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Using EPG data to display articulatory separation for phoneme contrasts

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Abstract

A recurring difficulty for researchers using electropalatography (EPG) is the wide variation in spatial patterns that occurs between speakers. High inter speaker variability, combined with small numbers of participants, makes it problematic (i) to identify differences in tongue palate contact across groups of speakers and (ii) to define "normal" patterns during visual feedback therapy. This paper shows how graphing EPG data in terms of articulatory separation of phoneme contrasts reduces these two problems to some extent. The graphs emphasise the importance of establishing the presence and extent of separation, as revealed in the EPG data, for phoneme contrasts produced by speakers. Separation graphs for contrasts /i/ - /u/, /s/ - /ʃ/ and /t/ - /k/ are presented using EPG data from adults and children with typical speech and those with speech disorders. When used in conjunction with acoustic and auditory perceptual analyses, it is proposed that representing articulation data in terms of separation will prove useful for a range of clinical and research purposes.

Introduction

Electropalatography (EPG) has become a popular phonetic and clinical tool for recording one aspect of articulation, namely tongue palate contact, during continuous speech (for recent descriptions see Gibbon & Wood, 2010; McLeod & Singh, 2009). The individual palatograms – raw data – recorded during continuous speech are unwieldy and for data management purposes, researchers have developed various reduction indices (e.g., percent contact, centre of gravity COG; coarticulation index; asymmetry index; lateral index) that measure phonetically and clinically relevant aspects of articulation. However, the wide variation in contact for typical speakers creates difficulties for researchers and clinicians when comparing data between speakers.

A number of recent EPG studies confirm that, even in typical adults and children, there is a wide variation between speakers in EPG index values for any given target sound (Cheng, Murdoch, Goozee, & Scott, 2007; Gibbon, Lee, & Yuen, 2007; Gibbon, Yuen, Lee, & Adams, 2007; Liker & Gibbon, 2008; Liker, Gibbon, Wrench, & Horga, 2007; McLeod, Roberts, & Sita, 2006). For example, Gibbon, Yuen, et al. (2007) conducted a study on normal alveolar stops and found that although all the speakers produced similar "horse-shoe" spatial patterns for these targets, some speakers had more than twice as much contact as others. Studies of typical velars (Liker & Gibbon, 2008), bilabials (Gibbon, Lee, & Yuen, 2007), vowels (Gibbon, Lee, & Yuen, 2010) and affricates (Liker et al., 2007) had similar results insofar as some speakers had twice or three times more contact than others. One explanation for this variation is that the amount of contact relates to inter speaker differences in palatal shape. More specifically, individuals with flatter palates tend to have higher overall amounts of contact than those with more steeply arched palates (Hiki & Itoh, 1986). There are other possible explanations as well. It may be the case that the amount of contact reflects speakers' long-term jaw and tongue settings. In other words, speakers may produce high amounts of contact when they articulate because they have overall raised habitual settings. Likewise speakers with low amounts of contact have low settings. Another possible explanation is that the degree of articulatory effort exerted by speakers influences the amount of contact. Here, speakers with higher overall amounts of contact exert more tongue-palate pressure, as a result of increased effort, compared to speakers with lower amounts of contact.

The high variability in articulation between speakers is compounded by the fact that EPG studies tend to have small numbers of participants. Studies with larger groups, such as 48 participants reported by Cheng et al. (2007) and 20 participants reported by Zharkova, Schaeffler and Gibbon (2009) are rare. An alternative approach, which avoids comparing EPG patterns, or mean index values across speakers, is to compare differences between articulation for phoneme contrasts within speakers. The reasoning is that during a recording

session, conditions such as an individual's palate shape, tongue setting, overall rate and style of speech will remain relatively constant for the individual. This constancy allows for more meaningful comparisons to be made about sounds and sound contrasts produced by each speaker. In this approach, absolute index values are less relevant than the existence, direction and extent of articulatory separation between phonemes in a contrast.

The current study seeks to expand the theme of intra speaker comparisons in order to overcome the difficulties of inter speaker variability. Instead of making comparisons across similar sounds, such as /t/ and /d/, the current paper will illustrate the advantages of comparing contrasting sounds in order to establish differences, or separation, between them. In the sections that follow, examples of articulatory separation graphs are presented for the vowel and consonant phoneme contrasts /i/ – /u/; /s/ – /ʃ/; and /t/ – /k. These contrasting pairs are of high potential interest in EPG studies because they are articulated differently and they are vulnerable to articulatory errors, for example, in individuals with cleft palate (Gibbon, Smeaton-Ewins, & Crampin, 2005). The graphs are based on data collected in previous EPG studies, which have recorded data from adults and children with typical speech, and from children with cleft palate.

Example 1: /i/ – /u/ separation in adults with different accents

Figure 1 shows mean percent contact for multiple repetitions of the vowels /i/ and /u/ produced by 10 adults with typical speech, which were recorded as part of an EPG study on vowels by Gibbon et al. (2010). Percent contact is a straightforward measure that calculates the percentage of contacted electrodes across the whole palate. These authors found that contact for these vowels was located in the posterior, lateral regions of the palate forming a posterior central groove or channel that was free of contact. The vowel /i/ had more contact than /u/ due to lateral contact for /i/ extending further towards the anterior region of the palate.

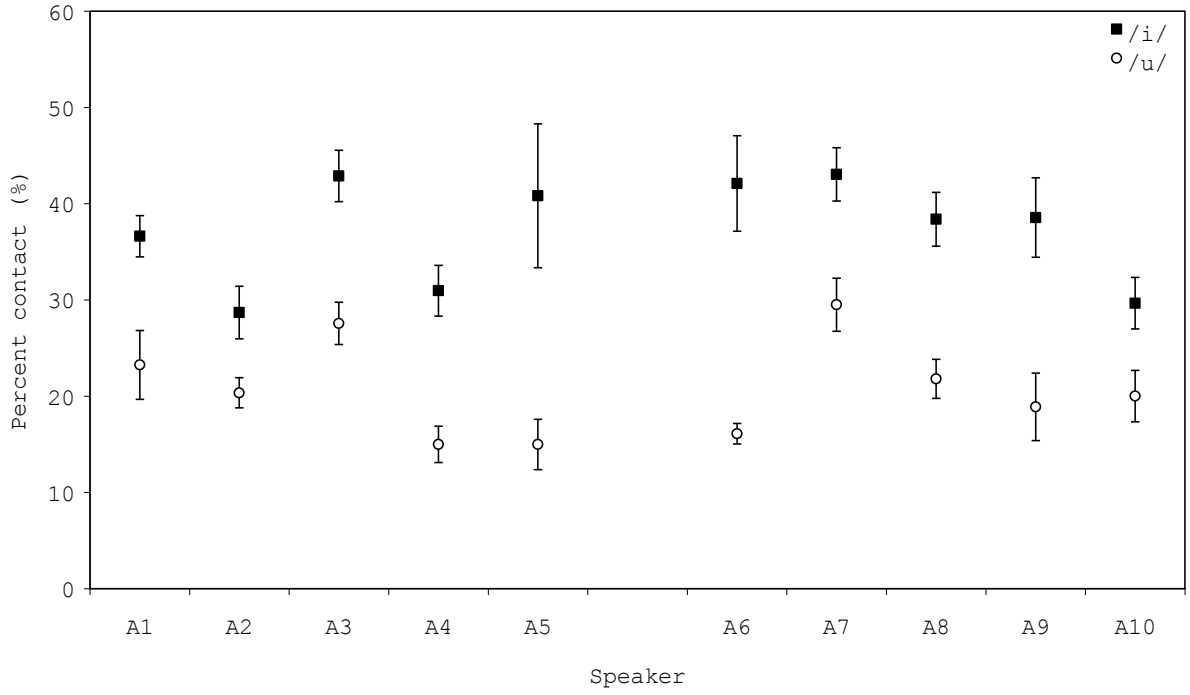


Figure 1. Total percent contact and variability (+/- 1SD) for 10 speakers for vowels /i/ and /u/. The five speakers to the left of the graph have a Southern British accent, those on the right have a Scottish English accent. (Data from study by Gibbon, Lee and Yuen, 2010)

For each speaker shown in Figure 1, the graph displays the expected finding that mean contact for /i/ is higher than for /u/. The figure shows clearly that each speaker maintains distinct articulations for these target sounds. In other words, there is clear articulatory separation between them, with no overlap. The extent of separation between the vowels varies considerably between speakers, however, with A6 having the largest (26%) difference between the mean percent contact for /i/ and /u/ and A2 having the least (10%). The figure illustrates that a straightforward comparison of mean percent for /i/ or /u/ across speakers is not particularly useful because of the wide inter speaker variability. For instance, A2's mean percent for /i/ is almost identical to A3's mean for /u/, although both speakers have the same accent.

Example 2: /s/ – /ʃ/ separation in adults and children with typical speech

The data shown in Figure 2 are from a study that used COG to measure place of articulation (Geraghty & Gibbon, 2008). The COG is a well-established general measure of place of articulation in the region of the hard palate (Gibbon, Hardcastle, & Nicolaidis, 1993). The index gives a single numerical value representing the position of the greatest concentration of activated electrodes across the palate in the front/back dimension. A high value represents a forward, i.e. anterior, place of articulation, whereas a low value reflects a posterior place of articulation. For the alveolar and post-alveolar contrast, COG for /s/ is predicted to be higher than for /ʃ/ because /s/ is produced at a more forward place of articulation compared to /ʃ/.

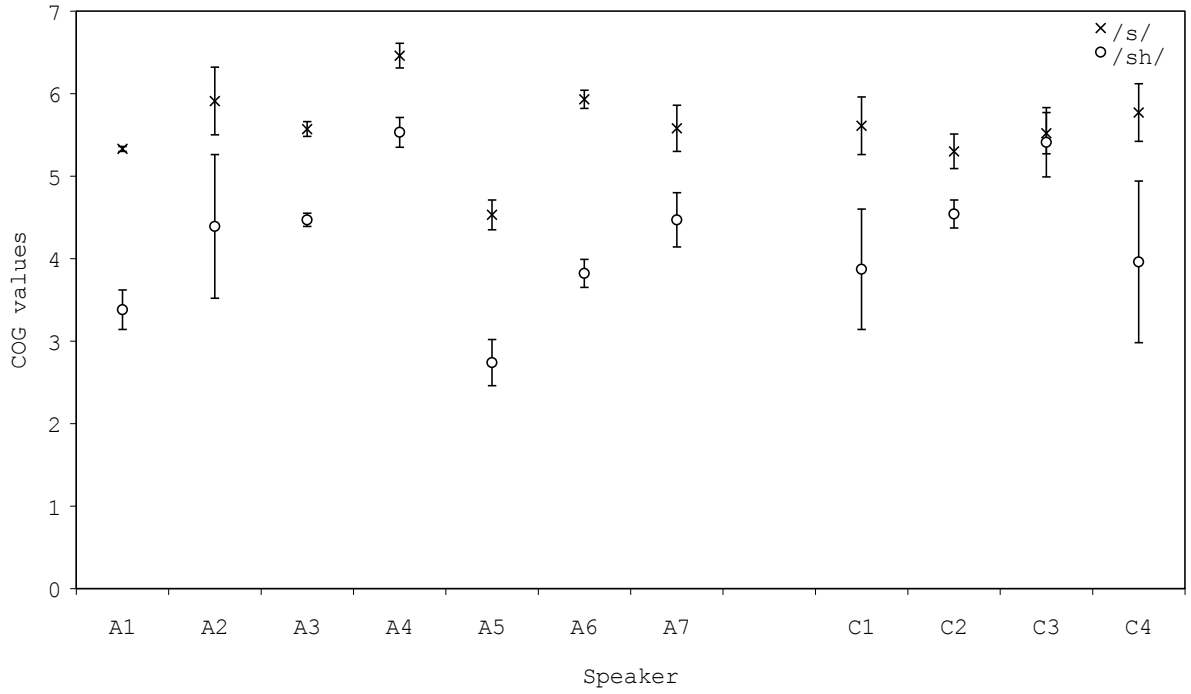


Figure 2. Centre of gravity (COG) mean and variability (+/-1SD) fof adults (A1-A7) and children (C1-C4) with typical speech for the /s/ - /ʃ/ contrast. (Data from Geraghty and Gibbon, 2008).

As predicted, Figure 2 shows that COG for /s/ is higher than for /ʃ/ for all speakers. The figure also shows that almost all speakers have articulatory separation between the sounds in the contrast. The exception is child speaker C3, where the articulations overlap, and there is no clear separation between them. Once again, the extent of separation varies between the remaining speakers. Speakers A3 and A4, for example, have less separation than

A5 and A6. As with the vowels /i/ and /u/ discussed above, comparison of mean COG values for /s/ and /ʃ/ between speakers is not particularly meaningful because of wide inter speaker variability. For instance, A5's mean COG for /s/ is almost identical to A7's mean COG for /ʃ/. The children show the same general trends in placement for /s/ and /ʃ/ with the adult speakers, with the exception of C3. Without accompanying acoustic or perceptual analysis, it is not possible to know whether C3's production of the /s/ – /ʃ/ contrast is neutralised or whether a contrast is maintained with a different phonetic feature, such as lip rounding. This type of separation graph could be useful in detecting developmental changes in the emergence of this contrast in children. For example, it might be predicted that separation for /s/ and /ʃ/ in terms of tongue-palate contact evolves gradually as children's speech matures. Some adults may not have fully separated articulations for this contrast (e.g. the famous actor Sean Connery – known for his role in James Bond films –produces /s/ and /ʃ/ in a similar way with the result that listeners tend to hear both as /ʃ/).

Example 3: /t/ – /k/ separation in adults and children with typical speech

Figure 3 is a separation graph of COG values for /t/ and /k/ produced by seven adults and four children with typical speech from the Geraghty and Gibbon (2008) study. Here, there is much wider separation between /t/ and /k/ compared to /s/ and /ʃ/ for all the speakers. For example, the COG difference for /s/ and /ʃ/ ranged from 1-2, but for /t/ and /k/ it ranges from 3-4.5 (compare A7 to C1). The finding of wide separation between COG values for /t/ and /k/ is also reported in Liker and Gibbon (2008) using a variation on the standard COG measure. A second observation from Figure 3 is that /t/ is always more anterior than /k/, and that unlike for /s/ and /ʃ/, there is no overlap between speakers in the COG values for the different phonemes. In other words, none of the speakers had mean COG values for /t/ that were similar to other speakers' mean COG value for /k/.

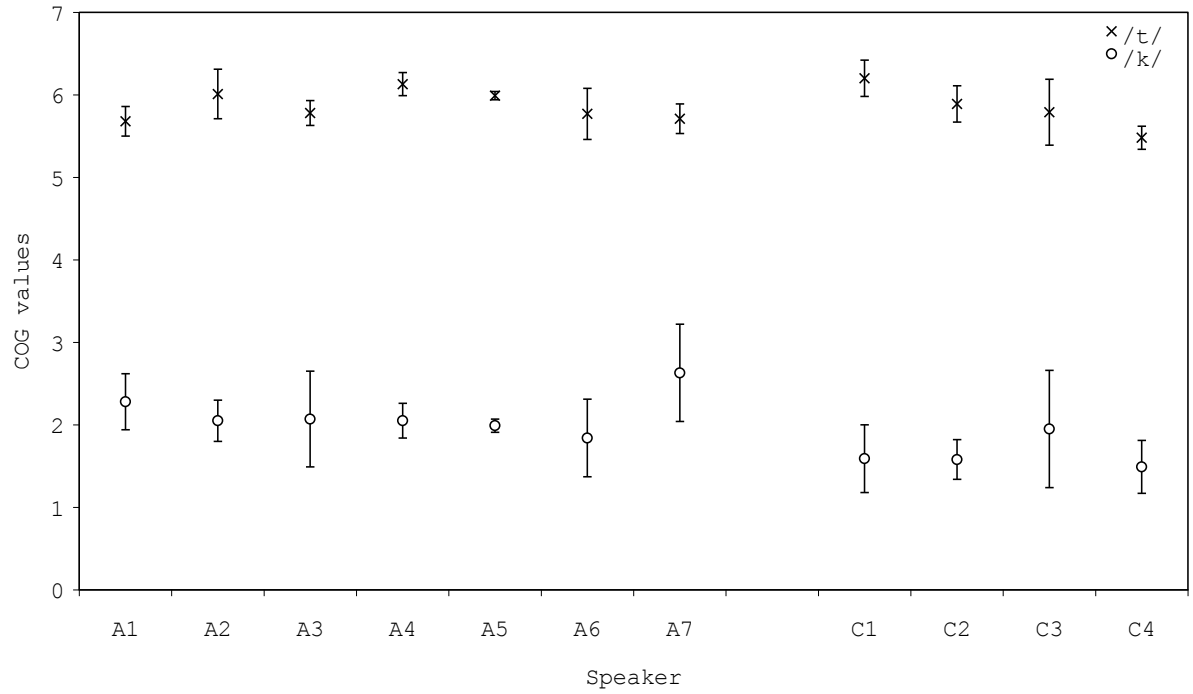


Figure 3. Centre of gravity (COG) mean and variability (+/-1SD) for adults (A1-A7) and children (C1-C4) with typical speech for the /t/ - /k/ contrast. (Data from Geraghty and Gibbon, 2008).

The greater COG separation for /t/ and /k/ compared to /s/ and /ʃ/ is expected and largely due to greater actual distance within the oral cavity between place of articulation for the contrasts. It is important to note, however, that the graphs show a representation of distance and that actual distance on the palate was not directly measured, and cannot be estimated, from EPG data alone.

Example 4: /t/ and /k/ separation in children with cleft palate

The wide separation evident in the EPG data for /t/ and /k/ from typical adults and children shown in Figure 3 stands in stark contrast to the reduced separation shown by the majority of children with cleft palate shown in Figure 4. This is data from a study by Gibbon, Ellis and Crampin (2004) that investigated articulatory placement characteristics for alveolar and velar stop targets in the speech of 15 school age children with repaired cleft palate. Further details of spatial patterns and auditory perceptual analyses of the contrasts shown in Figure 4 are reported in Gibbon et al. (2004). Unlike the typical speakers, whose /t/ and /k/ separation ranged from 3-4.5, the maximum COG separation for the fifteen children with cleft palate was 2.5 (C1 and C3) and many children show no separation. Anatomical factors associated with cleft palate may have played a role in reducing alveolar-velar placement separation for these children – dental and occlusal problems, such as rotated or ectopic anterior teeth and Class III malocclusion (Peterson-Falzone, 1990), and small or narrow hard palates can significantly reduce intraoral area and consequently the space within which the tongue can move.

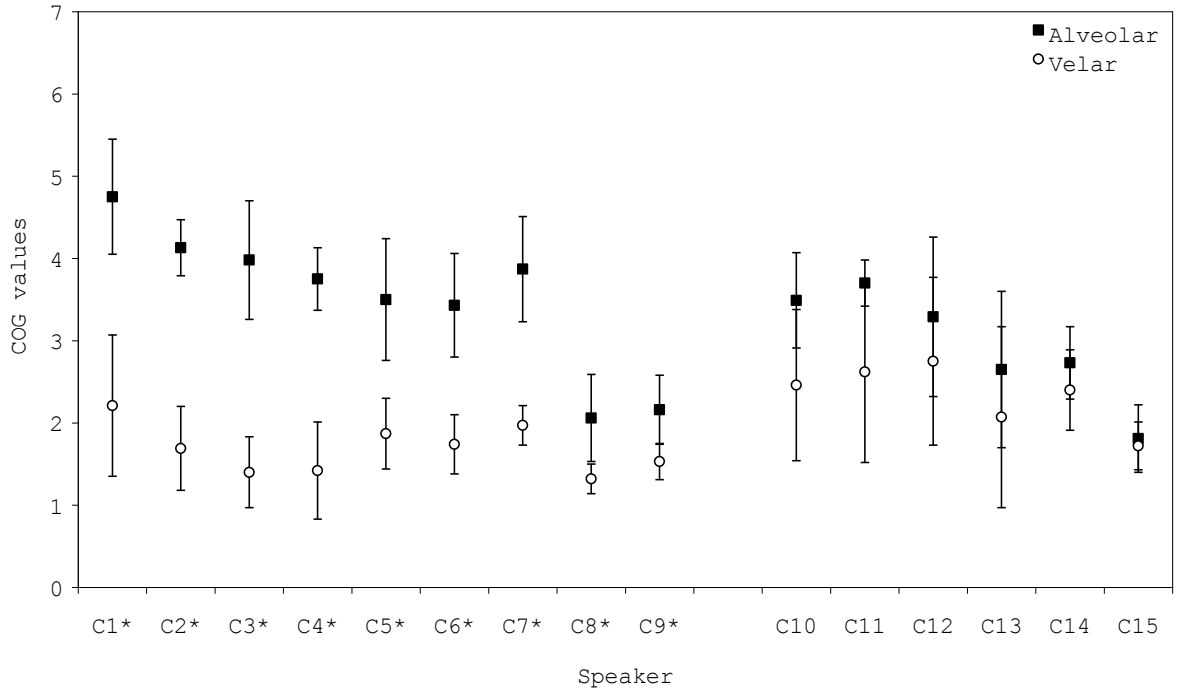


Figure 4. Centre of gravity (COG) mean and variability (+/-1SD) for the alveolar and velar targets produced by 15 children with cleft palate (values that reached significance at $p < 0.003$ are marked *). The figure is arranged so that at the right end of the figure the children demonstrate minimal separation, and to the left are those with clear separation. (Data from Gibbon, Ellis and Crampin, 2004).

Figure 4 is arranged to show the range of placement locations for alveolars and velars and the extent of separation displayed by the 15 children. To the right end of the figure are children demonstrating minimal separation, and to the left are those with clear separation that

resembles normal speakers' placements for alveolar and velar targets. Statistical analysis involving showed that 9 children (marked with an asterisk) had a significant difference between their COG values for alveolar and velar targets. Alveolar-velar COG values for the remaining six children failed to reach statistical significance levels, but nevertheless, alveolar targets had higher COG values indicating slightly anterior placement compared to velar targets. The somewhat more anterior placement for alveolars than velars suggests incomplete placement neutralization even in these non-significant cases.

Discussion

The separation graphs shown in the previous sections illustrate how EPG data can be represented in terms of articulatory separation for phoneme contrasts by individual speakers. This way of capturing articulation downplays comparisons of index values across speakers or with "norms" for specific phoneme targets. When used in conjunction with auditory perceptual and acoustic analyses, it is proposed that these displays will prove useful in (a) identifying differences in articulation of contrasts between groups of speakers; (b) revealing phenomena such as covert contrast; and (c) defining EPG patterns as therapy targets and therefore to set more appropriate EPG therapy goals.

The graphs can be helpful when investigating the extent of contrast separation across groups of speakers. For instance, the data for /i/ and /u/ contrast in Figure 1 are from speakers with a Southern British accent (A1-5), while those on the right (A6-10) have a Scottish English accent. Scottish vowel /ʉ/ is considered to involve a more fronted articulation than /u/ in Southern British English. It might therefore be expected that contact for /u/ would be higher in the Scottish speakers compared to the Southern British speakers. Furthermore, it might also be speculated that the Scottish speakers would show reduced separation, although not a merger for /i/ and /u/, compared to the Southern British speakers. Neither prediction is born out in the data presented in Figure 1, however, suggesting that any differences in vowel qualities are achieved using features other than those relating to tongue palate contact. Acoustic and perceptual analysis, plus the use of other instruments such as ultrasound, would be the obvious next step in determining the exact acoustic-articulatory relationship between this particular contrast.

The reduced articulatory separation for the alveolar and velar contrast displayed by the children with cleft palate needs to be interpreted in conjunction with perceptual analysis and overall speech intelligibility. For instance, it may be that some of the children who show significant separation are nevertheless judged to have perceptual neutralisation, for example, both alveolar and velar targets heard as midddorsum palatal stops. Gibbon and Crampin (2001) reported such a case, where /t/ and /k/ targets were judged by phonetically trained listeners as homophonous (i.e., both produced as [c]), but the EPG data revealed that the place of articulation for the [c] produced for /t/ was significantly more anterior than the place of articulation for the [c] produced for /k/.

EPG separation displays, combined with careful perceptual analysis, can play a useful role in uncovering instances of covert contrast, as illustrated by the case study by Gibbon and Crampin (2001). The phenomenon of covert contrast occurs when EPG differences between target phonemes occur, but evidence from listeners' perceptions indicates a phonological neutralization. In other words, there are differences between phoneme contrasts that are measurable from EPG data but are not detected reliably by the human ear (see Gibbon, 2002, for a review of instrumental studies of covert contrast). For example, analysis of the EPG data shown in Figure 4 demonstrated that about half of the children with cleft palate shown in Figure 4 had a significant articulatory difference between alveolar and velar targets. The evidence of articulatory contrast needs to be considered alongside other evidence, in particular perceptual or acoustic analyses, before drawing a conclusion about the presence or absence of covert contrast.

Representing EPG data in terms of separation graphs may assist in defining EPG patterns as therapy targets and therefore to set more appropriate EPG therapy goals for individuals undergoing visual feedback therapy. Gibbon and Wood (2010) point out that the target EPG pattern that the child attempts to copy – the therapy target pattern – resembles a normal pattern. Wide inter speaker variation in amount of contact evident in typical speakers means that therapy target patterns need to be tailored to each individual in terms of tongue palate contact. In some cases, perceptual and EPG analysis might determine that an appropriate therapy goal was greater separation between sounds in a contrast. Therapy goals might involve a combination of (a) moving placement forward for /t/, /d/; (b) moving placement backward for /k/, /g/; and (c) reducing placement variability.

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