LATERAL AND CENTRAL TONGUE BRACING COORDINATION IN TYPICAL SPEAKERS AND COCHLEAR IMPLANT USERS

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ABSTRACT

This paper addresses two research questions: 1. how are lateral and central bracing coordinated in typical Croatian speakers as opposed to prelingually deaf cochlear implant (CI) users, and 2. how are bracing patterns related to hearing status and intelligibility in CI users.

Electropalatographic (EPG) and acoustic recordings of eight typical adult speakers and three CI users with different hearing status and speech intelligibility scores were included in this investigation. They were recorded in a communicative situation which facilitated spontaneous speech. Bracing patterns were analysed during Croatian words /ʃlapama/, which were repeated four times by each speaker. Central and lateral bracing were under competing demands during ʃl-sequences, while subsequent non-lingual sequences did not constrain the tongue directly.

The analysis showed that the coordination and coarticulation between central and lateral bracing differed between typical and atypical speakers. CI users with different hearing status and speech intelligibility scores differed in their bracing patterns.

Keywords: tongue bracing, cochlear implant (CI), coarticulation, electropalatography (EPG), Croatian.

1. INTRODUCTION

Tongue bracing has been described as active mechanical support of the tongue whereby the tongue is in contact with a rigid vocal tract surface during speech [6]. Initial research of this phenomenon focused on lateral bracing in a specific set of sounds, mostly from English [5, 11], while other languages, such as Argentinian and Cuban Spanish [9], Croatian [12] and German [4], received less attention in this respect.

Subsequent research showed that human tongues seek to be actively braced all the time during speech [2, 6] and that bracing could potentially constitute one of the universal postures during speech [14]. These investigations emphasized that bracing was not only a characteristic of one specific set of speech sounds, but rather that it was a pervasive and active strategy during speech. They also showed that bracing could be lateral and central - default bracing posture should be lateral and if lateral bracing was blocked (e.g. during lateral sound productions) or hard to achieve (e.g. during open vowels) then central bracing would take over.

There are several competing and complementary explanations of the purpose of such tongue movement strategy during speech: it is important for supporting the tongue during complex sound productions [18], for deceleration of the tongue during stop productions [4], for establishing proper aerodynamic and acoustic conditions [8] and for somatosensory feedback [6, 17].

Instrumental kinematic techniques such as imaging and palatographic techniques are often used in investigations of the bracing patterns. EPG seemed suitable for the present investigation, because EPG was designed to capture the timing of tongue-to-palate contact patterns during speech [19].

While previous research has recently focused on bracing as pervasive and active strategy in typical speech [6, 14, 20], the pervasiveness and the coordination of bracing patterns in atypical speech has remained largely uninvestigated. Since it is hypothesized that bracing is important for the achievement of acoustic goals and for somatosensory feedback [6, 8, 17, 18], bracing in the speech of persons with hearing impairments is of particular interest. Prelingually deaf CI users require special attention in this respect, because previously published studies showed that their coarticulation and coordination strategies are more atypical when compared with their postlingually deaf counterparts [7, 16]. Therefore, this paper addresses the following research questions: 1. how are lateral and central bracing coordinated in typical Croatian speakers as opposed to their prelingually deaf cochlear implant counterparts, and 2. how are bracing patterns related to hearing status and intelligibility in atypical speakers. EPG recordings of quasi-spontaneous speech are used to test the coordination and coarticulation between lateral and central bracing in words with ʃl-sequences followed by non-lingual sound sequences. Quasi-spontaneous speech provides an opportunity to analyse bracing patterns in a more natural communicative situation than reading sentence lists. Words with ʃl-sequences offer the opportunity to analyse coordination between lateral (constriction gesture in postalveolar fricative /ʃ/) and central bracing (apical gesture in alveolar lateral approximant /l/) when they are under competing demands. And finally, non-lingual sound sequence (/apama/ in word /ʃlapama/) provides the opportunity to investigate the pervasiveness of bracing in sequences where tongue is not the primary articulator.

2. METHOD

2.1. Participants and speech material

Speech material was obtained from the CROCO corpus [13] and two groups of speakers were included in this study: typical and atypical group. The group of typical participants comprised eight speakers (four female: T1, T2, T7, T8; four male: T3, T4, T5, T6) of Standard Croatian with no speech and hearing impairments, ranging in age between 21 and 24 (mean 22.4). Their speech was rated by five trained phoneticians and those eight speakers received the best scores for speech sound production and overall speech intelligibility among 105 candidates (average score was 6.3 on a scale from 1 to 7). In the second group of participants, three adult prelingually deaf CI users were included. These participants were selected for their different clinical characteristics (table 1) among seven prelingually deaf CI users. They had no other diagnosed impairments.

CI user	A1	A2	A3
Age	24	18	28
Age @ implant.	2	5.3	10
Age @ therapy	2	5.7	3.6
Speech audiogram	90% WR @ 45dB	70% WR @ 65dB	60% WR @ 50dB
N of speech errors	0	22	30
Intelligibility score [3]	8.5/10	5.9/10	3.2/10

Table 1: Clinical data for the three atypical CI speakers (A1, A2, A3). Speech errors were analysed via broad phonetic transcription of the whole recording session by two trained phoneticians.

Speech material was obtained through a dialogue situation, whereby each speaker was asked to describe the path through a maze and read signs at nine check-points marked throughout the path (Fig 1). Participants had to explain to the experimenter where the line was drawn on the map, because the experimenter had the same map, but the line marking the path was not shown. The goal was to explain to the experimenter the position of the line relative to the check-points. Each sign contained a two-syllable or three-syllable word and among these words was the target word for the present investigation ("šlapama" /'ʃlapama/, meaning "with slippers"). Each participant repeated the target word four times.

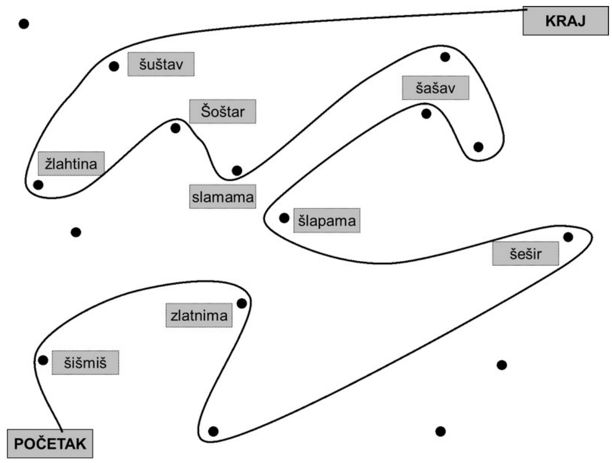

Figure 1: An illustration of the map description exercise for the elicitation of the quasi-spontaneous speech in this investigation.

2.2. Instrumentation and data preparation

EPG and acoustic data were recorded simultaneously using WinEPG system and Articulate Assistant software [1]. EPG data was collected at 100 Hz sampling frequency, while the sampling frequency for the acoustic signal was 44100 Hz. Reading style EPG palate called Mcyam plate [10] was used by all speakers.

Annotation was performed according to well established acoustic criteria. The beginning of the postalveolar fricative /ʃ/ was marked when high frequency noise started. The end of the fricative and the beginning of the dentoalveolar lateral approximant /l/ was marked when high frequency noise stopped and voicing of the approximant started. The end of the approximant and the beginning of non-lingual sequence /apama/ was annotated when the frequency and intensity discontinuity in the harmonic sound was observed.

2.3. EPG indices and data analysis

Central and lateral bracing were analysed at mid-point of each annotated region and also throughout every annotated region at a predetermined number of equally spaced sample points. The analyses were performed at mid-point in order to analyse overall bracing pattern at its least coarticulated point for each annotated region. The analyses were also done during the whole annotated region in order to analyse the bracing patterns dynamics. In order to average productions of different durations and to visualize them, the duration of each annotated region was normalised via equally spaced sample points. The number of sample points (NSP) was determined according to the following equation:

$$(1) \qquad NSP = \frac{t\_min}{10}$$

where t_min was the duration of the shortest annotation regions in milliseconds (/ʃ/=119ms in typical speakers and 107ms in CI users; /l/=37ms; /apama/=332ms in typical speakers and 404ms in CI users) and 10 represented the number of milliseconds between successive EPG frames, determined by the EPG sampling frequency (100 Hz).

Central bracing was quantified by measuring the dentoalveolar area weighted index (the number of activated electrodes in the anterior two rows of electrodes divided by the total number of electrodes in dentoalveolar region). Lateral bracing was quantified by measuring the lateral contact area weighted index (the number of activated electrodes in the two outermost columns of electrodes at each side of the palate divided by the total number of electrodes in that region) (Fig 2). The significance of the difference between central and lateral bracing, as well as between speakers was tested via Repeated Measures ANOVA.

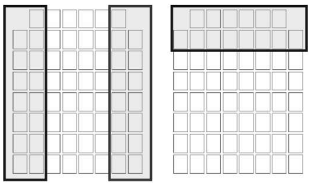

Figure 2: An illustration of the EPG palate areas for the calculation of lateral (left) and central (right) bracing.

3. RESULTS

The results of the central and lateral bracing at mid-point of each annotated region (/ʃ/, /l/, /apama/) show that the coordination of lateral and central bracing is different in typical speakers when compared with atypical speakers (Fig 3). In typical speakers lateral bracing is stronger than central bracing during /ʃ/, while the opposite can be seen during /l/ and finally during the non-lingual sequence /apama/ central bracing equals zero and lateral bracing is equal to the level it showed during /l/. Differences between lateral and central bracing in typical speakers are statistically significant (F(1, 7)=6.927, p=0.03), with the significant interaction between the annotated region and type of bracing (F(2, 6)=38.688, p=0.00).

In atypical speakers the coordination between lateral and central bracing is different from the coordination pattern observed in typical speakers, whereby lateral bracing is higher than central bracing in all annotated regions. The switch between predominantly lateral bracing in /ʃ/ and predominantly central bracing in /l/, which can be observed in typical speakers, is absent in CI users. The difference between lateral and central bracing is not statistically significant in atypical speakers (F(1, 2)=1.757, p=0.32) and there are no significant interactions between the annotated region and bracing type (F(2, 1)=0.295, p=0.79).

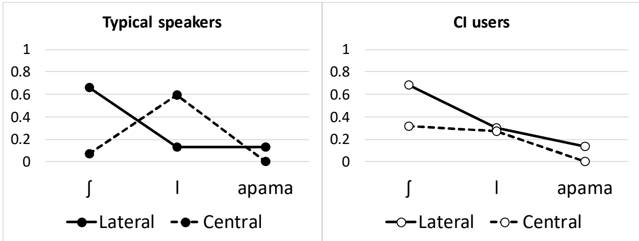

Figure 3: Lateral and central bracing in three annotated regions (/ʃ/, /l/, /apama/) in typical speakers (left chart) and CI users (right chart).

Figures 4 and 5 show central and lateral bracing coordination during normalized durations of each annotated region for each speaker. The results for the typical speakers (Fig 4) show that lateral bracing starts to decrease, while central bracing starts to increase at the end of /ʃ/ or during /l/. Central bracing peaks during or immediately after /l/, while lateral bracing remains low. During non-lingual sequence there are noticeable differences between typical speakers, whereby some speakers show high amount of lateral bracing (e.g. T1, T7) and some speakers have very low lateral bracing (e.g. S3, S5), while some appear to have their tongues completely unbraced during initial portion of the non-lateral sequence (e.g. S4, S6).

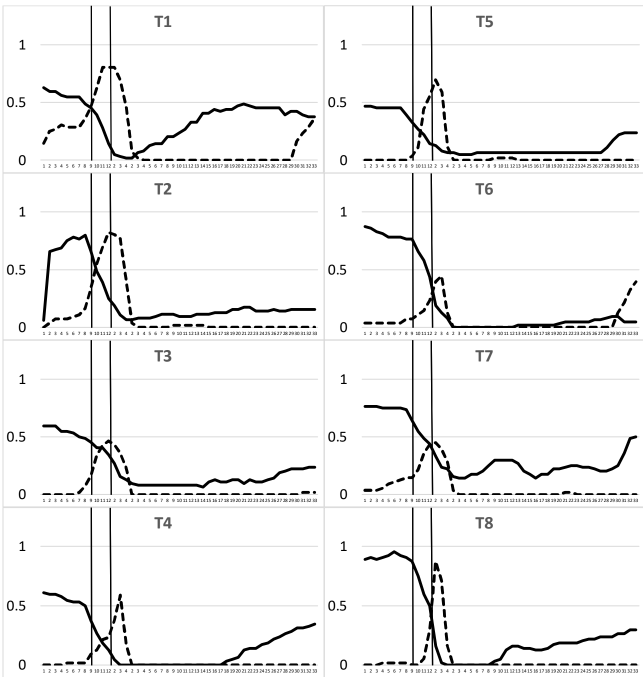

Figure 4: Lateral (solid line) and central (dashed line) bracing during three annotated regions (/ʃ/, /l/, /apama/) at equally spaced sample points in typical speakers (T1-T8). Vertical lines mark annotation boundaries.

The results for the atypical speakers (Fig 5) reveal differences in bracing patterns between the three CI users. Speaker A1 shows patterns which are comparable to those observed in typical speakers, while the other two atypical speakers have noticeably different patterns. In speakers A2 and A3 there is no typical switch between predominantly central and predominantly lateral bracing at the point of transition between the fricative and the lateral approximant. Furthermore, A3 shows very low amount of contact in both lateral and central zone, with almost no difference in lateral pattern throughout the whole word.

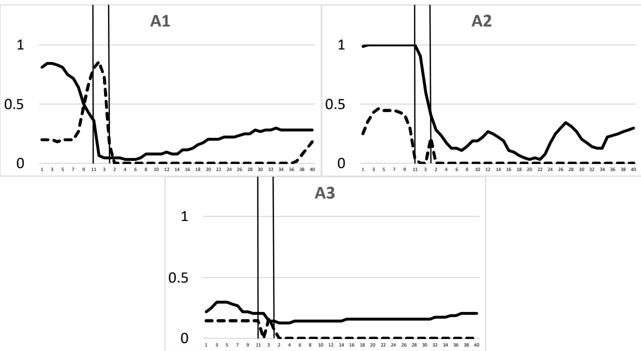

Figure 5: Lateral (solid line) and central (dashed line) bracing during three annotated regions (/ʃ/, /l/, /apama/) at equally spaced sample points in CI users (A1-A3). Vertical lines mark annotation boundaries.

4. DISCUSSION

The results of the present study show that the coordination between central and lateral bracing differs between typical speakers and CI users, whereby typical speakers have significantly different amount of central versus lateral bracing, while this difference is very low and non-significant in CI users. The results also reveal differences in bracing pattern dynamics among CI users and those differences coincide with their different clinical data (table 1).

The results of the analysis of typical speakers are consistent with previously published findings [5, 6, 14]. The analysis shows that typical speakers have their tongues braced throughout the whole target word and that they share similar coordination pattern for central and lateral bracing. Importantly, this investigation shows that when lateral and central bracing are under competing demands, a consistent bracing coordination pattern emerges. At the point of transition between /ʃ/ and /l/, lateral bracing starts to decrease, while central bracing increases. The timing of the switch between lateral and central bracing maxima differs somewhat between speakers. It occurs either at the acoustic boundary between /ʃ/ and /l/ (T1), or during /l/ (T2, T3, T4, T5, T7) or at the acoustic boundary between /l/ and /apama/ (T6, T8). This is consistent with the DAC model of coarticulation [15], which predicts similarly high coarticulation resistance in anterior lingual fricatives and lateral sounds (with fricative gesture showing more resistance in most speakers analysed here). This finding together with the finding that lateral bracing continues even during the non-lingual sequence confirms previous findings from other languages that lateral bracing is primary tongue-bracing strategy [6]. It should be noted that T4 and T6 have their tongues completely unbraced during initial phases of the non-lingual sequence, which does not support the claim that the tongue is always braced. One possible reason for this lack of bracing might be that lateral bracing is not the default form of tongue-bracing for these speakers and that bracing occurs elsewhere during those sections of /apama/ [6].

The analysis of bracing pattern dynamics in CI users builds upon previously documented results and also shows some novel findings. All three CI users show constant and uninterrupted bracing during the whole word. However, the three CI users differ in the coordination of central and lateral bracing and this difference is reflected in their clinical data (see table 1). A3 has highest age at implantation, poorest results of the speech audiogram, lowest intelligibility score and highest number of speech sound errors. She shows very low amount of overall bracing and very little change in the bracing pattern during the transition between the fricative and the lateral approximant. A2 has lower age at implantation and better overall hearing and intelligibility results. Her EPG results show that the overall amount of bracing is comparable to the amount of bracing in typical speakers, but similarly to A3, there is no switch between lateral and central bracing maxima. A1 has earliest age at implantation, best speech audiogram results, highest intelligibility score and no speech sound errors. Her bracing patters are almost identical to those in typical speakers (e.g. T1, T2). Since the coordination between lateral and central bracing might be related to speech intelligibility, these results have important potential implications for speech therapy and should be investigated further.

The limitations of this study should be kept in mind. The number of speakers included in this study is relatively low and some aspects of tongue bracing cannot be captured via EPG [6].

5. ACKNOWLEDGEMENTS

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