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Adult speakers' tongue-palate contact patterns for bilabial stops within complex clusters

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Abstract

Previous studies using Electropalatography (EPG) have shown that individuals with speech disorders sometimes produce articulation errors that affect bilabial targets, but currently there is limited normative data available. In this study, EPG and acoustic data were recorded during complex word final /sps/ clusters spoken by 20 normal adults. A total contact (TC) index measured amount of tongue-palate contact during clusters in words such as 'cri<u>sps</u>'. Bilabial closure was inferred from the acoustic signal. The TC profiles indicated that normal adults hold their tongues in a steady /s/-like position throughout the cluster; most speakers (85%, n=17) had no significant difference in TC values during bilabial closure compared to flanking fricatives. The results are interpreted as showing that normal speakers produce double bilabial-alveolar articulations for /p/ in these clusters. Although steady state TC profiles were typical of the group, absolute TC values varied considerably between speakers, with some speakers having up to three times more contact than others. These findings add to our knowledge about normal articulation, and will help to improve diagnosis and treatment of individuals with speech disorders.

Introduction

In many languages, including English, there are no phonological constraints on tongue position during bilabial consonant production (e.g. Recasens, 1999). However, this does not mean that there is no, or minimal, tongue-palate contact during bilabials in some contexts. Previous studies using various methodologies and different languages have shown that the amount of contact during bilabials in normal adult speech varies greatly, depending on the phonetic context (Carney & Moll, 1971; Gay, 1977; Engstrand, 1988; McAllister & Engstrand, 1991; Lindblom, Sussman, Modarresi & Burlingame, 2002; Gibbon, Lee & Yuen, 2007a; Zharkova, 2007). In one electropalatographic (EPG) study by Gibbon et al. (2007a), the amount of tongue-palate contact was calculated in the consonants /p/, /b/ and /m/ in vowel-consonant-vowel sequences, in eight English speakers with no speech disorders. The results showed that at the middle of the bilabial closure these consonants had between 15% and 45% total EPG contact, depending on the vowel environment. The contact was the highest when the consonants were surrounded by two vowels /i/, and the lowest when one of the surrounding vowels was /a/.

There is also evidence from the literature on consonant clusters that lingual consonants produce strong coarticulatory effects on bilabial consonants. Recasens, Fontdevila, Pallarès & Solanas (1993) conducted an EPG study of vowel-consonant-consonant-vowel sequences in Catalan, where /p/ was one of the consonants in the cluster, and the other consonant was /t/ or /k/. They demonstrated a significant effect on tongue-palate contact pattern in a bilabial consonant from lingual consonants. There is, to our knowledge, no EPG data on lingual coarticulation in complex consonant clusters involving bilabial consonants, such as /sps/. Given that /s/ is a lingual consonant involving a significant amount of tongue-palate contact for its production (e.g. McLeod, Roberts & Sita, 2006), it can be predicted that there will be strong lingual coarticulatory effects on bilabials in complex consonant clusters containing /s/.

Past studies of the tongue behaviour during a bilabial stop between two identical vowels, using different experimental techniques, have observed the 'trough effect', i.e. discontinuity in coarticulation between the two vowels (e.g. Bell-Berti & Harris, 1974; Gay, 1974; Engstrand, 1988; Engstrand, McAllister & Lindblom, 1996; Lindblom et al., 2002; Fuchs, Hoole, Brunner & Inoue, 2004; Vazquez Alvarez, Hewlett & Zharkova, 2004). In EPG studies, the trough was manifested by a decrease in the number of activated electrodes between the two vowels (e.g. McAllister & Engstrand, 1991; McAllister & Engstrand, 1992; Engstrand et al., 1996). Various explanations have been proposed, such as the syllable boundary effect resulting in discontinuity in motor programming (Gay, 1978); relaxation of vowel-related tongue position during the bilabial (e.g. Engstrand, 1988); or aerodynamic constraints on producing bilabial stops (e.g. Fuchs et al., 2004). It is not known whether the trough effect occurs in /sps/ clusters. This study will provide empirical evidence from EPG data.

Complex consonant clusters can be expected to be particularly problematic for speakers with speech disorders because elements of the cluster, such as those involving lip and tongue movements, need to be controlled very precisely in time and space (e.g. Greenlee, 1974; Levelt, Schiller & Levelt, 2000; McLeod, van Doorn & Reed, 2001). A range of consonant clusters is always included in perceptually based standardized assessments of articulation and phonology, such as the Edinburgh Articulation Test (Anthony, Bogle, Ingram, & McIsaac, 1971), the Goldman Fristoe Test of Articulation (Goldman & Fristoe, 2000) and more recently the Diagnostic Evaluation of Articulation and Phonology (Dodd, Hua, Crosbie, Holm, & Ozanne, 2003). However, the overall number and range of clusters tested is limited. Likewise, complex clusters are included in EPG assessments, but the focus tends to be on lingual clusters such as /kt/, /kl/, /gs/ and /st/ rather than on those involving bilabials, or complex clusters.

To determine exactly what constitutes abnormal patterns for bilabial production in disordered speech, it is necessary to gather normative data from typical speakers (e.g. Gibbon, 1999). Bilabial sounds are sometimes produced as articulation errors in speakers with speech disorders. For example, speakers with cleft palate have been reported to produce bilabial-lingual double articulations for bilabial targets /p/, /b/, and /m/ (Gibbon & Crampin, 2002). These abnormal articulations involved speakers producing abnormally high amounts of contact during the bilabial closure phase. It is important to establish the characteristics of tongue-palate contact patterns in typical speakers in order to be able to differentiate between typical and disordered patterns during bilabial closure in a range of different phonetic contexts, including complex consonant clusters.

The current study aimed to gather data from normal adult speakers with the purpose of measuring the extent of tongue-palate contact during bilabial closure in /sps/ clusters. This cluster was selected on the basis that it was not only complex, but also because the surrounding fricatives made it possible to infer /p/ closure from the acoustic waveform. The study set out to determine whether there was evidence of strong coarticulatory effects of /s/ on the /p/ in normal speakers. One of the aims was to find out whether trough effect occurs in /sps/ clusters in non-disordered adult speech.

Method

Participants

The participants were 20 normal English adult speakers, five males and 15 females, ranging in age from 25 to 63 years, with an average age of 45 years. The participants were either members of staff at Queen Margaret University, Edinburgh, or they were speech and language therapists who worked in the UK and had artificial palates because they used EPG in their clinical work. Participants reported no history of speech, language or hearing difficulties. They were all native speakers of English and had a variety of accents. An institutional ethics board approved the study and consent was obtained from participants. The consent procedure did not inform participants about the purpose of the study, so they were unaware of how their EPG data would be analyzed in the experiment.

Instrumentation

To obtain the EPG data we employed the WinEPG system (for the description of the artificial palate, see Hardcastle & Gibbon, 1997; for more details on the method used in this study see Gibbon et al. 2007a) and its associated software for data capture and analysis (Articulate Instruments Ltd., 2007) at a sampling rate of 100 Hz. EPG was synchronized with acoustic data, sampled at 22.05 kHz. In order to record the dynamic tongue-palate contact patterns, each speaker had an artificial palate individually constructed to fit against the hard palate. The palate contained 62 electrodes, placed in eight horizontal rows according to well-defined anatomical landmarks. All participants were familiar with wearing an EPG palate, and were instructed to acclimatize to its presence for up to 30 minutes prior to the EPG recording.

Speech material

Speakers read out loud sentences containing six words containing /sps/ clusters (clasps, crisps, grasps, lisps, wasps and wisps), see Appendix 1. Each sentence was spoken three times. The total number of recorded tokens was 360, but 46 (13%) tokens were excluded from subsequent EPG analysis; 44 were excluded because there was no identifiable closure and burst evident on the acoustic waveform, and a further two were excluded due to a technical fault in the EPG recording.

EPG annotations

For each /sps/ token included in the EPG analysis, three annotations were added. Each of these annotations was placed according to events identified on the acoustic signal. One annotation was placed over the closure period of /p/, identified as a silent period on the acoustic signal. The duration of both sibilants (/s1/ and /s2/) in the /sps/ cluster was measured. Onset of /s2/ was measured directly at the end of the stop burst. An interval corresponding to exactly one half of the shortest sibilant was measured from /p/ closure onset into /s1/, and an annotation was placed at the end-point of the interval. An interval of the same length was measured from /p/ closure offset into /s2/, and an annotation was also placed at the end-point of the interval. Placement according to these criteria ensured the same distance between /s1/ and /p/ closure onset, and between /p/ closure offset and /s2/. An illustration of the annotations is given in Figure 1.

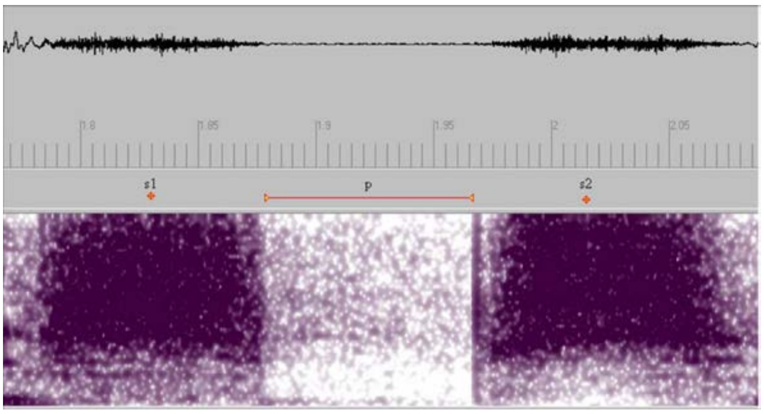

Figure 1. Illustration of the three (/s1/, /p/, /s2/) annotations placed on a /sps/ cluster.

EPG analysis

The purpose of the EPG analysis was to identify the amount of tongue contact during bilabial closure and to compare this with contact during the flanking /s/ targets. Specifically, the analysis aimed to identify coarticulation, with evidence for a strong effect being /s/-like tongue-palate contact remaining constant during the entire cluster sequence. An EPG index – total contact (TC) – measured the amount of tongue-palate contact at the three annotation points. TC was calculated as the percentage of contacted electrodes across the whole of the palate. TC was measured at the first fricative in the /sps/ sequence (/s1/), the second fricative in the sequence (/s2/), and the mean TC across all EPG frames during /p/ closure. For each speaker separately, these TC values were compared, using Univariate ANOVAs to identify differences in amount of contact between /p/ and flanking /s/ targets. The cut-off value for detecting significant differences was set at 0.05. TC values were calculated for ten equally spaced time points during the /p/ closure and these values plotted for each subject, together with TC values for /s1/ and /s2/.

Results

Total contact (TC) values during /sps/ clusters for all participants are shown in Figure 2. The first observation is that most speakers have a relatively constant amount of EPG contact throughout the clusters, as evidenced by flat TC profiles. These flat profiles suggest steady state tongue positions, with similar amounts of EPG contact during /p/ and flanking /s/ targets. Statistical evidence supports this view; the majority of speakers (85%, n=17) showed no significant difference in TC for /p/ compared to either s1 or s2. For one speaker, TC values during /p/ were significantly lower than both surrounding consonants (the difference between /s1/ and /p/ was significant at the 0.01 level; the difference between /s2/ and /p/ was significant at the 0.001 level). This is indicative of the trough effect (an example of this speaker's EPG patterns can be found in Figure 3). Two further speakers exhibited a significant difference only between /p/ and /s2/ ($p < 0.05$ in both speakers).

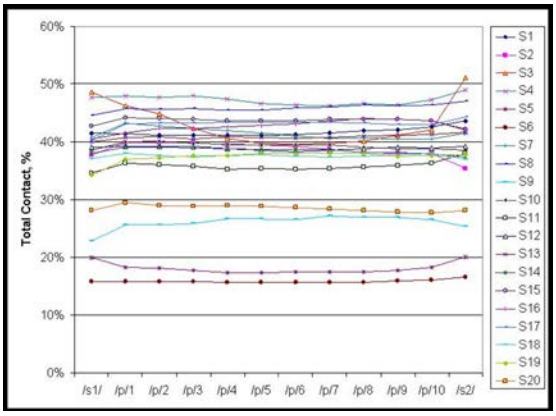

Figure 2. TC profiles for 20 participants (S1 – S20). The first value on the *x* axis represents the time point in /s1/. The ten middle values on the *x* axis represent ten equally spaced time points during the /p/ closure. The last value on the *x* axis represents the time point in /s2/.

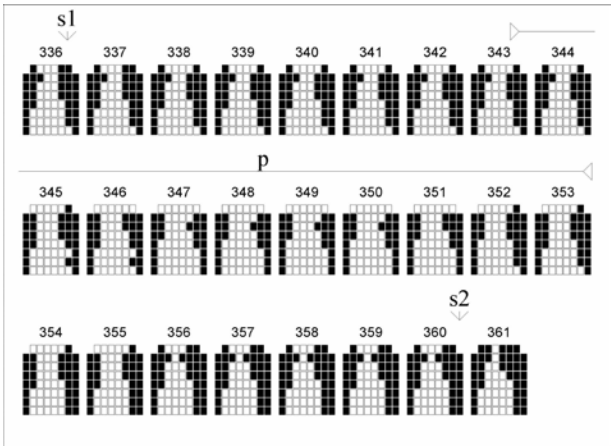

Figure 3. Dynamic EPG patterns for one exceptional speaker who had lower TC values for /p/ compared to flanking /s/ consonants during the cluster (indicative of a trough effect).

The second notable feature of the TC values displayed in Figure 2 is that there is considerable variation between speakers in the amount of contact produced during /sps/ clusters. Speakers with the highest TC values have two or even three times more contact compared to those with the lowest TC values (the highest values are around 47% compared to the lowest around 15%).

The TC profiles indicate that for most speakers, EPG patterns remain relatively constant during /sps/ clusters. In other words, speakers keep their tongues in a steady position throughout the sequence, producing what can be interpreted as a double bilabial-alveolar articulation during /p/ targets. Although TC values indicate amount of contact during these sequences, they provide no information about what the EPG patterns actually look like during the bilabial closure. These details are shown in Figure 4, which presents composite patterns for all the EPG data that occurred during bilabial closure for the 20 participants. This figure shows that a full articulatory oral constriction occurs during bilabials in /sps/ clusters and that this contact resembles an /s/-like configuration. The figure also further illustrates the finding from Figure 2, that some speakers have a high overall amount of contact (e.g. TC values around 50% in S4 & S8) while others have much lower amounts (e.g. TC values around 15% in S5 & S6).

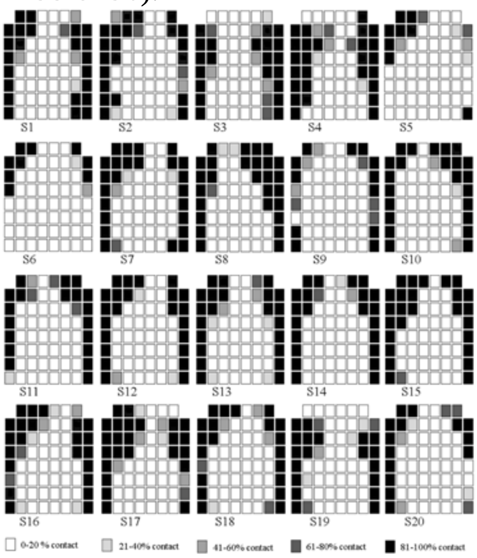

Figure 4. Average TC patterns over the /p/ closure for each speaker.

Discussion

This is the first study to investigate tongue-palate contact during bilabials in complex clusters. The results show that most normal adult speakers maintain a steady /s/-like tongue configuration throughout the cluster sequence. The overwhelming majority of speakers had no significant change in the amount of EPG contact during /p/ compared to flanking /s/ consonants, i.e. there was a strong lingual coarticulatory effect on /p/ exerted by the two sibilants. Trough patterns in EPG contact throughout the /sps/ sequence were generally not observed; only one speaker displayed a trough. One interpretation of this finding is that the tongue position moves minimally during the bilabial stop in this type of cluster because there are no requirements to achieve a posture different from either flanking fricative consonants. The resulting effect is a double bilabial-alveolar articulation evident during the /p/ target. In other words, /p/ demonstrates in this context maximal lingual coarticulation and is an example of the principle of economy of effort in producing speech gestures (Lindblom, 1983).

The location of EPG contact in /p/ during /sps/ clusters is different from contact described as occurring when bilabials are in vowel contexts. A previous study conducted by Gibbon et al. (2007a) found that EPG contact during bilabials in all vowel contexts was relatively low (0-10%) in the most anterior region of the palate (EPG row 1) with contact increasing gradually towards the back of the palate. EPG row 7 in the palatal region had the highest amount of contact (37-60%). This is in contrast to the location of contact evident in /p/ in /sps/ clusters. The contact in /p/ observed in the present study is concentrated in the lateral and anterior regions of the palate during /p/ closure, with minimal contact in the palatal and velar regions. Across-speaker similarities in the tongue-palate contact location and in the flatness of the Total Contact profiles throughout the /sps/ sequence are important findings. These findings have implications for determining the effects of speech impairments on tongue-palate contact. For example, a full closure across the palate or an extensive contact in the palatal and/or velar region could be considered deviations from typical patterns.

Tongue-palate contact during the /sps/ sequence for all speakers in this study was less than 52%. A relatively large extent of across-speaker variability in the amount of contact was observed. Some speakers had up to three times more contact than other speakers. This variability in the overall amount of contact is consistent with other studies which found that some adult speakers without speech disorders had two or three times more contact than other speakers; for example, see Gibbon et al. (2007a), for bilabial consonants in consonant-vowel-consonant sequences; Liker & Gibbon (2008), for velars; Gibbon, Yuen, Lee & Adams (2007b), for alveolar stops; Liker, Gibbon, Wrench & Horga (2007), for affricates. Gibbon & Wood (to appear) claim that “the precise relationship between speaker characteristics (e.g., anatomy, articulatory settings, speech style) and EPG data is unknown at present”. There are several possible reasons for the across-speaker variability in the amount of contact. Some explanations have been suggested in Gibbon & Wood (to appear); for example, inter-speaker differences in palatal shape; long-term jaw and tongue settings; the degree of articulatory effort exerted by different speakers. Differences between regional accents of English might also be considered as a potential explanation for some across-speaker variation in the amount of contact; for example, accents with higher vowels for particular targets could have more contact, and that would have affected the contact pattern throughout the /sps/ sequence. However, we do not know of any EPG studies reporting evidence that different accents affect amount of contact.

Although the acoustic records showed bilabial closure in 87% of tokens, an auditory analysis (conducted by the first author) of all /sps/ tokens identified a lower percentage as having a perceptually identifiable closure phase and a burst. Perceptually, only just over half (60%) had an identifiable closure plus burst; a minority (35%) were judged as consonant sequences with a bilabial fricative substituting for /p/ (i.e. [s÷s]). A small number (4%) of tokens were realised as a long [s], substituting for the whole /sps/ target cluster; and 1% had no audible fricative before /p/ closure (i.e. [ps]). Importantly, listeners find this variation acceptable.

Taken together, the results show that normal production of complex clusters, such as /sps/, requires strong coarticulation, which could serve as a useful benchmark measurement of speech motor skill, against which to assess relatively subtle deviances from adult performance. Indeed, complex clusters could be systematically integrated in standard speech and language therapy assessments to test, for example, children's maturity in speech motor control, or the extent of loss of fine motor control in adults with acquired neurological disorders. To date, at least for English, only a small subset of clusters are included, and only in a few of the available speech and language assessments; for example, word-initial /skw/ and /spl/ in the DEAP's Phonology Assessment subtest (Dodd et al., 2003). It has been claimed in the literature on childhood maturation that typically developing children demonstrate more adult-like coarticulatory patterns with increasing age (e.g., Kent 1983; Thompson & Hixon 1979; Nittrouer, Studdert-Kennedy & Neely 1996; Zharkova, Hewlett & Hardcastle 2008a). Based on the previous literature, we could expect that coarticulatory patterns in /sps/ sequences will develop towards adult-like patterns with age. Some of our pilot data suggest that by the age of seven years old English-speaking children are capable of producing adult-like EPG patterns during /sps/ clusters (Zharkova, Schaeffler & Gibbon, 2008b). More data is needed to establish how much individual variation in contact patterns occurs in typical development.

The results of the present study provide quantitative information that could be used as a basis for a larger investigation. Other complex clusters could be investigated, such as those in wasp tail, or desks, to determine what coarticulatory effects operate in those clusters. Other instrumental techniques for analyzing articulation, for example, ultrasound, will need to be employed, in order to have a direct representation of tongue contour dynamics.

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Appendix 1.

The speech material containing the target /sps/ clusters. The target words are underlined.

Chrissy talks to people in Spean Bridge about lisps.
He clasps his hands and bites his lips.
Her speech sounds lispy but she still talks about wasps.
She grasps the neeps and crisps before they disappear.
Those yellow wisps of hair make him look all waspy.

Figure captions