticulation with increasing age. Slopes are highest for the 3-year-olds, intermediate for the 5-year-olds and lowest for adults. While our current results are very clear about this age effect, previous investigations displayed different pictures: Repp [10] for example found no V-to-V coarticulation in his younger (4;8 years) but in his older participant (9;5 years) suggesting an increase of coarticulation. Barbier [12] did not find anticipatory V-to-V coarticulation in 4-year-olds. Nittrouer [4] did find V-to-V coarticulation in 3-7-year-olds but no age effect and Boucher [9] actually found an effect of age comparable to our result. The only previous study investigating lingual anticipatory V-to-V coarticulation in children with direct articulatory measurements as we did is Barbier [12]. However, their stimulus material differs substantially from ours in that they included two full vowels instead of a schwa and a vowel. Schwa is generally more malleable than other vowels (e.g., [22]), which might explain why there are effects in our study but not in [12]. A strong claim such as Nittrouer et al.'s [4, p.387] "children's gestures are organized into separate syllabic units, as adult gestures are." is nevertheless challenged by the present findings which suggest that there is still ongoing change towards adult-like (syllabic) patterns in 5-year-olds.
While there are substantial changes in the magnitude of V-to-V coarticulation, the coarticulatory patterns, i.e. the influence of the intervening consonant on V-to-V coarticulation, does not change with age as proposed by the non-significant three-way-interactions between vowel midpoint, cohorts, and consonants.

5. Conclusion

To answer the three initial questions, we studied lingual anticipatory V-to-V coarticulation in German 3- and 5-year-olds as well as adults measuring the highest point of the tongue. Our results converge towards the conclusion that both children and adults exhibit V-to-V coarticulation independent of the nature of the intervocalic consonant. Further, the degree of V-to-V coarticulation decreases across life.
We are currently developing more refined measures to explore whether an influence of the intervocalic consonant may be manifest in the global tongue contour or curvature degree.

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7. References

[1] D. Recasens, "An acoustic analysis of V-to-C and V-to-V coarticulatory effects in Catalan and Spanish VCV sequences." (1987). *Journal of Phonetics*, vol. 15, pp. 299-312, 1987.

[2] D. Recasens, "V-to-C coarticulation in Catalan VCV sequences: An articulatory and acoustical study." *Journal of Phonetics*, vol. 12, pp. 61-73, 1984.

[3] D. Recasens. "Vowel-to-vowel coarticulation in Catalan VCV sequences." *Journal of the Acoustical Society of America,* vol. 76, pp. 1624-1635, 1984.

[4] S. Nittrouer, M. Studdert-Kennedy and S. T. Neely. "How children learn to organize their speech gestures: Further evidence from fricative-vowel syllables." *Journal of Speech and Hearing Research,* vol. 39, pp. 379-389, 1996.

[5] J. R. Green, C. A. Moore, and K. J. Reilly. "The sequential development of jaw and lip control for speech." *Journal of Speech, Language, and Hearing Research*, vol. 45(1), pp. 66-79, 2002.

[6] L. Ménard and A. Noiray. "The development of lingual gestures in speech: Comparing synthesized vocal tracts with natural vowels." *Fait de Langue,* vol. 37, pp. 189-202, 2011.

[7] A. Noiray, L. Ménard, and K. Iskarous. "The development of motor synergies in children: Ultrasound and acoustic measurements." *The Journal of the Acoustical Society of America,* vol. 133(1), pp. 444-452, 2013.

[8] A. Smith. "Speech motor development: Integrating muscles, movements, and linguistic units." *Journal of communication disorders*, vol. 39(5), pp. 331-349, 2006.

[9] K. M. Boucher, "Patterns of anticipatory coarticulation in adults and typically developing children", M.S. thesis, Brigham Young University, Provo, UT, 2007.

[10] B. Repp. "Some observations on the development of anticipatory coarticulation." *Journal of the Acoustical Society of America,* vol. 79(5), pp. 1616-1619, 1986.

[11] A. Noiray et al. "Emergence of a vocalic gesture control: Attunement of the anticipatory rounding temporal pattern in French children." E*mergence of language Abilities*, S. Kern, F. Gayraud and E. Marsico, Eds. Newcastle upon Tyne: Cambridge Scholars Publishing, 2008, pp. 100-116.

[12] G. Barbier et al. "Speech planning as an index of speech motor control maturity." *14th Annual Conference of the International Speech Communication Association*, 2013.

[13] C. A. Fowler and L. Brancazio. "Coarticulation resistance of American English consonants and its effects on transconsonantal vowel-to-vowel coarticulation." *Language and Speech,* vol. 43(1), pp. 1-41, 2000.

[14] S. E. G. Öhman. "Coarticulation in VCV utterances: Spectrographic measurements." *Journal of the Acoustical Society of America*, vol. 39, pp. 151-168, 1966.

[15] A. Noiray, J. Ries, M. Tiede, M. (2015). "Sonographic & Optical Linguo-Labial Articulation Recording system (SOLLAR)," presented at Ultrafest VII, Hong Kong, 2015.

[16] Boersma, P. & Weenink, D. "Praat: doing phonetics by computer" [Computer program]. Version 6.0.20, retrieved 3 September 2016 from http://www.praat.org/.

[17] MATLAB Release 2016a, The MathWorks, Inc., Natick, Massachusetts, United States.

[18] H. M. Sussman, K. A. Hoemeke, H. A. McCaffrey. "Locus equations as an index of coarticulation for place of articulation distinctions in children." *Journal of Speech and Hearing Research,* vol. 34, pp. 769-781, 1992.

[19] R Core Team. "R: A language and environment for statistical computing." R Foundation for Statistical Computing, Vienna, Austria, 2016.

[20] D. Bates et al. "Fitting linear mixed-effects models using lme4." *Journal of Statistical Software*, vol. 67(1), pp. 1-48, 2015

[21] A. Kuznetsova, P. B. Brockhoff, and R. H. B. Christensen. "lmerTest: Tests in linear mixed effects models." R package version 2.0-32. https://CRAN.R-project.org/package=lmerTest, 2016.

[22] C. Browman and L. Goldstein, "Targetless schwa: An articulatory analysis" Haskins Laboratories, New Haven, CT, Status Report on Speech Research, SR-101/102, 1990.