Tongue-palate contact for nasal versus oral stops in speakers with repaired cleft palate

Alice Lee, Ph.D.

Nicola Bessell, Ph.D.

Fiona E. Gibbon, Ph.D.

Department of Speech and Hearing Sciences, University College Cork, Cork, Ireland

Address correspondence to:

Dr. Alice Lee, Department of Speech and Hearing Sciences, University College Cork, Brookfield Health Sciences Complex, College Road, Cork, Republic of Ireland. Tel.: +353 (0)21 490 1540; Fax: +353 (0)21 490 1542. E-mail: a.lee@ucc.ie

ABSTRACT

Most previous studies of speech disorders associated with cleft palate have reported a higher incidence of errors for oral stops, fricatives and affricates compared to nasal stops. However, the results of a recent ultrasound study have raised the possibility that errors affecting nasal consonants might not be as rare as originally thought. A review of the electropalatography (EPG) literature on cleft palate speech has also shown that atypical tongue-palate contact patterns can occur during nasal consonants and that nasal and oral stops are often produced with similar atypical lingual gestures. Therefore, this study investigated the production of nasal stops (/n/ and /ŋ/) and the homorganic oral stops (/t/, /d/ and /k/, /ɡ/ respectively) in eight children with repaired cleft palate using perceptual judgements and evaluation of tongue-palate contact patterns. Results of the perceptual judgements support the findings in the literature that there was a higher percent phoneme correct for the alveolar nasal (about 90%) than for the oral stops (60-70%). However, there was a low percent phoneme correct for the velar nasal (about 50%) and the percent correct as determined by the EPG data was lower than those based on perceptual judgements. Two children showed similar atypical articulatory gestures for the oral and nasal alveolar stops. We discuss the possibility that the nasal errors may be of phonemic as opposed to phonetic origin. The results underscore the importance of considering the phonological dimension of production when assessing the speech of children in this clinical group.

Keywords: nasal stops; oral stops; cleft palate; speech disorder; perceptual judgements; electropalatography (EPG)

INTRODUCTION

Cleft palate is a congenital defect that occurs due to an interruption to the fusion of the palatal shelves during the first trimester of gestation, resulting in an abnormal opening in the soft palate and, in some cases, the hard palate as well (Kummer, 2014; Zajac & Vallino, 2017). Babies born with cleft palate usually receive surgical treatment at an early age to create adequate velopharyngeal function; however, due to various reasons, oral-nasal coupling may continue in the form of velopharyngeal dysfunction (VPD) and/or oronasal fistula which can lead to resonance and articulation problems (Chapman & Willadsen, 2011; Kummer, 2014). The articulation errors associated with cleft palate can be classified into two broad types: passive (or obligatory) errors and active (or compensatory) errors (Harding & Grunwell, 1998; Trost, 1981). Passive errors are caused by the presence of VPD and/or oronasal fistula; hence, once these structural deficits are rectified by surgical or prosthetic means, passive errors should be eliminated spontaneously (Kummer, 2014). In contrast, active errors are characterised by the use of atypical placement for articulation (Harding & Grunwell, 1996). Warren (1986) suggested that atypical lingual placement is one of the compensatory strategies that some speakers use to maintain aerodynamic stability during speech production in response to reduced intraoral pressure as a result of VPD. In order to make use of airflow before it is lost or reduced at the site of VPD or oronasal fistula (Kummer, 2014), narrow constriction is created at the posterior section of the vocal tract to increase airway resistance (Warren, 1986). Hence, active error sounds are produced at places which are below the level of VPD (e.g., at the uvular, pharyngeal, or glottal level) or posterior to the location of the oronasal fistula (e.g., midpalatal region or at velar level), resulting in retracted place of articulation but preserved manner of articulation (Trost, 1981).

Following the reasoning of Warren's regulation/control theory (1986), if the use of atypical lingual gestures as a compensatory strategy is for maintaining intraoral pressure during speech, it could be hypothesised that speech sounds requiring high intraoral pressure (e.g., fricatives, affricates and stops; Hixon, Weismer, & Hoit, 2008) would be more likely to be produced as errors compared to those that do not require high intraoral pressure (e.g., nasal phonemes; Zajac, 2000) during production (see e.g., Bressmann et al., 2018). Indeed, the overwhelming majority of studies using perceptually based data of the most frequently misarticulated speech sounds in individuals with history of cleft palate support this hypothesis (see e.g., Bressmann et al., 2018; Harding & Grunwell, 1996, for a review). However, the results of a recent ultrasound study by Bressmann and colleagues raise the possibility that errors affecting nasal consonants might not be as rare as originally thought (Bressmann et al., 2018). Investigating the nature and extent of nasal errors has diagnostic and therapeutic significance because their presence could have a negative impact on speech intelligibility.

Ultrasound study on productions of nasal stops

Using perceptual judgements based on the audio and video information from midsagittal ultrasound scanning of tongue movement during speech, Bressmann et al. (2018) reported a variety of articulation errors in 11 children and young adults (aged 6-20 years) with history of cleft palate during the production of alveolar and velar nasal stops. The speech samples analysed in their study were repetitions of nonsense syllables in vowel-consonant-vowel structure, where the consonants were alveolar and velar nasal stops (/n/ and /ŋ/) and the vowels were /ɑ/-/ɑ/, /i/-/i/ and /u/-/u/ pairs. The study showed that none of the 11 speakers was judged to have 100% correct production of both nasal sounds; five showed articulation errors for both sounds and six of them showed errors in either /n/ or /ŋ/. For the six speakers who had one of the nasal sounds correct, five were completely correct for /n/ and one for /ŋ/. In addition, the articulation errors demonstrated were different between speakers and some of the individuals showed variable errors within targets, with correct production of the nasal targets only in some vowel context or different articulatory errors over repetitions of the same stimulus.

The types of errors observed for the two nasal consonants were detailed in the Bressmann et al. (2018) study. For /n/, the errors included backing to a palatal nasal ([ɲ]) or velar nasal ([ŋ]); co-production of a palatal nasal and a palatal click ([ɲ͡ǂ]), an alveolar nasal and an alveolar click ([n͡ǃ]), or an alveolar nasal and a lateral ([n͡l]); gliding to [w] in /i/-/i/ context; backing to a velar nasal with insertion of a bilabial approximant or a velar plosive after the target (i.e., [ŋw] and [ŋɡ] respectively); and a nasalised retroflex ([ɽ̃]) (Bressmann et al., 2018). For /ŋ/, the articulation errors observed were fronting to a palatal nasal; fronting to an alveolar nasal with insertion of a palatal or alveolar plosive, or co-production of a velar plosive and a glottal plosive after the target (i.e., [nc], [nd] and [nɡ͡ʔ] respectively); target consonant produced, but with insertion of a voiced alveolar plosive, voiceless or voiced velar plosive, a palatal click, or a voiced velar plosive followed by a palatal approximant (i.e., [ŋd], [ŋk], [ŋɡ], [ŋǂ] and [ŋɡj] respectively); a pharyngeal plosive ([ʡ]); co-production of a palatal nasal and a palatal plosive ([ɲ͡ɟ]); a velar plosive or velar plosive with insertion of a palatal approximant ([ɡj]) (Bressmann et al., 2018).

The participants in Bressmann et al.'s (2018) study had articulation errors for other speech sounds as well; however, details of the active errors observed for the affected oral speech sounds were not provided. Hence, it is uncertain whether the errors for the nasal sounds and oral sounds were produced using common incorrect articulatory gestures. Imaging the midsagittal contour of the tongue using ultrasound is useful in studying the lingual gestures used during the production of speech errors. But, as pointed out by the authors (Bressmann et al., 2018), ultrasound provides minimal information regarding the occurrence of tongue-palate contact, which is important for our perception of place of articulation. Thus, studying the nasal errors using another instrumental measure – electropalatography (EPG) – would probably add to our understanding of this topic.

EPG study on productions of nasal stops

EPG is an instrumental technique that has been used even more frequently than ultrasound in studying articulation errors associated with cleft palate. The technique detects, visually displays and records the timing and pattern of contact between the tongue and the palate during speech (see Method section for further details of the EPG technique). A review of the EPG literature showed that there have been a few studies that reported individuals with history of cleft palate who had articulation errors affecting nasal sounds (Gibbon & Crampin, 2001, 2002; Gibbon & Hardcastle, 1989; Howard, 2004; Jesus & Reis, 2013; see table 1 for a summary). Different atypical tongue-palate contact patterns were reported for the nasal consonants. For the bilabial nasal, three of the EPG studies (Gibbon & Crampin, 2002; Gibbon & Hardcastle, 1989; Jesus & Reis, 2013) reported the production of bilabial-lingual double articulation; that is, simultaneous lip closure and contact between the tongue and some part of the palate. This articulatory pattern was very different from the negligible amount of tongue-palate contact during /m/ shown in the typical speakers (Gibbon, Lee, & Yuen, 2007). For the alveolar nasal, all five EPG studies reported retracted place of complete constriction across the palate from the alveolar region to the palatal and/or velar region, with obviously increased amount of contact as well when the tongue made contact with both palatal and velar regions of the palate. The study by Howard (2004) also reported the use of alveolar-velar double articulation during production of /n/ in one of the speakers. These contact patterns would be considered abnormal for /n/ targets because typical speakers generally showed complete contact across the palate in the alveolar region and contact at the lateral sides of the palate (see e.g., Gibbon, Yuen, Lee, & Adams, 2007; McLeod & Singh, 2009; see also figure 1b in this paper). For the velar nasal, two of the EPG studies (Gibbon & Crampin, 2001; Jesus & Reis, 2013) reported fronted place of contact for the phoneme. The speaker in the study by Gibbon and Crampin showed complete constriction across the palate in the palatal and velar region (thus, the amount of contact increased) whereas the speaker in the Jesus and Reis' study showed that the place of contact was brought forward to the palatal region, compared to the velar region they observed in their control speaker.

Insert table 1 about here

Aside from the atypical contact patterns observed for the nasal consonants, three of the EPG studies (Gibbon & Crampin, 2002; Howard, 2004; Jesus & Reis, 2013) also reported variability in the contact patterns within each consonant segment and between different tokens of the same target sound (see also table 1). Some of the speakers showed appropriate contact patterns for the target in some but not all productions, whereas other speakers produced abnormal contact patterns for all of their productions. Intra- and inter-token variability in contact patterns has not been a feature of typical articulation reported in previous EPG studies (see e.g., Gibbon, Yuen, et al., 2007; McLeod & Singh, 2009).

Aims of the present study

The tongue-palate contact patterns reported for the nasal errors and those for the errors for the non-nasal consonants in these five EPG studies suggest that the speakers who showed errors with nasal sounds used similar atypical articulatory gestures for producing the oral cognates as well. Hence, we speculated that the presence of nasal errors, which cannot be explained by Warren's (1986) theory, might be due to generalisation of compensatory strategies for the oral stops to the homorganic nasal stops. As the previous EPG studies were mostly case studies with incomplete information in terms of comparison of articulatory patterns of nasal stops to those of the oral stops and nasal stops and data of oral stop production were not reported nor compared to that of nasal errors in Bressmann et al.'s (2018) paper, this study was carried out to investigate the tongue-palate contact patterns for nasal stops (/n/ and /ŋ/) and to compare these with their oral counterparts (/t/ and /d/; and /k/ and /g/). Perceptual judgements of the speech sounds as well as classification of the contact patterns were used and the results were compared to those from typically developing children. The study aimed to find out whether nasal errors occurred, as reported in Bressmann et al.'s (2018) study, and whether similar articulatory gestures were used for producing nasal and homorganic oral stops.

METHODS

This is a retrospective analysis of EPG data collected from children with repaired cleft palate and typically developing children in a previous research project. Ethics approval was granted by the Research Ethics Committee of Queen Margaret University, Edinburgh, for conducting the research project. Written consent was obtained from the participants prior to data collection.

Participants

The participants were eight children with repaired cleft palate (six boys and two girls, aged 8;02-12;04 years; with a mean age of 9;08 years and SD of 1;05 years) and two typically developing children (two boys, aged 10;00 years and 12;00 years respectively) who took part in a previous research project on EPG therapy. Before the EPG therapy, the children with repaired cleft palate showed articulation errors associated with cleft palate, affecting alveolar fricatives in all cases as well as alveolar stops or affricatives in some cases. The details of the age, gender, medical history and articulation skills are summarised in Appendix A. The typical children had no history of speech, language, or hearing difficulties according to parents' report.

Speech samples

The speech samples of the children with repaired cleft palate analysed in this study were collected before EPG therapy. The stimuli used in the EPG recordings of the original project were reviewed and those that contained oral or nasal alveolar or velar stops as singleton consonants were included in this study. The stimuli were 22 words and five sentences that elicited a total of 31 tokens – four /t/, six /d/, six /n/, five /k/, four /g/ and six /ŋ/ – at different word positions from each participant (see Appendix B). There were six missing data points – /d/ in 'a shed' and 'a said' of three participants (child 2, 6 and 8).

The participants were instructed to read aloud the words and sentences. Their productions were recorded using the Reading EPG3 system that simultaneously captured the tongue-palate contact data (sampled at a frequency of 100 Hz) and the acoustic signal (sampled at a frequency of 10k Hz and saved in WAV format). Each participant wore a custom-made Reading EPG plate that fitted against the hard palate for recording the tongue-palate contact data. The EPG plate was an acrylic dental plate and the one used in the Reading EPG system had 62 electrodes embedded on the lingual surface of the plate for detecting the tongue's contact with the palate (Hardcastle, Gibbon, & Jones, 1991). The 62 electrodes were arranged in eight horizontal rows across the palate, with six electrodes in the most anterior row and eight in the second to eighth rows. The first row of electrodes was placed at the palatal junctures of the upper front incisors and the last row was at the juncture between the hard and soft palate (Hardcastle et al., 1991). In addition, the spacing between the first four rows was half the spacing between the last four rows (Hardcastle et al., 1991). Figure 1a shows a Reading EPG plate of a typical adult speaker and figure 1b shows two EPG frames or palatograms, with the filled squares illustrating a typical contact pattern for alveolar and velar stops.

Perceptual judgements

Perceptual judgement of articulation was completed by the first and second authors based only on the audio recordings captured by the EPG system, without access to the corresponding tongue-palate contact pattern data. Neither author was familiar with the children's nasals from previous EPG analyses. The audio files were played through two high quality headphones both connected to a computer, using acoustic analysis software, Praat version 5.3.80 (Boersma & Weenink, 1992-2018). The judges knew the speech stimuli. They listened to the entire word or sentence first and the words that contained the phonemes were played again for as many times as needed. The two judges made independent judgements on the speech sounds perceived and documented these using narrow phonetic transcription. The judgements were then compared to measure inter-judge agreement. Items where there was a discrepancy in the phonetic transcription were discussed but the method of consensus judgements was not used. This is because variability between listeners in the speech sounds perceived might be due to the use of atypical lingual gestures, particularly, articulatory gestures that are undifferentiated (Gibbon, 1999). Hence, only productions that were received as acceptable realisations of the target phonemes by both judges were considered as correct articulation.

EPG data analysis

The EPG data recorded using the Reading EPG3 system was processed by using the Import software (Articulate Instruments Ltd.) before it could be read and analysed using the WinEPG (Articulate Instruments Ltd., 2008) – the Windows® version of the Reading EPG system. The target segments were identified and annotated based on visual inspection of the wide-band spectrogram and careful listening of the audio signals. Nasal consonants are characterised by reduced overall energy relative to the adjacent segments on the wide-band spectrogram (Kent & Read, 2002); thus, the boundary where there was a marked change in energy level was taken as the onset or offset of the nasal stops (Croot & Taylor, 1996). For the oral stops, the closure period – from the point of an abrupt decrease in energy level of the preceding segment to the start of release (Croot & Taylor, 1996) – was annotated. The analysis of EPG data included classification of tongue-palate contact patterns and quantitative measures, based on the EPG frame at the temporal mid-point of each target segment. The tongue-palate contact pattern captured at this point was considered as representative of the lingual articulatory gesture for producing the corresponding target sounds, thus, avoiding any potential coarticulatory effects from adjacent segments.

The classification of tongue-palate contact patterns followed the principles used in Gibbon et al. (2007). The following criteria were set with reference to the typical contact patterns reported for 8- to 11-year-old typically developing children reported by Cheng, Murdoch, Goozée and Scott (2007). For contact patterns to be considered as correct for oral and nasal alveolar stops, the patterns should show (1) anterior constriction – 100% contact across the palate in any or all of rows 1-3 and (2) no contact in the posterior central region, specifically, zero contact at the two central electrodes in row 5 and the central four electrodes in rows 6-8. For oral and nasal velar stops, the patterns should show (1) posterior constriction – some contact in any or all of rows 5-8 (complete contact in the last row is not necessary) and (2) no contact in the anterior central region, that is to say, zero contact at the six electrodes at the centre in rows 1-4. The two EPG palatograms shown in figure 1b fulfil the criteria for the alveolar and velar stops respectively. The identification of correct contact patterns was done by exporting the information of amount of contact in each of the specific rows or regions stated above to Excel spreadsheets and the data was then checked using Excel formulas. For example, the “COUNTIF” formula was used to check if the amount of contact measured in the two central electrodes in row 5 and the central four electrodes in rows 6-8 was equal to zero or not for the alveolar stops. After this, the first author did a final manual check on the contact pattern classification results.

RESULTS

Perceptual judgements of consonants produced

One out of the eight children with repaired cleft palate (child 6) was perceived to have correct production for all the tokens of oral and nasal alveolar stops and so were the two typically developing children. Two speakers (child 2 and 7) showed some articulation errors with /t/ and /d/ but no errors for /n/. Overall, the number of children who showed some articulation errors for a target consonant was five for /t/, four for /d/ and five for /n/. In terms of percent phoneme correct for the eight children with repaired cleft palate, it was 66% (21 out of 32 tokens) for /t/, 74% (31/42) for /d/ and 90% (43/48) for /n/. Table 2 details the percent phoneme correct for each phoneme for each child and the perceived errors for the incorrect productions. As shown in the table, the production of a glottal stop for /t/ at the word medial or final position was perceived in two children: word medial and final (i.e., 'sweater' and 'biscuit' respectively) for child 2 and word final for child 8. This could be a feature called glottalling (Wells, 1982a) which is observed in many English accents (for a review, see Gibbon & Lee, 2010). Hence, when this dialectal variation was considered, the percent correct for /t/ was 75% (24/32).

Insert table 2 about here

The mean percent velar stops correct for the eight children with repaired cleft palate was 70% (28/40) for /k/, 66% (21/32) for /ɡ/ and 46% (22/48) for /ŋ/. Many of the productions for target /ŋ/ were perceived as [n]. It is known that realising /ŋ/ as [n] in words ending '-ing' is common in informal speech, and is dialectally appropriate for speakers from some socioeconomic and regional groups (Wells, 1982b) and that the use of [n] is most likely when the '-ing' word is a present participle (Houston, 1985). If these factors were considered, the productions of [n] for /ŋ/ for the word 'melting' elicited in a sentence would be regarded as acceptable and the mean percent phoneme correct for /ŋ/ was 52% (25/48). Overall, none of the children showed 100% correct production for all the tokens of oral and nasal velar stops (see table 3). One speaker (child 3) showed no errors with the velar nasal but some articulation errors with the two oral stops; three (child 1, 5 and 6) showed no errors for the two oral stops but errors with the velar nasal. Two speakers showed 100% correct production for one of the oral stops (/ɡ/ for child 4 and /k/ for child 7) but errors in the other two consonants; and two speakers showed errors for the three velar stops. The number of speakers who showed some articulation errors was four for /k/ and /ɡ/ and seven for /ŋ/. For the two typically developing children (child 9 and 10), they were perceived to show 100% correct for all productions, expect child 10 where [p] was perceived by both judges for /k/ in “the chalk”.

Insert table 3 about here

The inter-judge agreement for the perceptual judgements was 89% (270/304) overall. Both judges showed 100% agreement for judging the productions by the two typically developing children whereas the agreement for judging those produced by the children with repaired cleft palate was 86% (208/242), ranging from 72.4% (21/29) to 93.5% (29/31). The inter-judge agreement was highest for transcribing the productions for targets /d/ (90%; 38/42), /n/ (90%; 43/48) and /k/ (90%; 36/40), followed by /t/ (88%; 28/32), /ɡ/ (84%; 27/32) and /ŋ/ (75%; 36/48) produced by the children with cleft palate.

Classification of tongue-palate contact patterns

Applying the criteria of complete contact in alveolar region and zero contact in the posterior central part of the palate, 12% (4/32) of the productions for /t/, 36% (15/42) for /d/ and 50% (24/48) for /n/ by the children with repaired cleft palate were considered as showing correct contact pattern. As stated above, the use of glottal stop for /t/ at word medial and word final positions could be a dialectal variation. An open pattern with zero or minimal tongue-palate contact has been reported for glottal stops (see Gibbon, 2004); hence, with that taken into account, the percent correct for /t/ was 38% (16/42).

For the oral stops, the error contact pattern that occurred most frequently was presence of contact in the posterior central region of the palate but no predominant error pattern was observed for the nasal stop (see table 4). Out of the eight children with repaired cleft palate, only one (child 8) showed 100% correct tongue-palate contact pattern for /n/ but the same child had 0% correct for /t/. Another four children had 0% correct for at least one target phoneme – all three targets for child 1; /t/ and /d/ for child 2 and 6; and /t/ for child 3. The rest was inconsistent errors in contact patterns for the three alveolar stops (see table 2 for detailed results of individual child). In addition, visual inspection of the tongue-palate contact data revealed that child 1 and 7 seemed to have used similar atypical articulatory gestures when producing oral and nasal stops and this trend was particularly apparent in child 1 (see figure 2). This contrasted with the findings from other children, for example child 3 and 6, where there were more common features in the contact patterns between the two oral stops than between the oral and nasal stops (see also figure 2).

Insert table 4 and figure 2 about here

The two typically developing children did not show 100% correct contact pattern for the three alveolar stops – the accuracy was 63% (5/8) for /t/, 92% (11/12) for /d/ and 75% (9/12) for /n/. Two tokens of /t/ and one token of /d/ produced by child 9 did not show complete contact across the palate in the alveolar region. The nasal stop produced in the word "new" by both child 9 and 10 and one token of /t/ of child 10 showed contact at the sides of the posterior central region of the palate. Despite the excess amount of contact, the contact patterns could be deemed as correct patterns for alveolar stops as they were characterised by complete contact in the anterior region with lateral contact at the sides of the palate. Another token that did not pass the criteria but could be considered as acceptable contact pattern for the target was a /n/ token produced by child 9. There was a complete contact across the palate but this occurred in row 4 instead of row 1-3. The error contact patterns observed in these two typical children are displayed in figure 3.

Insert figure 3 about here

For the velar stops, overall, 70% (28/40) of the productions for /k/, 63% (20/32) for /ɡ/ and 38% (18/48) for /ŋ/ were judged to have correct tongue-palate contact pattern, that is, presence of contact in the velar region and zero contact in the anterior central region of the palate. Again, when sociolinguistic and/or dialectal variation where /ŋ/ could be realised as [n] was considered, the tongue-palate contact pattern for /ŋ/ in two children (child 4 and 8) were regarded as correct, as both patterns fulfil the criteria set for the alveolar stops; while the pattern of one child (child 2) remained incorrect. Hence, the percent correct was 42% (20/48).

The presence of some contact in the anterior central part of the palate was the most frequently observed error contact pattern for the oral and nasal velar stops (see table 4). Child 5 showed 100% correct contact pattern for the three phonemes and child 1 showed 100% correct for /ɡ/. There were three children who had 0% correct contact pattern for one of the velar stops – /ɡ/ for child 2 and /ŋ/ for child 3 and 8 (see table 3 for detailed results). Figure 4 shows the different contact patterns for the velar stops observed in the children with repaired cleft palate. Child 3 showed complete contact across the palate in the velar region but there was a small amount of contact in the anterior central region of the palate in the contact pattern of /ɡ/ and /ŋ/, the contact patterns were thus considered as incorrect according to criterion 2. For child 8, the figure shows that the three contact patterns for the three velar stops were incorrect but the error patterns were similar between the two oral stops and they were different from that of the nasal stop. The two typically developing children showed 100% correct contact for the three velar stops.

Insert figure 4 about here

Finally, an additional observation based on the EPG data was that there was within segment variability in tongue-palate contact patterns in the children with repaired cleft palate. Figure 5 illustrates the changing contact pattern from the onset of the nasal targets through the offset in two of the children (child 2 and 5), with comparison to the less varying contact pattern observed in one of the typical children (child 10).

Insert figure 5 about here

DISCUSSION

This study used EPG and perceptual judgements to investigate whether speech errors produced by children with cleft palate affecting nasal consonants, specifically /n/ and /ŋ/, occurred, as recently suggested by Bressmann et al. (2018). Results of the perceptual judgements of speech in the current study showed higher percent phoneme correct for the alveolar nasal stop than for the oral cognates – about 90% correct for /n/ compared to 60-70% correct for /t/ and /d/ – which generally support the findings in the literature. Most of the previous studies reported between 60-90% correct for alveolar nasal stop in contrast to a lower range of 30-70% correct for the oral stops, based on perceptual judgements (Grunwell et al., 2000; Philips & Harrison, 1969; Spriestersbach, Darley, & Rouse, 1956; Van Demark, 1969; Van Demark, Morris, & Vandehaar, 1979). However, for the velar stops, this study revealed a lower percent phoneme correct for the velar nasal (about 50% correct) than for the oral stops (about 60-70% correct) which was in contrast with previous findings where they found a higher percent correct for /ŋ/ (70-80%) than for /k/ and /g/ (50-60%; Spriestersbach et al., 1956; Van Demark, 1969). Even with factors of sociolinguistic and/or dialectal variation taken into account, the percent phoneme correct for /ŋ/ found in this study was still low. In addition, neither of the two TD children produced the [n] variant for the target /ŋ/. Hence, the current finding probably reflected certain level of articulatory difficulties related to the production of the velar nasal in these children. As detailed information of social and dialectal background of the speakers in this study were not available to the investigators, we recommend that future studies should document relevant information on dialects of the speakers, or check with care givers whether those variations were accepted or used in the family of the speakers

Compared to the results of perceptual judgements, the percent phoneme correct was much lower when it was determined based on the EPG data, with half of the productions for alveolar nasal stop and less than half of the productions for velar nasal stop were classified as correct in terms of tongue-palate contact pattern. Only one child with repaired cleft palate was considered as showing correct tongue-palate contact pattern for /n/ and another child had correct contact pattern for /ŋ/. Hence, the results based on tongue-palate contact pattern analysis seemed to agree with the findings of higher number of errors with nasal phonemes reported in the study by Bressmann and colleagues (2018) who also used an instrumental technique (ultrasound) to evaluation nasal consonant productions. The different findings reported in the earlier studies and the recent study were likely to be related to the assessment methods used.

In this study, phonetic transcription was used to document the speech sounds produced by the speakers for the target phonemes. Both listeners knew the target words and one listener had knowledge of the speaker characteristics of each child. It has been shown that factors, such as listeners' familiarity with the test stimuli and speaker identity, could have an impact on perceptual judgements in general (for a review, see e.g., Knight, 2010; Miller, 2013). Hence, the procedure used in the current study might have favoured the speakers, resulting in a higher percent phoneme correct overall based on the perceptual judgements. Although this is a methodological limitation, this arrangement is similar to procedures used in clinical assessments where clinicians are aware of the test materials and the case histories of their clients.

The lower score for percent phoneme correct based on the EPG classification compared to perceptual judgements could be related to the setting of criteria for defining correct tongue-palate contact patterns. The criteria used in this study were based on evidence reported in previous studies of lingual gestures for alveolar and velar stops in typical adult speakers (e.g., Gibbon & Wood, 2010; McLeod & Singh, 2009) and one study of tongue-palate contact patterns in typically developing children (Cheng et al., 2007). We selected these criteria based on current knowledge of typical children's productions. However, the criteria did not allow any flexibility when making judgement of correct versus incorrect contact patterns. As reported in the Results section, there were a small number of contact patterns that we observed in the typically developing children that did not pass the criteria but could be considered as acceptable patterns for the corresponding target phonemes. Similar situations were observed in some of the contact patterns produced by some children with repaired cleft palate. The fact that the precise criteria did not apply to all contact patterns may have been due to the nature of the speech stimuli, which were not controlled in terms of phonetic context. Furthermore, more information on the tongue-palate contact patterns for different consonants in different vowel context demonstrated by typically developing children would have been helpful for defining correct contact patterns for the present study.

The different findings regarding the occurrence of nasal errors reported in the earlier studies and the recent study might also be related to the differences in participant characteristics. The participants included in the current study and those in the study by Bressmann et al. (2018) were candidates for speech therapy; where those in the earlier studies were children with repaired cleft lip and/or palate. It is possible that individuals who had multiple persistent speech errors that need speech intervention were more likely to have errors that affect the nasal phonemes as well and/or that they might also have other speech difficulties, such as phonological disorder as a consequence of the cleft, in addition to the cleft-type speech characteristics (Chapman, 1993; Harding & Sell, 2001).

Regarding whether any of the children with articulation disorders associated with cleft palate used similar atypical lingual gestures for producing the nasal and homorganic oral stops, the results of this study showed that this was observed in some of the children. As reviewed above, articulation errors were not expected for nasal phonemes because the production of nasal phonemes requires coupling of oral and nasal cavities and does not require building up of intraoral pressure and therefore, there is no need to use any compensatory strategies when producing nasal sounds (Warren, 1986). However, as shown in this study and other previous studies, there were children with repaired cleft palate who indeed showed errors with nasal sounds. The impact of a palatal cleft on articulation is not limited to the incidence of obligatory/passive and compensatory/active articulation errors – children with history of cleft palate are likely to show speech errors of phonological origin (see e.g., Harding-Bell & Howard, 2011; Harding & Sell, 2001). In some children, their errors 'may initially occur as a consequence of the cleft, but over time become incorporated into the child's developing phonologic rule system' (Chapman, 1993, p. 64). We hypothesise that, for those children who showed similar lingual gestures when producing oral stops and the nasal counterpart, the initial structural deficits might have caused the use of atypical lingual gesture as a compensatory strategy to produce oral stops but this was generalised to the nasal counterpart. They might have treated the homorganic oral and nasal stops as one class of speech sounds as these sounds share the same place of articulation in their language. This highlights the importance of assessing the phonological dimensions of speech production problems in children with history of cleft palate and being aware of the various possible speech diagnostic categories (Harding-Bell & Howard, 2011; Harding & Sell, 2001).

This retrospective study is probably the first study that has compared the tongue-palate contact patterns during the production of alveolar and velar oral and nasal stops by English-speaking children with repaired cleft palate and typically developing children. The main findings were that articulation errors with nasal stops did occur although it was not as often as oral stops within the speakers and that EPG revealed atypical tongue-palate contact patterns for some of the nasal consonants that were perceived as correct. Therefore, clinicians should be aware of the possibility of errors affecting nasal consonants and the limitations of perceptual judgements in detecting these errors. The finding of perceptually correct nasals produced by using atypical articulatory gestures is essential for figuring out an individual's broader difficulties in speech production which had led to the speech errors demonstrated. Furthermore, for some children who showed articulation errors for oral sounds but correct productions for the homorganic nasal consonant, one possible treatment strategy is the use of facilitative phonetic context to help the generalisation of a correct lingual gesture from one speech sound to another that share similar place of articulation (Kent, 1982); for example, using alveolar nasal stop to facilitate the production of alveolar oral stops. This strategy might be useful if the nasal consonant were really articulated correctly. If no positive change in the articulation of the oral targets was observed, it is quite likely that actually the nasal consonant was not articulated correctly either and the approach of treatment should be revised.

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DECLARATION OF INTEREST

The authors report no conflicts of interest.

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APPENDIX A

Gender, age (year; month), medical history, and articulation skills of the eight children with repaired cleft palate.

Child	Gender	Age	Medical history	Articulation skills
1	M	12;04	Cleft palate	Articulation disorder associated with cleft palate, affecting alveolar consonants.
2	F	8;08	Velopharyngeal insufficiency (pharyngoplasty at 4;10)	Articulation disorder associated with velopharyngeal insufficiency, affecting all lingual consonants. EPG assessment showed minimal tongue-palate contact; the place of constriction probably occurred at some point in the pharyngeal region.
3	F	10;00	Cleft palate (repaired at 1;08; revision at 3;03. Following surgery there were two midline fistulae which were repaired a year later.)	Articulation disorder associated with cleft palate, affecting alveolar stops and fricatives. EPG assessment showed inconsistent tongue-palate contact patterns for alveolar stops – adequate alveolar patterns in some occasions but contact in velar region in other times.
4	M	8;06	Velopharyngeal insufficiency (pharyngoplasty at 4;02)	Articulation disorder associated with velopharyngeal insufficiency, affecting alveolar fricatives. EPG assessment showed minimal tongue-

				palate contact; the place of constriction probably occurred at some point in the pharyngeal region.
5	M	11;01	Unilateral cleft lip and palate (bone graft at age 10)	Articulation disorder associated with cleft palate, affecting alveolar fricatives and affricates. EPG assessment showed contact in velar region for these sounds.
6	M	9;07	Unilateral cleft lip and palate (repaired at 3;06; lip revision at 4;05)	Articulation disorder associated with cleft palate, affecting all alveolar stops, fricatives and bilabial obstruents. EPG assessment showed alveolar-velar double articulation for alveolar stops and contact in alveolar region and simultaneous bilabial closure for bilabial stops. Complete velar contact was observed for /s/ and /z/.
7	M	8;02	Incomplete palate (repaired at 1;01)	Articulation disorder associated with cleft palate, affecting alveolar fricatives and the voiceless affricate. EPG assessment showed complete constriction in the anterior regions of the palate for these sounds, with simultaneous contact in the velar region in some occasions. Double articulation was also observed for stops but they were perceived as adequate.

8	M	8;11	Velopharyngeal insufficiency (pharyngoplasty at 6;01)	Articulation disorder associated with velopharyngeal insufficiency, affecting all lingual consonants. EPG assessment showed minimal tongue-palate contact for all lingual consonants except /n/ and /i/; the place of constriction probably occurred at some point in the pharyngeal region.

APPENDIX B

Stimuli used in the present study.

Stimulus	/t/	/d/	/n/	/k/	/g/	/ŋ/
	Targets					
1. a biscuit	1					
2. the chalk				1		
3. a circus				1		
4. a clown			1			
5. a crayon			1			
6. a desk		1				
7. the dolls		1				
8. the fishing						1
9. the gold					1	
10. a hanger						1
11. a kick				1		
12. a ladder		1				
13. a nose			1			
14. a pig					1	
15. a said		1				
16. a shed		1				
17. a spanner			1			
18. the sugar					1	
19. a sweater	1					
20. the tickling	1					1
21. a toolshed	1					

22. the watching						1
23. I did a finger painting of humpty dumpty.		1				1
24. I saw a shark at the seaside.				1		
25. My dad might buy a new pink car.			1			
26. Peter could ride the big bike.				1	1	
27. Shaun's snowman is melting.			1			1
Total	4	6	6	5	4	6

Table 1. Summary of previous findings regarding nasal errors demonstrated in speakers with history of cleft palate, as examined using electropalatography (EPG) and perceptual judgements.

Speaker(s)	Perceived speech characteristics	Tongue-palate contact patterns
A 13-year-old English-speaking boy with repaired complete bilateral cleft lip and palate[1]	Alveolar stops and nasal were perceived as velar consonants; alveolar fricatives sounded palatal; post-alveolar fricatives, lateral approximant, bilabials and velars sounded typical (before EPG therapy).	Retracted place of articulation: from alveolar to velar for alveolar stops, nasal and fricatives; from post-alveolar to palatal (with wider groove) for post-alveolar fricatives; labial-velar double articulation for bilabial oral and nasal stops.
A 36-year-old English-speaking man with repaired cleft palate[2]	Alveolar and velar stops were perceived as palatal stops; alveolar and velar nasals were perceived as palatal nasals; alveolar and post-alveolar fricatives were perceived as lateral fricatives; affricates were retracted and lateralised; approximants /r/ and /l/ were perceived as velar approximants (before EPG therapy).	Relatively more anterior place of contact for the productions for /t/ than for /k/ in general: at the start of stop closure, place of complete constriction was in palatal region for /t/ and velar region for /k/; at the frame of maximum contact, /t/ showed complete contact in the post-alveolar, palatal and velar region whereas /k/ showed complete contact in palatal and

		velar region; at the end of stop closure, complete constriction was in palatal region for both stops.
27 English-speaking children and adults with repaired cleft palate ± lip[3], with three who showed atypical contact patterns for /m/	Retracted or distorted articulations that affected some or all of these consonants: alveolar stops and fricatives, post-alveolar fricatives and affricates reported for the group. No errors perceived for the bilabials.	Double articulation (DA) for /m/: (1) a girl aged 9;10 showed consistent bilabial-alveolar DA, (2) a boy aged 12;06 showed simultaneous alveolar-velar DA and bilabial closure for 3/5 tokens of /m/ produced, and (3) a boy aged 10;07 showed bilabial-velar DA in one occasion. Child 1 and 2 also showed labial-lingual DA for the oral bilabials.
Three English-speaking teenagers with repaired cleft palate[4], with two who showed atypical contact patterns for /n/	No errors perceived for /n/ for the two girls. Girl 1 (aged 13:01): her /t/ productions sounded consistently glottalised; variability perceived for /d/ with some approximated the target; velar stops sounded within the range of velar and uvular; retraction to pharyngeal level for /s/ and palatal for /ʃ/.	Girl 1: retracted place of contact with inter- and intra-token variability for phonemes affected. For /n/, place of complete closure retracted from alveolar to palatal region at the start and end of stop closure, with near 100% contact at the frame of maximum contact. For the alveolar and velar stops, adequate patterns observed sometimes but incorrect patterns included lack of

	Girl 2 (aged 16:01): her /t/ productions sounded palatal; /k/ sounded velar/uvular; both /s/ and /ʃ/ sounded lateralised.	contact, retracted place of contact and asymmetrical contact patterns. Almost lack of contact was found for /s/; and asymmetrical pattern with inaccurately formed central groove for /ʃ/. Girl 2: three variants of /n/ production reported: (1) a pattern that resembled the typical horse-shoe shaped pattern for alveolar nasal stop, (2) retracted place of contact to the palatal and velar region, and (3) alveolar-velar double articulation. Pattern 2 above was also observed for /t/, /s/ and /ʃ/. Place of contact was mostly in velar region for /k/ tokens.
A 21-year-old Brazilian Portuguese-speaking man with velopharyngeal dysfunction and history of right unilateral cleft lip and palate[5]	Some productions of /m/ were perceived as distorted, some were judged as buccal clicks and some sounded acceptable. Many of the /n/ tokens were perceived as acceptable. The	Inter- and intra-token variability in contact patterns reported. Generally, bilabial-alveolar double articulation reported for /m/; place of contact retracted to palatal region for /n/ and the contact pattern was asymmetrical with high amount of contact at the left

	perceptual results for the Brazilian Portuguese palatal nasal (/ɲ/) was unclear.	side of the palate anterior to the location of complete constriction; and place of contact brought forward to palatal region for /ɲ/.

Note: [1] = Gibbon and Hardcastle (1989); [2] = Gibbon and Crampin (2001); [3] = Gibbon and Crampin (2002); [4] = Howard (2004); [5] = Jesus and Reis (2013).

Table 2. Results of perceptual judgement (top row: percent phoneme correct/PCC and errors perceived for the incorrect realisations) and tongue-palate contact pattern analysis (bottom row: percent correct/PC-EPG and error patterns observed) for each of the eight children with repaired cleft palate for oral and nasal alveolar stops (/t/, /d/ and /n/).

	/t/ (n = 4)		/d/ (n = 6)		/n/ (n = 6)	
	PPC	Errors perceived	PPC	Errors perceived	PPC	Errors perceived
Child	PC-EPG	Error patterns observed	PC-EPG	Error patterns observed	PC-EPG	Error patterns observed
1	100%	--	83%	[d]/[g] “dolls”.	83%	[nŋ] (J1), [nɲ] (J2) “spanner”.
	0%	E2 all tokens.	0%	E2 all tokens.	0%	E2 all tokens.
2	25% (75%)	[ʔ] “biscuit”, “sweater”; [t]/[k] “tickling”.	0%	[ʔ] “dolls”, “ladder”, “desk”; [n] “did”.	100%	--
	0% (25%)	E1 “sweater”, “tickling”; E1, E2 “biscuit”, “toolshed”.	0%	E1 all (four) tokens.	33%	E1 “clown”, “crayon”, “nose”; E1, E2 “spanner”.
3	50%	[k] “tickling”; [k] (J1), [ʔ] (J2) “biscuit”.	67%	[t] (J2) “ladder”; [d]/[g] (J2) “desk”.	83%	[ŋ] (J1) “crayon”.

	0%	E1 “sweater”; E2 “toolshed; E1, E2 “biscuit”, “tickling”.	33%	E1 “did”, “ladder”; E2 “dolls”; E1, E2 “desk”.	67%	E1 “crayon”, “spanner”.
4	75%	[t]/[k] (J1) “biscuit”.	100%	--	83%	[n]/[ŋ] (J1), [n]/[m] (J2) “crayon”.
	50%	E1 “biscuit”; E1, E2 “tickling”.	67%	E1 “ladder”, “desk”.	50%	E1 “crayon”, “snowman”; E1, E2 “clown”.
5	100%	--	100%	--	83%	[ŋ] (J1) “clown”.
	25%	E2 “sweater”, “tickling”, “toolshed”.	67%	E2 “desk”, “dolls”.	50%	E2 “crayon”, “snowman”, “spanner”; E1, E2 “clown”.
6	100%	--	100%	--	100%	--
	0%	E2 all tokens.	0%	E2 all (four) tokens.	67%	E1, E2 “clown”, “nose”.
7	75%	[ʔh] (J1), [ʔ] (J2) “biscuit”.	100%	--	100%	--
	25%	E1 “biscuit”; E2 “tickling”, “toolshed”.	67%	E2 “desk”, “ladder”.	33%	E1 “nose”, “spanner; E1, E2 “clown”, “crayon”.

8	0% (25%)	[ʔ] “biscuit”; [ʔx] “sweater”; [ʔħ] “toolshed”; [ñ̥] (J1), [x] (J2) “tickling”.	0%	[ʔ] “ladder”, “did”; [n͡ʔ] (J1), [dˤ] (J2) “dolls”; [d͡ʔ] (J1), [dˤ] (J2) “desk”.	83%	[ñ] (J2) “snowman”.
	0%	E1 all tokens.	17%	E1 “dolls”, “did”, “ladder”.	100%	--

Note. J1 = Judge 1; J2 = Judge 2; E1 = Error contact pattern 1 – absence of complete contact in alveolar region; E2 = Error contact pattern 2 – presence of contact in posterior central region of the palate. There were two missing data points, /d/ in “a said” and “a shed”, for child 2, 6 and 8. For target /t/, the results in brackets show the percent correct when /t/ → [ʔ] in word medial and word final position was considered as acceptable dialectal variations.

Table 3. Results of perceptual judgement (top row: percent phoneme correct/PCC and errors perceived for the incorrect realisations) and tongue-palate contact pattern analysis (bottom row: percent correct/PC-EPG and error patterns observed) for each of the eight children with repaired cleft palate for oral and nasal alveolar stops (/k/, /g/ and /ŋ/).

Child	/k/ (n = 5)		/g/ (n = 4)		/ŋ/ (n = 6)	
	PPC PC-EPG	Errors perceived Error patterns observed	PPC PC-EPG	Errors perceived Error patterns observed	PPC PC-EPG	Errors perceived Error patterns observed
1	100%	--	100%	--	67%	[n] "painting"; [nŋ] (J2) "melting".
	80%	E2 "bike".	100%	--	83%	E2 "fishing".
2	20%	[ʔ] "circus"; [x] "shark"; [q] (J2) "chalk"; [ç]/[x] (J1), [ʕ] (J2) "bike".	25%	[ʔ] "pig", "sugar", "gold".	17% (33%)	[n] "hanger", "watching"; [nŋ] "tickling"; [n]/[ŋ] (J2) "fishing", "melting".
	40%	E2 "chalk", "circus", "bike".	0%	E2 all tokens.	17%	E2 "hanger", "painting", "melting", "tickling", "watching".
3	80%	[ʔ] "shark".	75%	[d] (J1) "gold".	100%	--

	80%	E2 “bike”.	50%	E2 “big”, “sugar.	0%	E2 all tokens.
4	60%	[x] “circus”; [ŋ̰̃] “shark”.	100%	--	17% (33%)	[n] “watching”, “painting”; [n]/[ŋ] “melting”; [n]/[m] (J2) “fishing”; [n] (J2) “tickling”.
	80%	E2 “bike”.	25%	E2 “big”, “pig”, “sugar”.	17% (33%)	E2 “fishing”, “painting”, “melting”, “tickling”, “watching”.
5	100%	--	100%	--	50%	[n] “fishing”, “watching”; [n] (J2) “tickling”.
	100%	--	100%	--	100%	--
6	100%	--	100%	--	33%	[n] (J2) “fishing”, “tickling”; [n]/[ŋ] (J1), [n] (J2) “watching”; [n]/[ŋ] (J2) “painting”.

	60%	E2 “chalk”, “circus”.	75%	E2 “gold”.	67%	E2 “fishing”, “tickling”.
7	100%	--	25%	[kx] (J1) “pig”; [g̟] (J2) “sugar”, “gold”.	83%	[n] (J2) “painting”.
	60%	E2 “circus”, “bike”.	75%	E2 “big”.	17%	E2 “fishing”, “painting”, “melting”, “tickling”, “watching”.
8	0%	[ʔ] “circus”, “bike”; [ʔx] “kick”; [ʔ] (J2) “chalk”, “shark”.	0%	[ʔ] “gold”, “big”; [ʔʕ] “pig”; [ʔ] (J1), [ʕ] (J2) “sugar”.	0% (17%)	[n] “painting”; [n]/[ŋ] “fishing”, “tickling”, “watching”, “melting”; [ŋn] (J1), [n]/[ŋ] (J2) “hanger”.
	60%	E1 “circus”, “shark”.	75%	E2 “gold”.	0% (17%)	E2 all tokens.

Note. J1 = Judge 1; J2 = Judge 2; E1 = Error contact pattern 1 – absence of contact in velar region; E2 = Error contact pattern 2 – presence of contact in anterior central region of the palate. For target /ŋ/, the results in brackets show the percent correct when /ŋ/ → [n] was considered as acceptable dialectal variations.

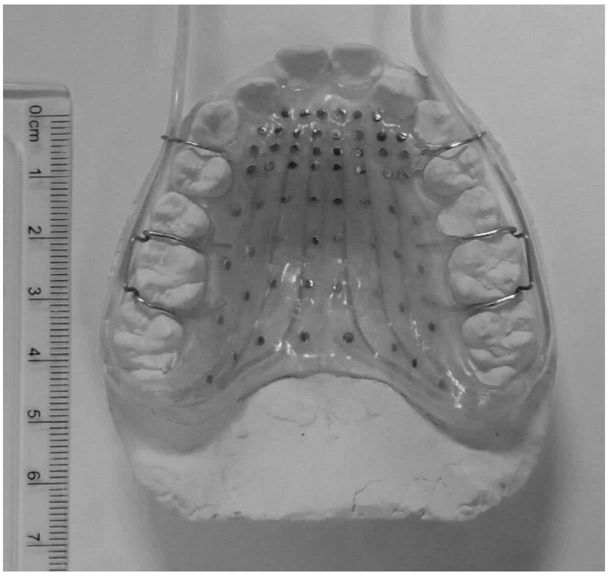
Table 4. Percentage and number of productions that showed error tongue-palate contact patterns for the oral and nasal alveolar and velar stops.

	Error pattern 1	Error pattern 2	Error pattern 1 + 2
Alveolar stops			
/t/	28% (9/32)	44% (14/32)	16% (5/32)
/d/	26% (11/42)	36% (15/42)	2% (1/42)
/n/	19% (9/48)	17% (8/48)	14% (7/48)
Velar stops			
/k/	5% (2/40)	25% (10/40)	0% (0/40)
/g/	0% (0/32)	37% (12/32)	0% (0/32)
/ŋ/	0% (0/48)	62% (30/48)	0% (0/48)

Note. For alveolar stops, error pattern 1 was absence of complete contact in alveolar region; error pattern 2 was presence of contact in posterior central region of the palate. For velar stops, error pattern 1 was absence of contact in velar region; error pattern 2 was presence of contact in anterior central region of the palate.

Figure 1. (a) Photograph of a Reading EPG plate of a typical adult placed on a plaster model of the person's palate and upper teeth. (b) Two EPG frames showing a typical contact pattern expected in children speakers for alveolar stops /t/, /d/ and /n/ (left) and velar stops /k/, /g/ and /ŋ/ (right), with filled squares representing tongue-palate contact. Row numbers 1-8 and lateral and central columns of electrodes are indicated, as are the phonetic regions of the palate and the part of the tongue presumed to make contact with these regions.

(a)



(b)

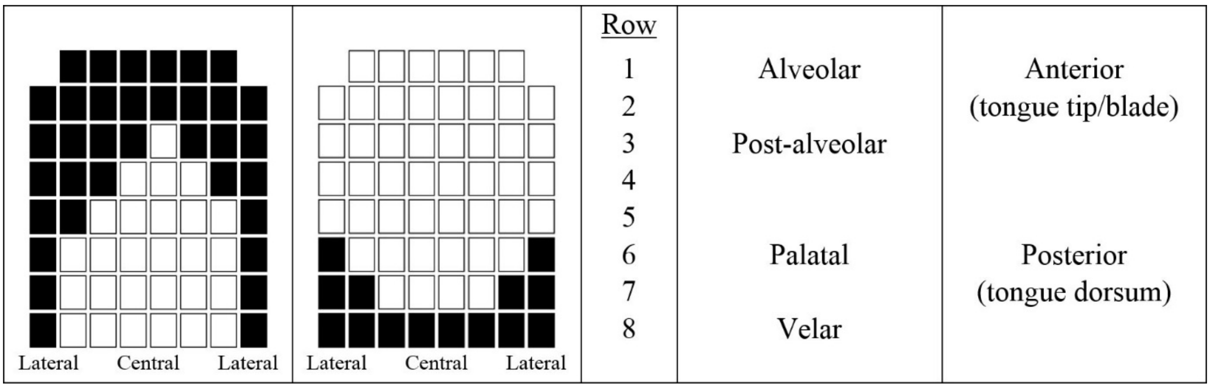
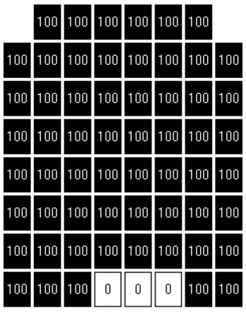
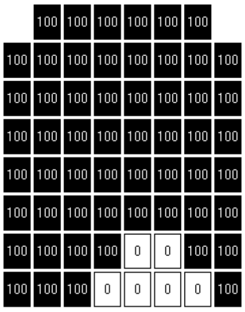
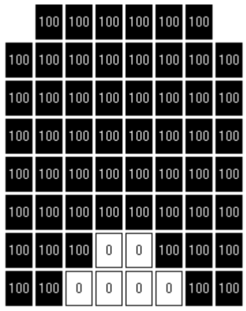
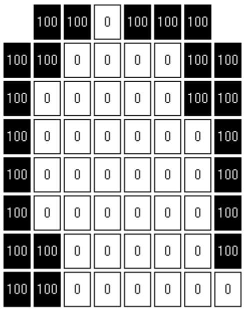
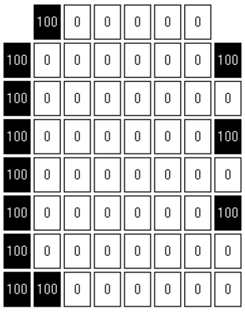
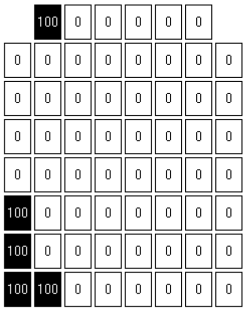
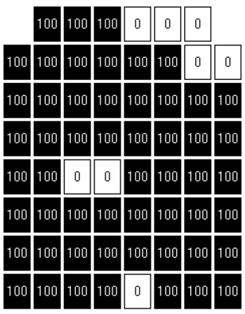
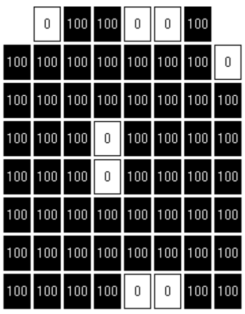
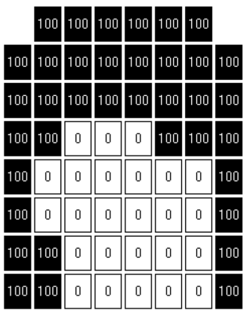
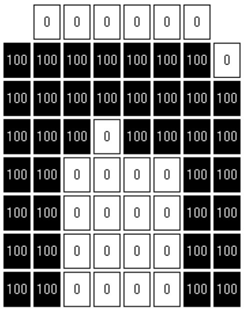


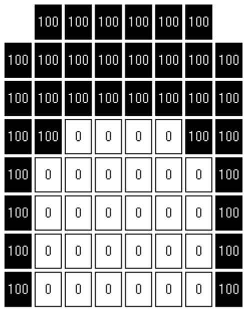
Figure 2. Tongue-palate contact pattern at the temporal mid-point of the oral and nasal alveolar stop segments produced by three children with repaired cleft palate (child 1, 3 and 6) and a typically developing child (child 10), with the phonetic transcription made by the two judges (J1 and J2) provided under each of the EPG frames.

	/t/ in “a sweater”	/d/ in “a ladder”	/n/ in “a spanner”
Child 1	 [t] (J1, J2)	 [d] (J1, J2)	 [nŋ] (J1), [nɲ] (J2)
Child 3	 [t] (J1, J2)	 [d] (J1), [t] (J2)	 [n] (J1, J2)
Child 6	 [t] (J1, J2)	 [d] (J1, J2)	 [n] (J1, J2)

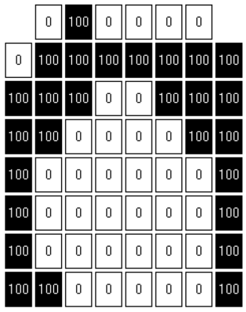
Child 10



[t] (J1, J2)



[d] (J1, J2)

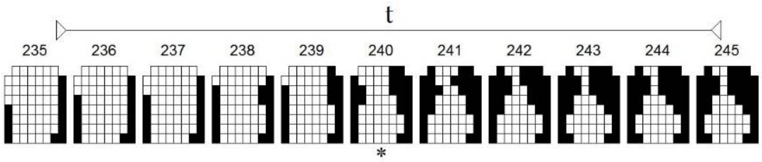


[n] (J1, J2)

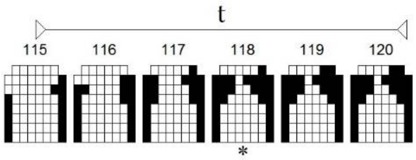
Figure 3. Dynamic EPG frames (with an asterisk marking the temporal mid-point of the segment) showing contact patterns observed in the two typically developing children (child 9 and 10) that did not pass the criteria of correct tongue-palate contact pattern defined for alveolar and velar stops: (a) absence of complete contact in alveolar region (row 1-3) and (b) presence of contact in posterior central region of the palate (central two electrodes in row 5 and central four electrodes in row 6-8).

(a)

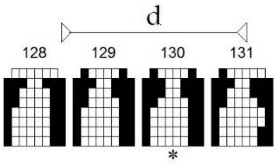
Child 9, “biscuit”:



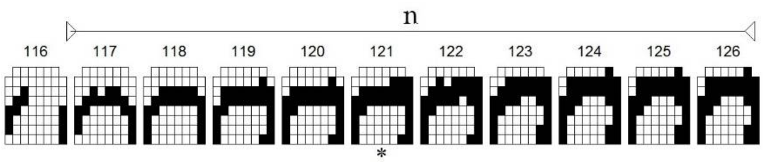
Child 9, “sweater”:



Child 9, “did”:

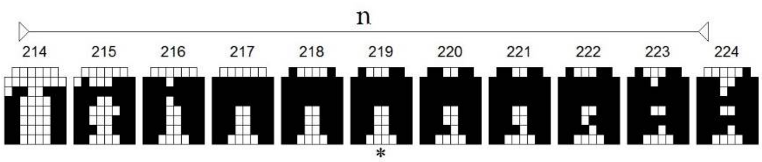


Child 9, “crayon”:

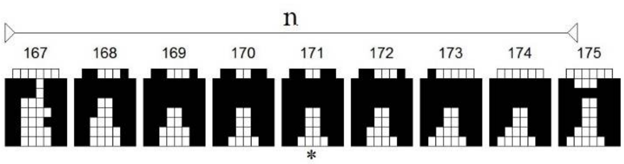


(b)

Child 9, “new”:



Child 10, “new”:



Child 10, “tickling”:

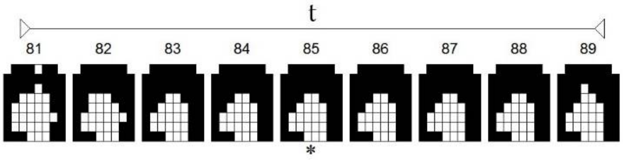
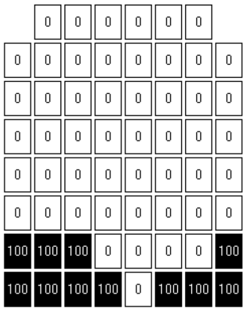
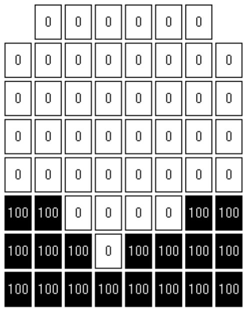
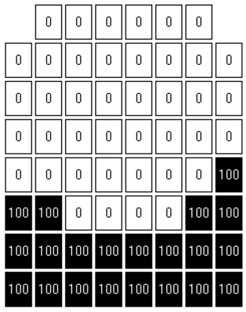
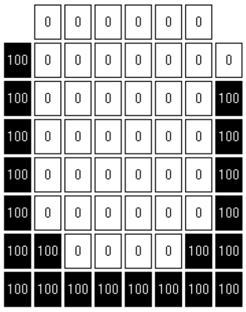
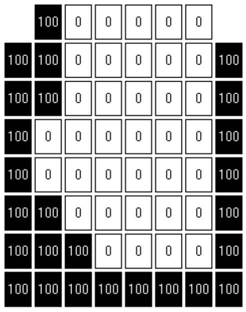
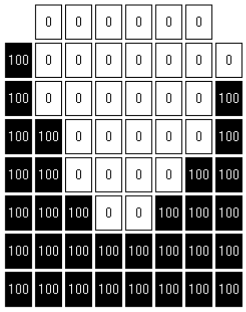
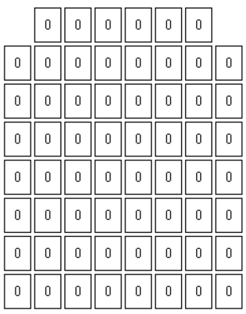
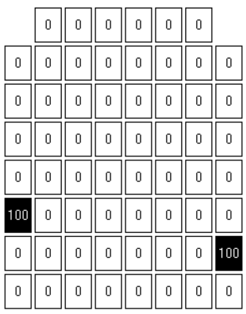
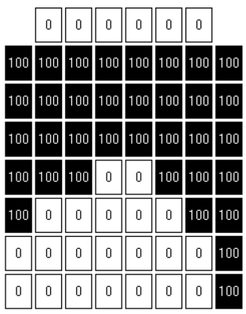
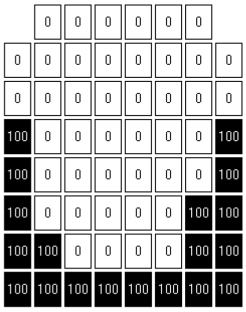


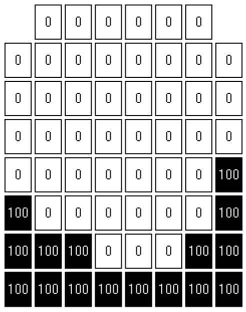
Figure 4. Tongue-palate contact pattern at the temporal mid-point of the oral and nasal velar stop segments produced by three children with repaired cleft palate (child 1, 3 and 8) and a typically developing child (child 10), with the phonetic transcription made by the two judges (J1 and J2) provided under each of the EPG frames.

	/k/ in "a circus"	/g/ in "the sugar"	/ŋ/ in "a hanger"
Child 1			
	[k] (J1, J2)	[g] (J1, J2)	[ŋ] (J1, J2)
Child 3			
	[k] (J1, J2)	[g] (J1, J2)	[ŋ] (J1, J2)
Child 8			
	[ʔ] (J1, J2)	[ʔ] (J1), [ʕ] (J2)	[ŋn] (J1), [n]/[ŋ] (J2)

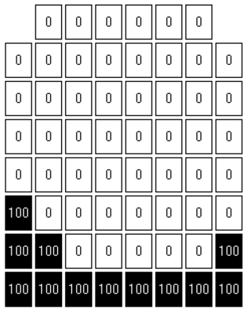
Child 10



[k] (J1, J2)



[g] (J1, J2)

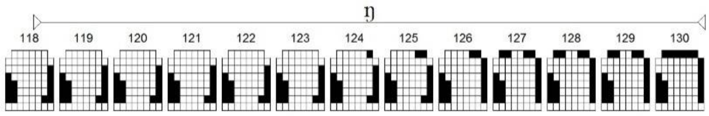


[ŋ] (J1, J2)

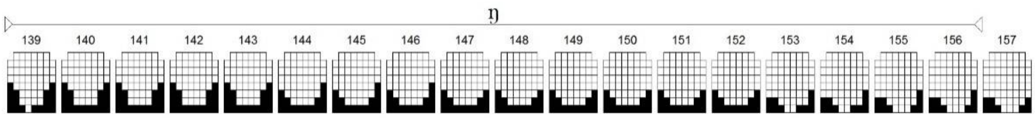
Figure 5. Dynamic EPG frames showing variability in tongue-palate contact patterns within a segment observed in children with repaired cleft palate (child 2 and 5) with comparison to the contact patterns for the same targets – (a) /ŋ/ in "watching" and (b) /n/ in "nose" – from a typically developing child (child 10).

(a)

Child 2 (/ŋ / → [n]):

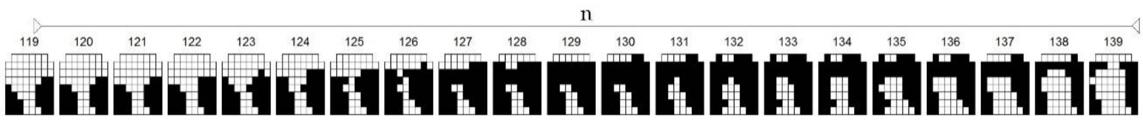


Child 10:



(b)

Child 5 (/n/ → [n]):



Child 10: