HOW DOES VOWEL CONTEXT INFLUENCE LOOPS?

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ABSTRACT: This study investigated the influence of vowel context onto the tongue back movement trajectories in /VCə/-sequences, where V was one of 14 German vowels. Three German subjects were recorded by means of EMA. The experimental settings, with a velar consonant and a comparatively large vowel system including a tense-lax distinction, was chosen to maximize coarticulation, which, in turn, should enhance the disentangling of, in a narrower sense, productional from linguistic influences on observed movement patterns. The main results of our study indicate dominating biomechanical principles operating on a front-back-dimension.

INTRODUCTION

Since the pioneering work of Houde (1968), articulatory looping patterns have often been observed in V1-[Velar]-V2-sequences: When the velar contact occurs during a forward-directed vowel-to-vowel transition, during the stop the tongue slides in forward-direction towards the second vowel target. These sequences are theoretically unproblematic and can directly be interpreted as a natural consequence of the vowel-to-vowel movement. However, when the contact occurs during a rearward movement, the direction is often temporarily reversed, i.e. during oral closure the movement goes in forward-direction resulting in small elliptical movement trajectories, or no movement at all is observed. Subsequent to Houde, congruent observations have been made in several studies, for example Kent & Moll (1975), Mooshammer, Hoole & Kühnert (1995), Löfqvist & Gracco (1994), Löfqvist & Gracco (2002), and several competing explanations were given for this phenomenon: Looping patterns as a passive forward movement of the tongue due to airstream mechanisms (Kent & Moll, 1972), as a result of an active gesture aiming at the maintenance of voicing (Houde, 1967), synonymously 'cavity enlargement' (Ohala, 1983). Counterevidence against the active planning or cavity enlargement hypothesis consist in the data on German collected by Mooshammer et al. (1995): Articulatory loops during the voiceless stops [k] were larger than during the voiced counterpart [g], but this does not rule out the potential effect of airstream mechanisms completely. Hoole, Munhall & Mooshammer (1998) contrasted normal versus ingressive speech, and ingressive speech resulted in size reduction of the looping pattern: As a consequence aerodynamic influences seem to be at work, but it is not clear when and how they operate. Löfqvist & Gracco (2002) try to explain looping patterns in more general principles of motor control, postulating the entire movement to be planned in terms of cost minimization principles. In a recent modeling study, Perrier, Payan, Zandipour and Perkell (2003) focus on tongue biomechanics moderated by place of articulation. In contrast to Löfqvist & Gracco, Perrier et al. conclude, looping patterns can be explained in terms of biomechanics alone and the trajectory as a whole does not have to be preplanned. Perrier et al. rather prefer a target-based planning reference frame. Furthermore, another finding of this study is the partially high sensitivity of looping patterns to place-of-articulation: Perrier et al. observed that for velars following a front vowel - in contrast to the context of a back vowel- *"a small forward shift of the consonant target, associated with very small changes in muscle commands, was enough to reverse the direction and the orientation of the loops, which are now forward directed and counterclockwise oriented."* (Perrier et al., 2003, p. 1596). Another reason to expect a sharp distinction on a front-back-dimension lies in a specific characteristic observed for the dorsal articulator by Alfonso & Baer (1982) consisting in differential initiation times of horizontal and vertical components of movements for the back vowels in contrast to synchronous onsets for front vowels. Whether this vowel-specific difference is also a potential explanation for the different looping patterns is one of the questions we hope to answer in this work.

One of the shortcomings of the literature on this subject is the incompleteness of the data situation. Previous studies were mostly restricted to environments consisting of the corner vowels /a,i,u/. The aim of this study is to describe velar stop production in a more complete vowel environment consisting of German vowel system with its tense-lax distinction. In Task dynamic terminology (Saltzman & Munhall, 1989), a /VCV/ "*gesture is defined along exactly the same set of tract variables and articulators as the flanking vowels*" (p. 50), if the consonant is a velar. This should lead to contextual variability related to openness of the vocal tract . One characteristic of the German vowel system is its tense-lax distinction, with tenseness bearing a relation to more peripheral and less open vocal tract configurations as shown by e.g. Hoole (1999). Therefore, the selection of German as a target language should generate a large amount of vowel-induced contextual variability.

METHODS

Tongue movements of three German speakers were recorded simultaneously by means of EMMA (AG100, Carstens Medizinelektronik) and EPG (Reading EPG3) systems. The speech materials consisted of nonsense words with CVCə-sequences with either velar or bilabial stops as consonantal context. The initial stop was voiced and the medial voiceless. All nonsense words were embedded in the carrier phrase "Sage .... bitte" ("Say .... please") and repeated up to 11 times.
A subset of this corpus is used in this study: The tongue movement data consist of the /Vkə/-sequences, with V being one of the 14 German vowels /iː,ɪ,yː,ʏ,eː,ɛ,øː,œ,aː,a,uː,ʊ,oː,ɔ/), and with C being /k/. The most anterior sensor was located around 1cm back from the tongue tip, while for the second most posterior sensor the posterior limit of the EPG palate was used as a reference. One sensor was placed in between these, and the fourth sensor was, if -possible- placed behind the second most posterior one. In any case, it was attempted to obtain an equidistant spacing between sensors. All the analyses in this paper refer to the most posterior sensor, henceforth called TB. Sample frequencies were 200 Hz for EMMA data. The movement data were low pass-filtered at a cutoff frequency of 30Hz. Derivatives were calculated by means of a three-point central difference filter. The following temporal landmarks were extracted manually from the acoustic signal by means of the software package PRAAT by Boersma & Weenink (1992–2003): (a)The onset of the second formant of the first vowel (b) the offset of the second formant of the first vowel, (c) the burst, (d) the voicing onset of the second vowel, (e) The onset of the second formant of the second vowel and (f), the offset of the second formant of the second vowel. From these temporal landmarks, four 'phases' of the VCə-sequence were defined: (I) the movement from the midpoint of the first vowel to the onset of closure, where the midpoint of the vowel is defined as the central sample of the temporal landmarks of (a) and (b), (II), the interval during closure defined as the time between (b) and (c). (III), the interval between the burst and voicing onset(c) and (d), and (IV), the interval during the /ə/, where the vowel mid of the second vowel is defined in analogy to interval (I). These intervals serve as the basis for the following *articulatory* analyses. In our opinion, the use of acoustic landmarks seems satisfied, because the commonly applied definition of articulatory landmarks from the speed signal was not consistently possible in all vowel environments.
In the next paragraphs, results deemed representative for our data are reported for three speakers: (a) Distances traveled during the above-defined phases of our test-stimuli. (b) The curvatures during the stop are considered informatively as they might show revealing patterns with respect to potential biomechanical impacts on the movement trajectory, (c) correlations between the positions in the mid of the first vowel and distances during the stop as well as respective significances. The curvature of the tongue back sensor was calculated for these intervals as $c = (\dot{x}\ddot{y} - \ddot{x}\dot{y})/v^3$, where $\dot{x}$ and $\dot{y}$ are the velocities of x and y-components of the sensors, and $\ddot{x}$ and $\ddot{y}$ are the corresponding accelerations and v the tangential velocity, calculated as $v = \sqrt{(\dot{x}^2 + \dot{y}^2)}$, i.e. the square root of the sum of the squared velocities. The distances are calculated by summing the distances over the whole of the trajectory.

RESULTS

Fig. 1 shows the distances traveled by the TB sensor during the intervals defined above pooled over all available repetitions. The most salient feature is the greater distance covered by the tense /aː/-realisations, independent of the individual speaker. Apart from this, there is an apparent clustering of front and back vowels for speakers cg and df with respect to the proportion of the movement which takes place during the closure: This proportion increases abruptly from front to back vowels, whereby this trend is more prominent for speaker cg. Another interesting aspect is that this differentiation between front and back vowels differs for cg and df: The central vowels /øː/ and /œ/ cluster with the front vowels for speaker cg, and exhibit a genuinely central pattern for df. Both these patterns are confirmed in Fig. 2: It shows correlations between the x- and y-positions of TB in the middle of the preceding vowel (left and right panels respectively) and the distances traveled during oral closure. For cg, /øː/ and /œ/ again cluster with the front vowels and for df, /øː/ and /œ/ maintain a central position. For the speakers cg and df, the correlations between the distances and the x- and as well the y-positions are on a significant level, whereas none of them is significant for speaker jd. For all of our speakers though, /aː/ lowers the correlations between y-position and distance traveled during closure. This is in accordance with the long paths traveled during the production of /aː/ shown in Fig. 1 and suggests that the patterns observed for /aː/ are due to a joint vertical movement of tongue and jaw with large amplitude.

Figure 1: Distances traveled during the four different intervals described. The stack bars indicate from bottom to top: first stack, white, distance traveled during the first vowel; second stack, black, distance traveled during oral closure; third stack, gray, distance traveled between stop release and the onset of the second vowel; fourth stack, white, distance traveled during the second vowel. Upper case characters: lax vowels, lower case: tense vowels.

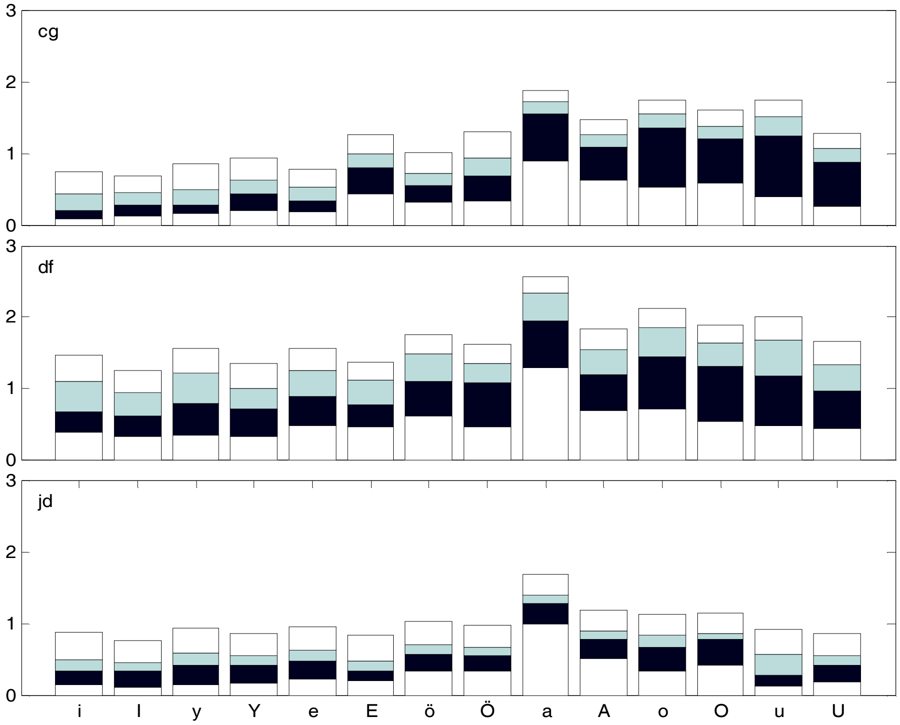

Fig. 3 depicts the calculated curvatures during oral closure. Negative signs indicate clockwise, positive signs counterclockwise movements. For more background on the curvature measure see Löfqvist et al. (1993) or Flash & Hogan (1985). The numbers below the boxes show the median curvature for the whole interval. The arrows above, below or inside the boxes show the dominant change in curvature for the interval, i.e. the most frequently occurring sign changes in the (up to 11) repetitions of the sequence. The data are grouped by tenseness, where the left panel shows the tense and the right panel the lax vowel contexts. In general, there is a higher probability of sign changes in curvature –as

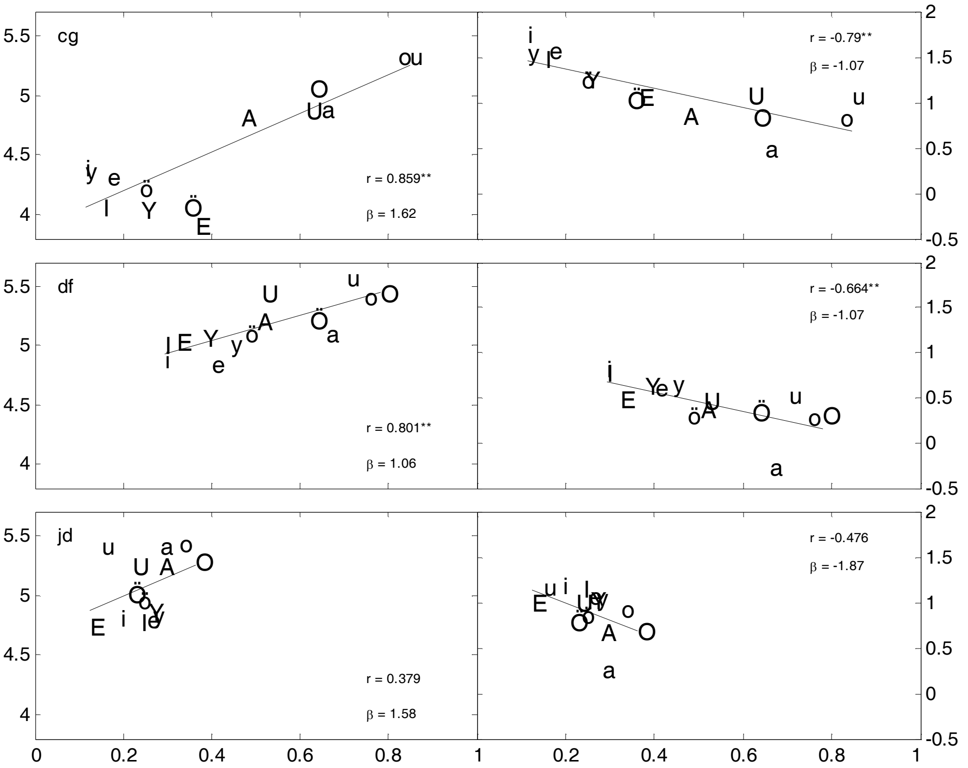

Figure 2: Correlations between the positions in the mid of the first vowel and the distances traveled during the velar stop. The left panel shows the correlation of distance and x-position and the right panel of distance and y-position Upper case characters: lax vowels, lower case: tense vowels.

indicated by the arrows in the figure- and more variability in curvature for the front vowels. Again, two of our speakers exhibit a more or less clear 'quantal' jump between front and back vowels: Speaker cg performs a counterclockwise movement for /oː/ and /uː/ in tense and lax vowel contexts. During the tense /aː/, TB performs a counterclockwise movement at closure onset, followed by a clockwise movement. /øː/ and /œ/ cluster with the front vowels. Speaker df exhibits the same 'quantal' pattern but with a different, almost categorical boundary between front and back vowels: For the tense vowel contexts, the movements go in a counterclockwise direction during closure for all back vowels and /øː/ and /œ/ . The same pattern is even observed for lax front vowel contexts as in /ʏ/ and /ɛ/. Here, the observation of a counterclockwise movement at closure onset and a clockwise movement at offset only holds for /ɪ/, whereas for the tense vowels, this behavior is firmly associated with the phonetic feature [-back]. This might be seen as an effect of the German vowel system with its more centralized lax vowels.

DISCUSSION

Taken together, the most demonstrative result of this study is a quite abrupt change in observed patterns on a front-back-distinction consistent with the studies by Perrier et al. (2003) or Alfonso & Baer (1982), which was only interrupted by some kind of outlying behaviour exhibited by /aː/, for which we consider vertical jaw movement as the main contributor. This could be further substantiated by applying jaw removement algorithms like e.g. the one proposed by Westbury et al. (2002) or by making use of more advanced fleshpoint methods like X-Ray Microbeam or the new EMA (Zierdt et al., 2000). However, the major part of our results are compatible with data by Munhall et al. (1991), who observed a reduced complexity in movement paths after algorithmic removal of the jaw. Another minor point to consider is concerned with the extraction of the dominant pattern as the sign pattern change most frequently occurring in the curvature plots: If one only reports the most frequently pattern, co-occurring patterns are suppressed in the curvature plots, although they might be of considerable incidence. We are envisioning the possibility of a more formal statistical treatment of co-occurrence patterns within different vowel contexts.

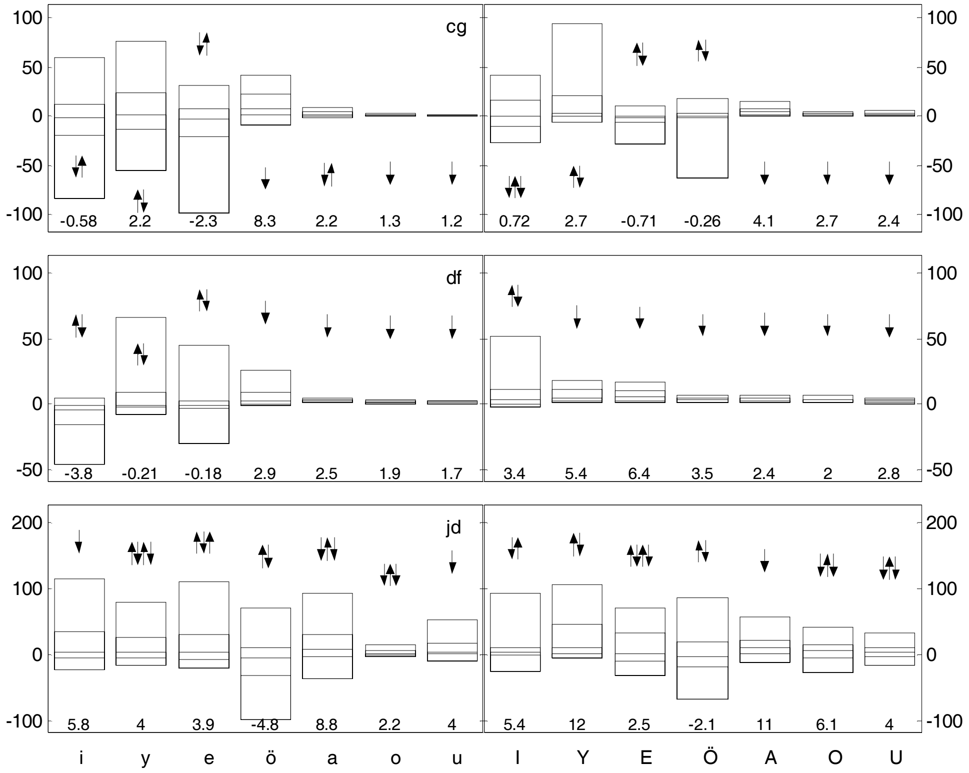

Figure 3: Percentile plot of curvatures of the tongue back sensor during consonantal occlusion. The horizontal lines represent the ntiles (95, 75, 50 (median), 25 and 5%) of the data. Further explanations see text. Upper case characters: lax vowels, lower case: tense vowels.

German distinguishes between palatal /ç/and velar /x/ -resp. uvular/χ/, see Kohler (1990)- voiceless fricative allophones determined by post-lexical rules depending on the preceding phoneme. For the stop system though, there exists no such phonological process. It often has been argued (cf. Keating & Lahiri, 1993, Pompino-Marschall & Mooshammer, 1997) that *"phonemic variation in place-of-articulation should be distinguished from coarticulatory/ assimilative allophonic variation"*. (Pompino-Marschall & Mooshammer, 1997, p.375). Our data provide counterevidence against a correlation of phoneme-membership and motor patterns: Two of our three speakers exhibit a more or less prominent quantal on the in back-front-dimension with no phonemic/ allophonic distinction present. Our finding of a strong back-front contrast can be interpreted in the lines of papers on motor control though, and, as the effect of asynchronous muscle commands. For the latter experienced empirical justification or rejection in velar consonant environments is missing. Hence, we envision to acquire physiological EMG data in combination with EMA movement data.

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