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Electropalatography in the description and treatment of speech disorders in five children with cerebral palsy

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Abstract

Some children with cerebral palsy have articulation disorders that are resistant to conventional speech therapy. The aim of this study was to investigate whether the visual feedback method of electropalatography (EPG) could be an effective tool for treating five children (mean age of 9.4 years) with dysarthria and cerebral palsy and to explore whether training improved the posteriorly placed articulation of the Swedish dental/alveolar target consonants /t/, /d/, /n/ and /s/ produced in different positions. An EPG analysis was conducted and some of the data were combined with a perceptual analysis. A more anterior placement was seen after treatment for the target sounds. Features of diagnostic importance revealed were unusual tongue–palate contacts, such as double articulation and abnormally retracted articulation. A possible change in stop closure duration was indicated. The results suggest that EPG could be of potential benefit for diagnosing, treating and describing articulation errors associated with cerebral palsy.

Keywords: *cerebral palsy, electropalatography, articulation disorder, speech therapy*

Introduction

Cerebral palsy is a group of disorders affecting the development of movement and posture and it is attributed to non-progressive disturbances that occur in the developing foetal or infant brain (Bax, Goldstein, Rosenbaum, Leviton, Paneth, Dan, Jacobsson, and Damiano, 2005). Cerebral palsy occurs in 1.92 per 1000 live births in Sweden (Himmelmann, Hagberg, Beckung, Hagberg, and Uvebrant, 2005). The exact prevalence of communication disorders associated with cerebral palsy is not known, but many children with this diagnosis experience difficulties ranging from having mild motor speech disorders to being fully non-verbal (Pennington, Goldbart, and Marshall, 2005).

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Three major types of cerebral palsy are recognised: spastic, dyskinetic and ataxic. Each of these major types is often associated with a characteristic type of dysarthria, that is, the spastic, dyskinetic and ataxic forms of dysarthria (Love, 2000). In general, labial phonemes are easiest for dyskinetic and spastic children to produce correctly, whereas alveolars are the most difficult, due to the inappropriate positioning of the tongue for phonetic segments because of a reduced range of tongue movement (Kent and Netsell, 1978). In their study, the dyskinetic speakers were unable to perform fine shaping of the tongue for consonant articulation. The limited range of tongue movements and the grossness of tongue shaping appeared to be the causes of abnormally long transition times between articulatory movements. In children with dyskinetic and spastic cerebral palsy, omission errors tend to exceed substitutions of phonemes, a finding that is normally not made in the speech development of typically developing children (Irwin, 1972). Velopharyngeal dysfunction is common in both spastic and dyskinetic groups and appears to be a major hazard to normal resonance, articulation and intelligibility (Netsell, 1969). Children with dyskinetic dysarthria may also experience respiratory control problems, which can lead to paradoxical or reverse breathing, air rushes through the vocal tract and sometimes even a lack of phonation; these problems have negative effects on speech performance (Hardy, 1983). Limitations in pitch and loudness due to increased subglottal pressure are common. Ataxic cerebral palsy is uncommon (Hardy, 1983) and no systematic studies of the speech of ataxic dysarthric children have been reported (Love, 2000).

In conventional speech therapy approaches for children with cerebral palsy, speech clinicians have used a variety of techniques to help them establish a particular articulation placement (Strand, 1995). These techniques have included using mirrors for visual feedback, providing verbal descriptions of target placements and using the fingers to manipulate the articulators. These techniques may help the children to improve further by imitation or auditory stimulation, which can be the starting point of many conventional treatment regimens. However, the effect of the techniques has not been demonstrated. Pennington et al. (2005) conducted an in-depth, exploratory systematic review to evaluate the effect of direct speech therapy given to children with cerebral palsy up to 2002. They pointed to the lack of rigorous research evidence of the effectiveness of dysarthria therapy to aid intelligibility. Since then, to our knowledge, only two studies have been conducted to evaluate the effectiveness of speech therapy for this group. The effect of speech therapy for six students aged 10–18 years with dysarthria and cerebral palsy was investigated by Pennington, Smallman, and Farrier (2006). The participants were given intensive individual therapy to increase and maintain breath support for speech and volume across utterances. Gains in intelligibility were observed at the single-word level but not for continuous speech. A comparative study of treatment modalities for improving articulation was made in a 13-year-old child with severe dysarthria associated with spastic cerebral palsy (Marchant, McAuliffe, and Huckabee, 2008). The results revealed significant improvements in single-word articulation but no perceptible changes in overall intelligibility.

If conventional speech therapy does not appear to be effective, electropalatography (EPG) could be an alternative treatment procedure, giving the speakers access to hitherto unavailable visual feedback for monitoring their own tongue movements in real time (Hardcastle, Gibbon, and Jones, 1991). EPG is a technique which records the location and timing of tongue contact with the hard palate during continuous speech. The EPG system consists of 62 electrodes in an individually designed palatal plate connected to either a computer or a portable training unit (PTU). On the screen, the speaker is presented with real-time visual feedback on tongue–palate contact (Scobbie, Wood, and Wrench, 2004). The use of visual feedback through EPG represents a relatively new approach to the clinical management of speech disorders. The results have shown positive outcomes for at least some clinical populations, especially those that have failed to respond to other treatment approaches, after having received speech therapy for some time and having reached a plateau where no progress is being made (Gibbon, 2008). During a 3-year project, 23 British children and young adults with speech disorders, without any improvement as a result of conventional speech therapy, received treatment with EPG. In 13 participants, the speech disorders had no known pathology, nine had a history of velopharyngeal inadequacy associated with cleft palate and one had a diagnosis of dysarthria. After treatment, 18 of the 23 participants, including the participant with dysarthria, produced perceptually normal articulation during careful speech of the sounds targeted during therapy (Dent, Gibbon, and Hardcastle, 1995).

EPG has been found to be valuable in the diagnosis and treatment of speech disorders due to acquired apraxia (Howard and Varley, 1995), cleft palate (e.g. Whitehill, Stokes, and Yonnie, 1996) and hearing impairment (e.g. Dagenais and Critz-Crosby, 1991), including speech after cochlear implant (e.g. Pantelmidou, Herman, and Thomas, 2003). Moreover, children with neurological conditions and cerebral palsy have been treated with EPG, but only a few case studies have so far been performed. Morgan Barry (1995) studied the effect of training in a 12-year-old child diagnosed with Worster-Drought syndrome that presents with severe developmental dysarthria and unintelligible speech, hypernasality and glottal articulation. The baseline assessment of EPG patterns showed minimal tongue-to-palate contact for all lingual obstruents. The child received eight sessions of EPG therapy over 6 weeks and, after this period of time, he was voluntarily able to produce acceptable alveolar stops. Gibbon and Wood (2003) presented a case study of a boy with mild cerebral palsy. An 8-year-old boy with velar fronting had not responded to conventional speech training that he had received between the age of 7 and 8 years. He produced alveolar and velar targets at the same anterior place of articulation. After therapy, he produced velar targets with a more posterior placement. Interestingly, the authors also found an unusual pattern of tongue–palate contact, with increased contact in the right-hand posterior region of the palate, and unusually long stop closure durations, which were interpreted as a subtle form of impaired speech motor control. Even though these studies are mostly small, single-case studies, the results indicate a possible positive effect of using EPG in order to establish new articulatory skills in children with developmental, neurologically related speech disorders.

A few studies have investigated the use of EPG as a therapy tool in Sweden. EPG training was studied in two Swedish boys, with mild and severe dysarthria, respectively, due to dyskinetic cerebral palsy, who took part in a clinical pilot study (Nordberg, Berg, Carlsson, and Lohmander, 2008). The targets for EPG therapy were speech errors affecting the dental/alveolar target /t/, which was consistently retracted to a velar placement. After an 8-week period of EPG therapy, the ability to produce the initial /t/ improved significantly. The intelligibility of single words was measured and improvements were made by one of the boys (Nordberg et al., 2008). Another study was a case study of an 11-year-old girl with an isolated cleft palate and retracted oral articulation, that is, the oral posterior placement of dental/alveolar plosives /t/, /d/ and /s/ (Lohmander, Henriksson, and Havstam, 2010). An instrumental and perceptual analysis revealed a significant improvement in the production of the target sounds /t/ and /s/ in words and sentences after 5 months of EPG therapy, improved accuracy of single words with the target consonants and improved intelligibility in spontaneous speech. An analysis of tongue–contact patterns revealed that the participant had more correct articulatory patterns of /t/ and /s/ after just 2 months of treatment, which is similar to results reported in individuals speaking other languages (Lohmander et al., 2010). In a case study by Lundeborg and McAllister (2007), a child with severe developmental verbal dyspraxia received a combination of EPG training and intra-oral sensory stimulation. The child's speech improved significantly, but, as the authors pointed out, it would be important in future research to evaluate the two therapy techniques separately.

Little is known about the articulatory dynamics of speech in children with dysarthria and cerebral palsy and, for this group, the EPG technique may help to detect where in the oral cavity the articulatory event occurs. It would be interesting to investigate whether the preliminarily good results of EPG treatment reported in individuals with neurologically related speech disorders could also be seen in Swedish speakers. This would increase the opportunity to generalise the results. The purpose of this study was to investigate whether the visual feedback method of EPG could be an efficient tool for treating children with articulation disorders and cerebral palsy. The specific aim was to study whether training the Swedish dental/alveolar consonants /t/, /d/, /n/ and /s/ with EPG feedback could improve the articulation of the targets in different positions in single words.

Method

Participants

This study comprised five children (C1–C5), three boys and two girls, aged between 7.4 and 13.9 years (mean 9.4 years), with cerebral palsy and dysarthria. Brief case histories of the participants collected from their clinical records are summarised in Table I. Three children had dyskinetic cerebral palsy, two had spastic cerebral palsy and, of the five children, four were diagnosed as having mild dysarthria and one was diagnosed with severe dysarthria. Before EPG treatment, a broad phonetic transcription was used with symbols from Engstrand (1999) for the production of the dental/alveolar target consonants /t/, /d/, /n/ and /s/ in the probe words /toː/, /dœɹ/, /nalə/ and /suːl/ for all participants. All the children displayed a retracted oral/posterior articulation pattern for the dental target consonants that were most often perceived as velars (Table I).

EPG instrumentation

The WinEPG™ system (Articulate Instruments Ltd., Musselburgh, East Lothian, UK) was used in this study (Scobbie et al., 2004). In order to record the dynamic tongue–palate contact patterns, each participant had an artificial palate individually constructed to fit against the hard palate. The palate contained 62 electrodes, placed in 8 horizontal rows according to well-defined anatomical landmarks, with the electrodes arranged in such a way that row 1 had 6 electrodes, while rows 2–8 each contained 8 electrodes (Hardcastle and Gibbon, 1997).

Procedures

Palatal appliances. Dental impressions were made for each child by his/her local dentist. The impression was taken as far back as the junction of the hard and soft palates at the very least and included the gums immediately behind the posterior molar teeth to guide the accommodation of the wires leading from the EPG palate. The EPG plates were created by a specialist dental technician at the Orthodontic Laboratory at the Institute for Postgraduate Dental Education in Jönköping, the only place in Sweden where EPG plates are produced. Organising and making the dental impressions, followed by the production of the EPG plate, took about 3 weeks.

Table I. Participants' details and perceptual description of place and manner of articulation for the initial targets in the probe words /to:/, /dœr/, /nalə/ and /su:l/ for all participants before EPG treatment.

Child	Age at assessment (years:months)	Severity of dysarthria	Associated medical condition	Target consonants			
				/t-/	/d-/	/n-/	/s-/
C1	10:1	Mild	Mild dyskinetic cerebral palsy, mild motor coordination disorder, walks without aids	Velar plosive	Velar plosive	Palatal/velar nasal	Velar fricative
C2	7:10	Mild	Mild dyskinetic cerebral palsy, mild motor coordination disorder, walks without aids	Glottal voiceless fricative	Velar plosive	Correct	Palatalised /velarised fricative
C3	7:4	Severe	Moderate dyskinetic cerebral palsy, moderate motor coordination disorder, walks with a walker	Velar plosive	Palatal/velar fricative	Palatal/velar nasal	Palatal/velar fricative
C4	8:7	Mild	Mild spastic cerebral palsy, mild motor coordination disorder, walks without aids	Velar plosive	Velar plosive	Palatal/velar plosive	Correct
C5	13:9	Mild	Mild spastic cerebral palsy, mild motor coordination disorder, walks without aids	Lateral /l/	Palatalised/ velarised plosive	Correct	Interdental fricative

Note: EPG, electropalatography.

Recording. The children in this study were given time to become accustomed to the EPG plate prior to the EPG recording. The actual EPG plate was used during this process and a decision was made to end the adaptation phase when the child told his/her parents or the first author (an SLP) when he/she had become accustomed to wearing the EPG plate. The time spent in the adaptation phase was more than 20 minutes, a recommendation made by Fletcher (1989). The children did not report any difficulties during the adaptation phase.

EPG recordings were made with the children wearing the EPG plate. The EPG data were recorded and displayed on a computer screen using the Articulate Assistant (version 1.17) software (Scobbie et al., 2004). The children were assessed with EPG on two occasions, once before the EPG therapy and again after 8 weeks of therapy. All the recordings were made at the Division of Speech and Language Pathology, Sahlgrenska Academy at the University of Gothenburg. Audio recordings without the EPG plate were made on the same occasion and a digital tape recorder (Sony Digital Audio Recorder PCM-R300, Sony, Japan) and a microphone (Sony Microphone ECM-M3957, Sony, Japan) were used.

Speech material. For the recording with the EPG plate, the children were encouraged to name 70 pictures from the Swedish Articulation and Nasality TEst (SVANTE) (Lohmander, Borell, Henningsson, Havstam, Lundeborg, and Persson, 2005). The children were asked to repeat the 70 words three times, in order to register the stability of production. The total number of named words was therefore 210. The target sounds for the EPG analysis in this study were only the Swedish dental/alveolar consonants /t/, /d/, /n/ and /s/ in the initial, medial and final positions and they were selected from SVANTE (Table II). The words were embedded in a carrier phrase beginning with the close-mid vowel [o]; for example, [o], during the EPG recordings, in order to avoid palatal contact. The recorded words were not the same as the words used in the treatment.

For the audio recordings, the children were encouraged to name the same speech material that was used for the EPG analysis, without the EPG palatal plate on this occasion.

Treatment. Before the EPG therapy was started, a meeting was held to inform the children and their parents about the planning and they gave their informed consent. Each family was lent a PTU and the therapy took place primarily at home where the children practised with the PTU for about 15 minutes a day, 5 days a week, over a period of 8 weeks and were supervised by their parents (40 treatment sessions). For one child, C3, this intensity was too high because he was participating in a physiotherapy programme at the same time as the EPG sessions. He therefore practised for 15 minutes a day, 3 days a week (24 treatment sessions). The children in this study were all cooperative. All other speech training was cancelled during this therapy period. The target consonants in training were placed in the initial, medial and final positions, followed by a vowel. At the beginning of the training period, there were syllables and words containing the target consonants. This was followed by sentences containing the target consonants and, finally, a short story. The children received constant visual feedback from the PTU in the training phase. An overview of the exercises is presented in Table III.

Data analysis

The Swedish consonant system consists of 18 consonants (Table IV). The dental/alveolar phonemes /t/, /d/, /n/ and /s/ are normally produced with the tongue at the most anterior place of articulation, according to the assignment of the EPG palatal plate (Hardcastle et al., 1991). The EPG pattern for a typical Swedish dental /t/ is shown in Figure 1. Three frames are

Table II. The named words, from the SVANTE test (Lohmander et al., 2005), in the EPG assessment that contained the target sounds /t/, /d/, /n/ and /s/ in the initial, medial and final positions.

	Word with phonetic transcription	English	Word with phonetic transcription	English	Word with phonetic transcription	English	Word with phonetic transcription	English
Initial targets								
/t/	teve [teːvə]	television	tå [toː]	toe	tåg [toːg]	train		
/d/	dusch [dəʃ]	shower	duva [dːʉva]	pigeon	dörr [dœɹ]	door		
/n/	nalle [nalə]	teddy	ner [neːɹ]	down				
/s/	sallad [salad]	salad	sitter [siteɹ]	sit	sol [suːl]	sun	säng [sɛŋ]	bed
Medial targets								
/t/	råtta [rɔta]	rat	matta [mata]	carpet	sitter [siter]	sit		
/d/	låda [loːda]	box	godis [guːdɪs]	sweet	bädda [bɛda]	make one’s bed		
/n/	måne [moːnə]	moon	höna [hœːna]	hen				
/s/	läsa [læːsa]	read	russin [røsɪn]	raisin				
Final targets								
/t/	vit [viːt]	white	katt [kat]	cat	hatt [hat]	hat		
/d/	röd [rœːd]	red	rädd [rɛd]	afraid	sallad [salad]	salad		
/n/	mun [mɵn]	mouth	russin [rɵsɪn]	raisin	vin [viːn]	wine		
/s/	godis [guːdɪs]	sweet	spis [spiːs]	stove				

Table III. An overview of the weekly EPG exercises.

Week	Exercises	Goal
1	Learn to place the EPG palate correctly. Test of different tongue–palate patterns	Discover the relationship between the movements of the tongue and different tongue–palate patterns on the display of the PTU
2	Production of syllables with the sound initial /t/, /d/, /n/ and /s/, followed by a vowel, and look at the display vary between anterior and posterior places of articulation	To reach an anterior place of articulation when producing /t/, /d/, /n/ and /s/
3	Production of words containing the sounds /t/, /d/, /n/ and /s/ in an initial position	Manage to create a horseshoe shape for /t/, /d/, /n/ and /s/
4	Production of /t/, /d/, /n/ and /s/ (all positions) in words. The children were told to look at the EPG display and not to look at the display	Stabilise the anterior production of /t/, /d/, /n/ and /s/
5	Production of two-word sentences containing /t/, /d/, /n and /s/ in an initial position	To achieve an anterior place of articulation when producing /t/, /d/, /n/ and /s/
6	Production of two-word sentences containing /t/, /d/, /n/ and /s/ (all positions)	To achieve an anterior place of articulation when producing /t/, /d/, /n/ and /s/
7	Production of three- and four-word sentences containing /t/, /d/, /n/ and /s/	To try to generalise the anterior place of articulation for /t/, /d/, /n/ and /s/ in single words to the target sounds in sentences
8	Short stories containing words and sentences with /t/, /d/, /n/ and /s/ (all positions)	To try to generalise the anterior place of articulation for /t/, /d/, /n/ and /s/ in words and sentences to a more complex short story

Notes: The type of speech therapy the children received each week and the desired goals are indicated. EPG, electropalatography.

Table IV. The Swedish consonant system (Engstrand, 1999).

	Bilabial	Labiodental	Dental	Alveolar	Palatal	Velar	Glottal
Plosive	p b		t d			k g	
Nasal	m		n			ŋ	
Fricative		f v	s		ʝ		h
Approximant				ɹ			
Lateral approximant			l				

Notes: The place of articulation for the Swedish phonemes /t/, /d/, /n/ and /s/ is mainly dental. ɧ, voiceless dorso-palatal/velar fricative; ɕ, voiceless alveolo-palatal fricative will also be included.

identified in the figure: (a) onset – the first frame showing complete mid-sagittal closure (representing the beginning of the stop closure phase), (b) maximum contact – the frame with the largest number of activated electrodes during closure (the point of maximum articulatory constriction) and (c) release – the last frame showing complete mid-sagittal contact across the palate; this is the end of closure and the beginning of the release phase (Gibbon, 1999).

EPG analysis

The target consonants were identified on the EPG printouts. The EPG frames of maximum contact during closure for the target sounds were selected and the centre of gravity (COG) and alveolar total (AT) were calculated from this frame as a quantitative measure.

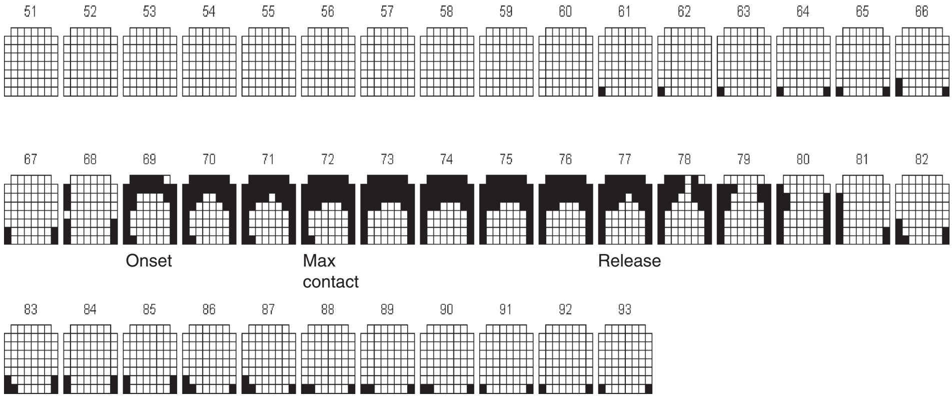

Figure 1. EPG printout of a /t/ pronounced by an adult in standard Swedish. The frames of onset, release and maximum contact are indicated.

The COG values represent the position of the greatest concentration of activated electrodes across the whole palate. Low COG values correspond to posterior tongue–palate contact and high values to anterior tongue–palate contact. The following formula was used to calculate COG in this study: $COG = 1/8[(1 \times R8) + (2 \times R7) + (3 \times R6) + (4 \times R5) + (5 \times R4) + (6 \times R3) + (7 \times R2) + (8 \times R1)]$/total number of activated contacts (R = row and R8 is the total number of activated contacts in row 8, i.e. the most posterior row) (Hardcastle et al., 1991). The AT value represents tongue contact with the first two rows. These scores range from 0 to 14, where a score of 14 indicates that all 14 electrodes in the first two anterior rows are activated. Accordingly, rows 1–2 are considered to represent dental/alveolar sounds, rows 3–5 palatal sounds and rows 6–8 velar sounds. This assignment is in line with Hardcastle et al. (1991).

Furthermore, a brief analysis of the temporal features of articulation was made. The segmentation of the EPG data was conducted using ‘totals displays’. A totals display is a graph that presents the number of activated electrodes within a region of the palate as a function of time (Hardcastle et al., 1991). The timing of the target initial /t/ was explored in this study and the totals displays for the anterior region (rows 1–4) of the EPG palate were therefore required. Four specific points across the totals displays were used to measure three phases of the consonant in this production: (a) the approach phase in which the tongue moves to form a pattern of closure on the palate, (b) the stable closure/constriction phase and (c) the release phase of the consonant in which the tongue moves from its position for the following sound (McAuliffe, Ward, and Murdoch, 2003). The duration of the approach, closure/constriction and release phases of the production of the word initial /t/ in the Swedish word /to:/ before and after EPG therapy was chosen as an example. The tongue-to-palate contact patterns were sampled at 10-millisecond intervals (100 Hz). The raw scores for phase durations for three repetitions of the target consonant were calculated (in milliseconds).

Pattern of tongue-to-palate contact and perceptual speech analysis

Qualitative observations of changes in the place of articulation from the EPG data were made. The target initial /t/ in the Swedish word /to:/ was selected for all five children from the speech material, as an example of a lingua-palatal pattern. Each child’s speech output was described individually by a speech language pathologist (first author) in terms of changes in the EPG pattern before and after treatment. The frames of onset, maximum contact and release were annotated and marked ‘Onset’, ‘Max’ and ‘Release’, respectively (e.g. Figure 4(a), showing the EPG pattern for C1 before EPG treatment). A perceptual analysis was made at the time of the EPG recordings by the first author. This was a broad phonetic transcription of the target initial /t/ in the Swedish word /to:/ before and after treatment, as one attempt to compare perceptual information with instrumental EPG data.

Statistical analysis

All COG and AT measures before and after training were subjected to non-parametric analyses of repeated measures according to the Wilcoxon matched-pairs test (STATISTICA, 2001).

Results

Quantifying changes in EPG patterns

The COG values at group level were significantly higher in the initial and medial target /t/, with a more anterior placement after treatment than before. There was also a significant change in the final targets, except for final /d/ and /n/, after the treatment period (Table V).

The AT measures revealed statistically significant higher values for initial and medial target consonants, with a more anterior place of articulation after treatment. For the final sounds, there was only a significant improvement in the AT values for final /t/ (Table V).

Articulatory timing

For each participant, the duration of the *approach, closure* and *release* phases of consonant production was calculated for the three repetitions of the *word initial /t/* that was being investigated. Each participant’s raw scores are given in Table VI. There were large variations both within each participant and between participants. Two participants (C1 and C4) reduced the duration of the approach and release phases of the target consonant after treatment. The mean *approach* phase duration before therapy was 125 ms and 126 ms, respectively, compared with 30 ms and 87 ms, respectively, after therapy. The mean phase duration of the *release phase* before EPG therapy was 150 ms and 166 ms, respectively, compared with 70 ms and 130 ms after therapy.

One participant (C2) changed the duration of the closure phase from a mean duration of 135 ms to 77 ms after therapy. One participant (C3) did not achieve complete closure before treatment, so closure phase durations could not be measured. There was a clear closure phase after EPG treatment.

Individual changes

C1. Observations of the EPG data before treatment revealed that the tongue placement for the targeted /t/ was retracted, with complete palatal closure at the onset of the closure and release phases (Figure 2(a)). After treatment, C1 changed the target /t/ to a more anterior contact across the palate (Figure 2(b)). The analysis of the temporal pattern revealed a reduced duration of the approach and release phases after therapy compared with before, whereas the duration of the closure phase was prolonged after therapy (Table VI). The /t/ pronounced before treatment was perceived as a velar fricative and, after therapy, the auditory impression was a clearly pronounced /t/.

Table V. Pre- and post-treatment results of centre of gravity (COG) and alveolar total (AT) measures of /t/, /d/, /n/ and /s/ consonant targets in the initial, medial and final positions in single words.

			Centre of gravity (WMPT)						Alveolar total (WMPT)				
			Before treatment		After treatment		Difference		Before treatment		After treatment		Difference
	Target	*N*	Median	Range	Median	Range	*z*	*N*	Median	Range	Median	Range	*z*
Initial	/t/	60	2.83	0.00–4.52	4.19	0.92–4.94	6.18***	60	0.00	0.00–14.00	14.00	0.00–14.00	6.18***
	/d/	44	3.25	0.00–5.13	3.98	1.23–5.13	3.14**	44	3.82	0.00–14.00	14.00	0.00–14.00	3.14**
	/n/	30	3.34	1.14–4.83	4.21	0.75–4.96	2.89**	30	3.82	0.00–14.00	13.05	0.00–14.00	2.89**
	/s/	60	3.46	0.50–5.75	4.12	1.25–5.34	3.12**	60	3.18	0.00–14.00	7.63	0.00–14.00	3.12**
Medial	/t/	45	3.79	0.70–4.71	4.34	1.32–5.08	4.15***	45	10.80	0.00–14.00	14.00	0.00–14.00	4.15***
	/d/	45	3.13	0.66–5.22	3.91	1.08–4.96	2.98**	45	5.92	0.00–14.00	9.55	0.00–14.00	2.98**
	/n/	30	3.74	0.50–4.70	4.32	0.66–5.24	2.64**	30	5.92	0.00–14.00	10.76	0.00–14.00	2.64**
	/s/	45	3.13	0.83–6.83	4.26	0.90–5.40	3.42***	45	2.55	0.00–14.00	6.37	0.00–14.00	3.42***
Final	/t/	45	3.98	0.92–4.67	4.34	1.38–4.80	4.02***	45	8.90	0–14.00	14.00	0.00–14.00	4.02***
	/d/	45	3.22	0.50–4.86	3.70	1.32–5.08	1.62	45	2.55	0.00–14.00	5.74	0.00–14.00	1.62
	/n/	60	4.00	0.50–4.76	4.18	0.50–5.93	0.83	60	6.75	0.00–14.00	10.82	0.00–14.00	0.83
	/s/	44	3.96	1.14–4.86	4.10	1.50–5.58	2.85**	43	5.73	0.00–14.00	7.00	0.00–14.00	2.13*

Notes: Pre- and post-treatment results of centre of gravity (COG) and alveolar total (AT) measures of /t/, /d/, /n/ and /s/ consonant targets in the initial, medial and final positions in single words. Comparisons before and after were made with the Wilcoxon matched-pairs test (WMPT).
* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Table VI. Durations for the approach, closure and release phases of the target consonant word initial /t/ in the Swedish word /to:/ pronounced three times by the children before and after EPG therapy (in milliseconds).

		Approach		Closure		Release	
Child	Realisation number	Before	After	Before	After	Before	After
C1	1	100	20	160	170	120	80
	2	mv	20	mv	160	mv	60
	3	150	50	40	150	180	70
C2	1	nc	70	nc	90	nc	90
	2	50	89	150	80	150	130
	3	109	79	120	60	130	70
C3	1	nc	60	nc	270	nc	40
	2	mv	140	mv	240	mv	70
	3	nc	60	nc	190	nc	100
C4	1	80	110	90	90	150	120
	2	119	80	80	159	170	160
	3	180	70	80	209	179	110
C5	1	70	60	230	190	80	140
	2	nc	60	nc	219	nc	50
	3	50	40	229	259	140	50

Note: EPG, electropalatography; mv, missing value; nc, no closure phase.

C2. Figure 3(a) and 3(b) illustrates the EPG patterns for C2. There was almost no contact across the palate for the target /t/, with no closure whatsoever before treatment (Figure 3(a)). After therapy, the EPG pattern for the target /t/ was a 'horseshoe-shaped' anterior complete contact across the palate, with little tongue–palatal contact during the closure phase. The analysis of the temporal pattern revealed a shorter duration of the closure phase after therapy compared with before, whereas a longer duration was found in the approach and release phases. Before treatment, there was no dental stop but only a glottal voiceless fricative ((h)). After treatment, C2 had a clearly pronounced /t/.

C3. The EPG patterns for C3 before treatment showed that he had almost no or only slight contact across the palate (Figure 4(a)). After treatment, there was complete closure in the alveolar region and a far greater amount of tongue–palate contact than before treatment. At maximum contact, there was complete contact across the palate in the anterior region, as well as complete side contact (Figure 4(b)). The analysis of the temporal pattern revealed no closure phases at all before therapy, whereas the approach, closure and release phases could be measured after treatment. Both before and after treatment, C3 produced the target stop on inhalation; before treatment, a velar stop was heard and, after EPG treatment, there was a clearly pronounced /t/, although it was still made on inhalation.

C4. EPG data revealed that the tongue placement for /t/ for C4 before treatment was clearly retracted, with complete velar closure in the onset and release phases (Figure 5(a)). Observations of the EPG data revealed a change in the place of articulation from a velar placement of the stop before treatment to a simultaneous anterior/posterior tongue–palate contact during the closure phase, referred to as double articulation (Gibbon, 1999). Figure 5(b) illustrates the alveolar/velar double articulation (frames 118–125) and the frame indicating release (frame 125). Figure 5(b) shows an alveolar release, with the subsequent release of velar closure (frame 127). The analysis of

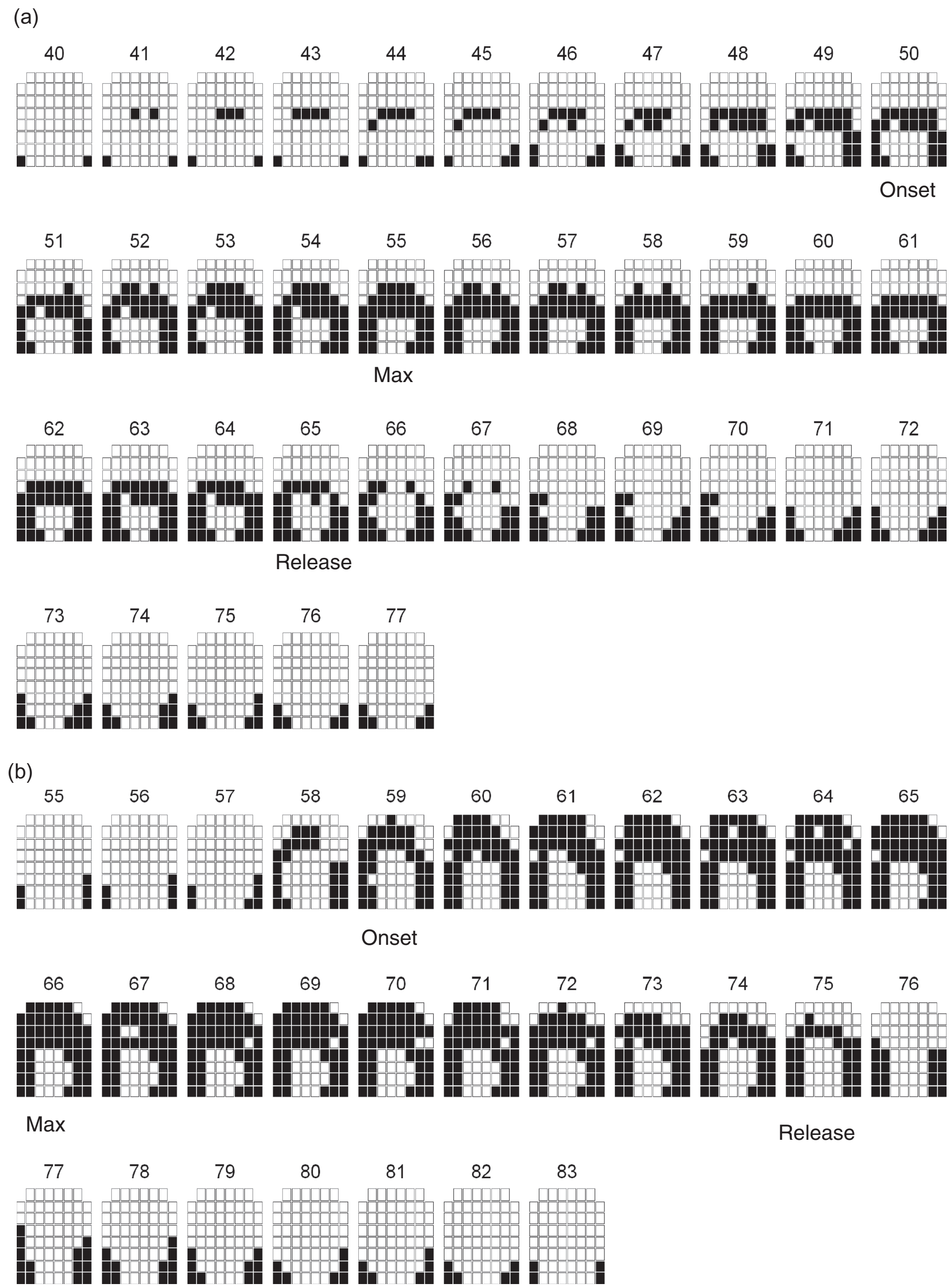

Figure 2. (a) EPG printout of the articulation contact patterns of a /t/ target for C1 in the Swedish word /to:/ before EPG therapy, with predominantly posterior contact. The frames of onset, release and maximum contact are indicated. (b) EPG printout of the articulation contact patterns of a /t/ target for C1 in the Swedish word /to:/ after EPG therapy, with predominantly anterior 'horseshoe-shaped' complete contact. The frames of onset, release and maximum contact are indicated.

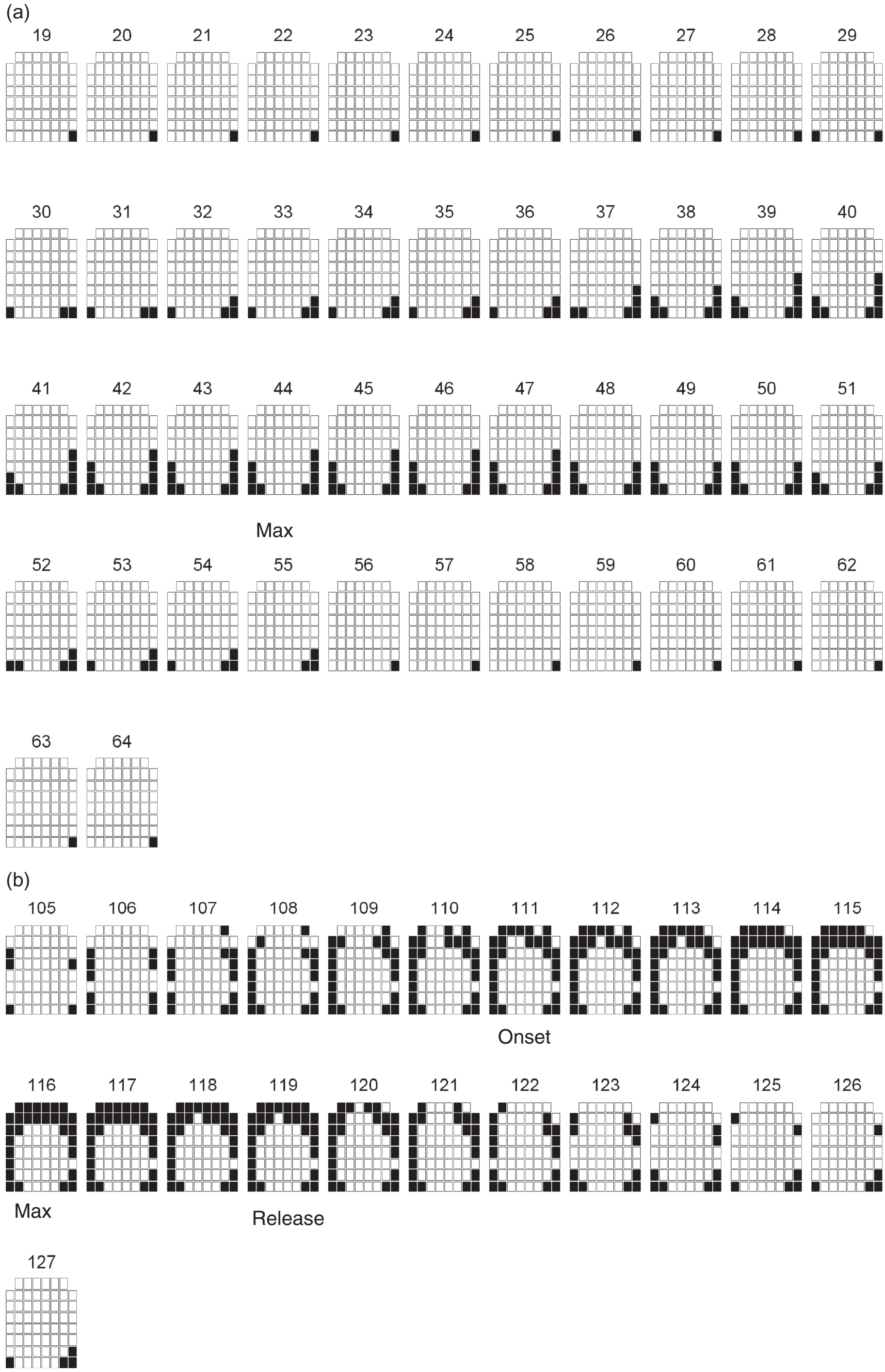

Figure 3. (a) EPG printout of the articulation contact patterns of a /t/ target for C2 in the Swedish word /to:/ before EPG therapy, showing almost no contact at all. The frame of maximum contact is indicated; there is no closure phase. (b) EPG printout of the articulation contact patterns of a /t/ target for C2 in the Swedish word /to:/ after EPG therapy, with predominantly anterior contact. The frames of onset, release and maximum contact are indicated.

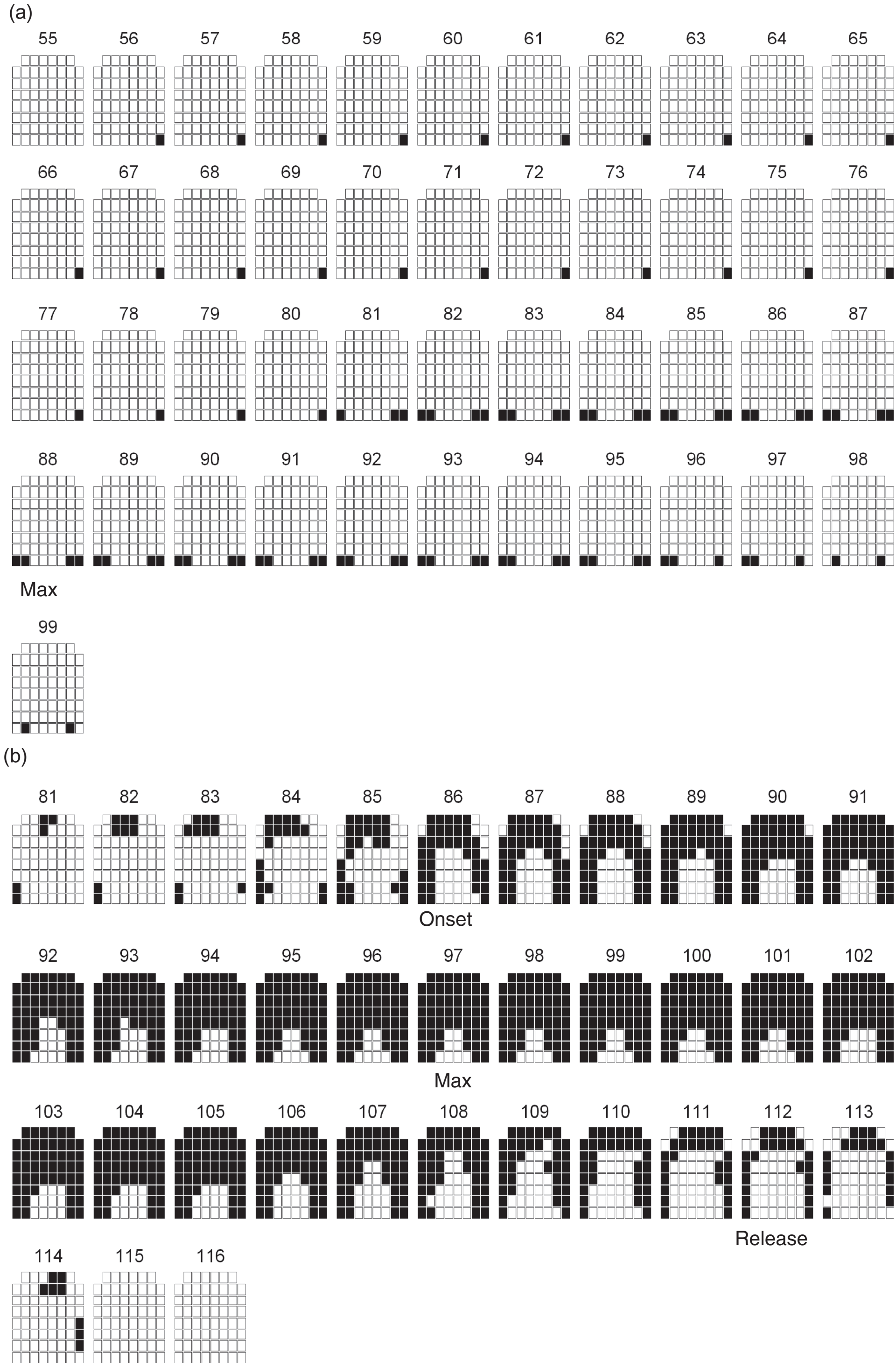

Figure 4. (a) EPG printout of the articulation contact patterns of a /t/ target for C3 in the Swedish word /to:/ before EPG therapy, showing almost no contact at all. The frame of maximum contact is indicated; there is no closure phase. (b) EPG printout of the articulation contact patterns of the /t/ target for C3 in the Swedish word /to:/ after EPG therapy, with increased tongue–palate contact and predominantly anterior contact. The frames of onset, release and maximum contact are indicated.

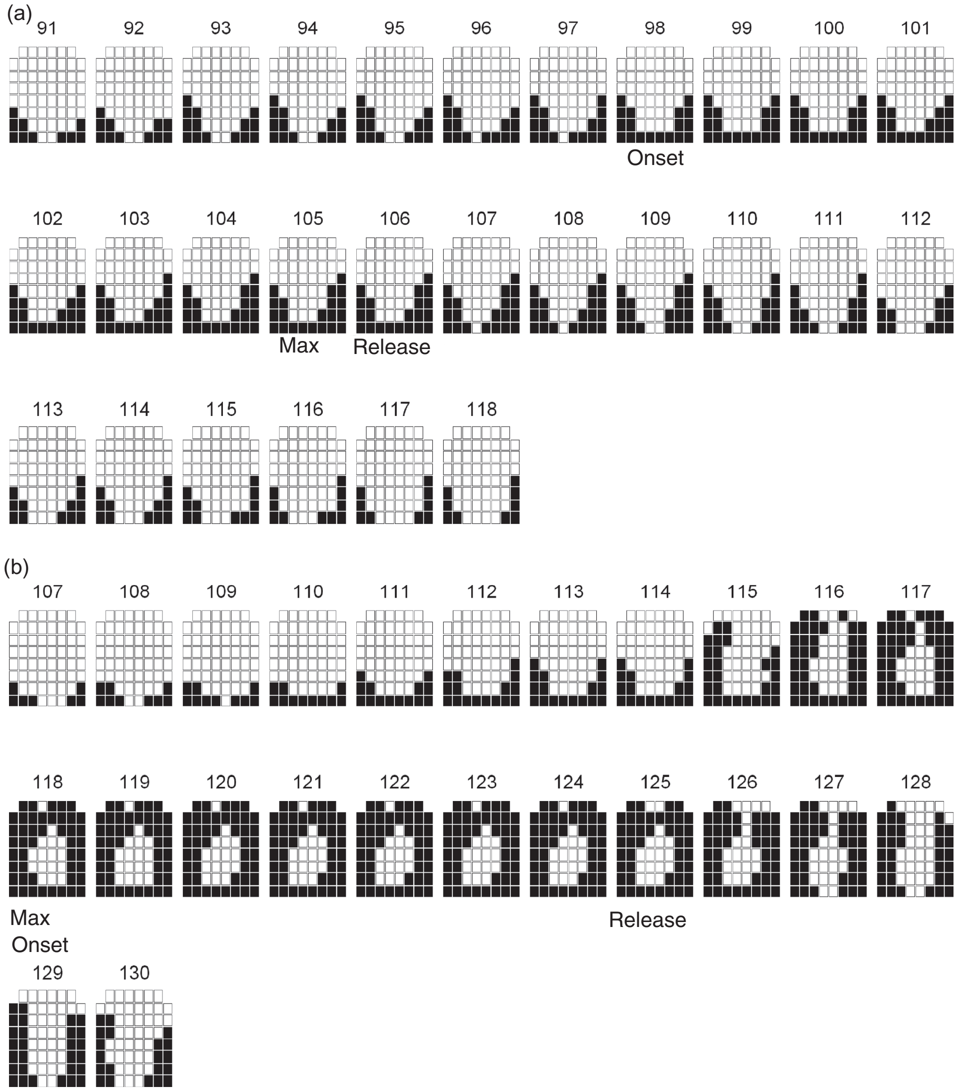

Figure 5. (a) EPG printout of the articulation contact patterns of a /t/ target for C4 in the Swedish word /to:/ before EPG therapy, with predominantly posterior contact. The frames of onset, release and maximum contact are indicated. (b) EPG printout of the articulation contact patterns of a /t/ target for C4 in the Swedish word /to:/ after EPG therapy, with a simultaneous anterior/posterior tongue–palate contact during the closure phase (frames 118–125), referred to as double articulation.

the temporal pattern revealed a reduction in the duration of the approach and release phases after therapy compared with before, whereas the duration of the closure phase was prolonged after therapy (Table VI). Interestingly, the target consonant was perceived as a velar stop before treatment and an acceptable dental stop after treatment.

C5. The EPG data for C5 before treatment demonstrated complete asymmetric closure and increased contact in the right-hand anterior and posterior regions of the palate (Figure 6(a)).

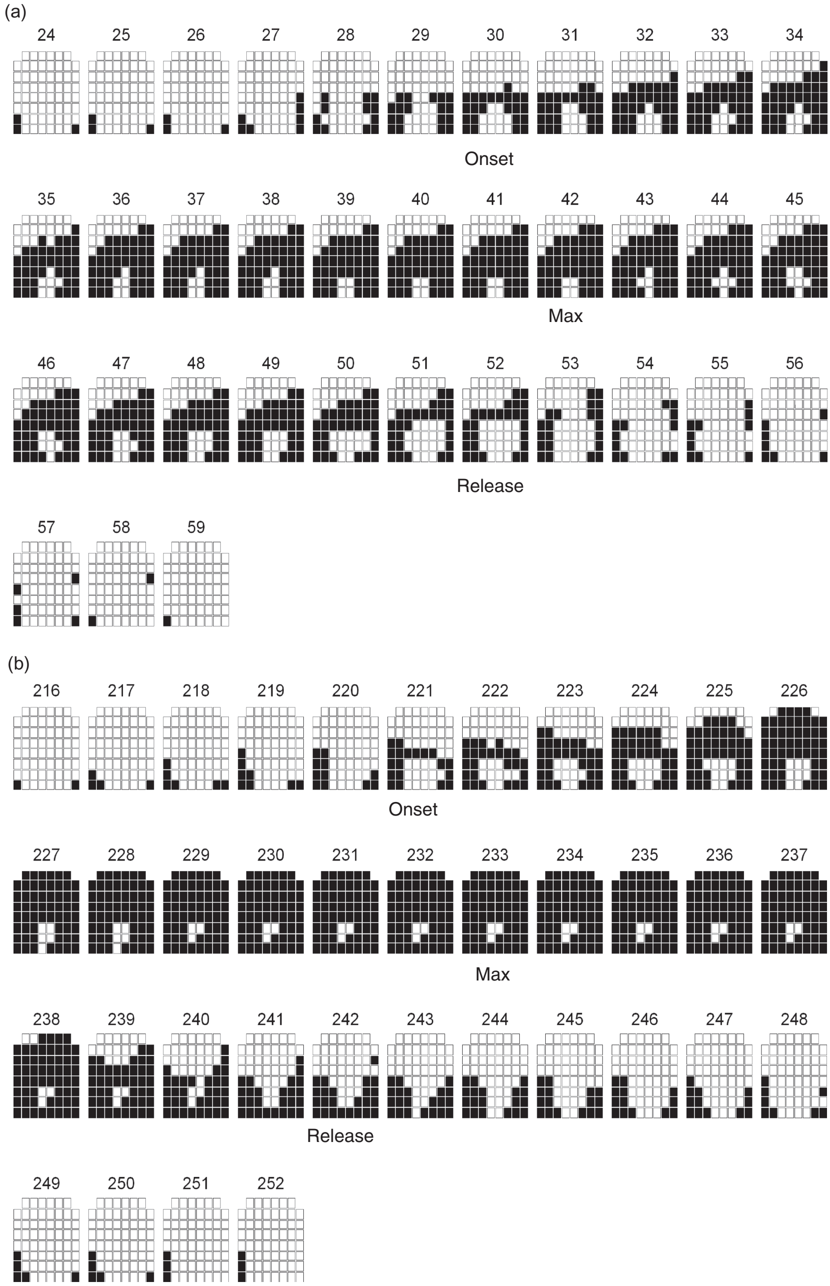

Figure 6. (a) EPG printout of the articulation contact patterns of a /t/ target for C5 in the Swedish word /to:/ before EPG therapy shows complete asymmetric closure and increased contact in the right-hand anterior and posterior regions of the palate. The frames of onset, release and maximum contact are indicated. (b) EPG printout of the articulation contact patterns of a /t/ target for C5 in the Swedish word /to:/ after EPG therapy; there is symmetric increased contact over the palate and almost full contact. The frames of onset, release and maximum contact are indicated.

After treatment, there was increased symmetric contact over the palate and almost full contact (Figure 6(b)). The analysis of the temporal pattern revealed a prolonged duration of the approach and release phases after therapy compared with before, while the duration of the closure phase was shorter than before therapy. Before treatment, the auditory impression of the sound was more like a lateral /l/ than a stop /t/. After treatment, a clearly dental /t/ was pronounced.

Discussion

This study set out to investigate whether EPG would be beneficial in treating speech errors in five children with dysarthria and cerebral palsy. In terms of the results, the EPG analyses revealed a significant improvement in articulatory contact patterns for the children supported by a perceptual analysis. The results of this study also provided useful guidelines for identifying abnormal contact patterns for dental/alveolar consonants in individuals with dysarthria and cerebral palsy. The primary use of the EPG technique in this study was to identify and describe changes in the articulatory placement of the target consonants /t/, /d/, /n/ and /s/.

Previous research using EPG has shown various spatial distortions in patterns for speakers with different speech disorders. Consonants produced with a large amount of tongue–palate contact have been referred to as 'undifferentiated lingual gestures' (Gibbon, 1999). One of these gestures is 'double articulation', that is, when the tongue tip/blade and tongue body overlap for a brief period, resulting in simultaneous anterior/posterior tongue–palate contact (Gibbon, 1999). This has been especially identified in studies of cleft palate speech (Gibbon, 2004; Gibbon, Ellis, and Crampin, 2004). One child in this study displayed retracted articulation of the initial /t/, perceptually judged as a velar plosive, before EPG therapy. After treatment, a double alveolar/velar articulation was found and the EPG pattern showed that the frames before the release phase for the plosive had both alveolar and velar contacts. The alveolar contact was released before the velar contact prior to the vowel starts. The alveolar release phase for this child pronouncing /t/ after treatment was perceptually judged as a dental /t/ but with the velar contact still there. Presumably, the EPG feedback helped this child to try to establish better lingual stability. As a result, she was able to perform a more accurate anterior tongue placement for complex articulations involving an attempt to separate tongue-tip and tongue-body movements when producing the target /t/ after EPG treatment. A similar finding was reported by Hardcastle, Morgan Barry, and Clark (1987), when two children with motor speech disorders associated with developmental dysarthria increased their tongue-body activity for alveolar targets. Gibbon (1999) called this the *deviant control* hypothesis, a strategy to compensate for a tongue-tip/blade system that lacks fine force control with the overuse of the better controlled tongue body.

One characteristic of mature lingual control is when the tongue tip/blade and the tongue body do not always move together but demonstrate the ability to move relatively independent of each other (Hardcastle, 1976). If a child produces these 'whole tongue' articulations during the speech acquisition period, the motor control of the tongue tip/blade and tongue body may fail to develop in the normal way through lack of experience of normal movement patterns (Gibbon et al., 2004). The retracted lingua-palatal placement, for example, for the initial /t/ for the children in this study before EPG therapy may be an example of their not yet having acquired the ability to move the tongue tip properly, due to impaired speech motor control. After therapy, the children displayed a more anterior lingua-palatal placement.

Comparisons of the EPG data and perceptual data in this study reveal lingual behaviours which were not identified by perceptual analyses alone. Before EPG treatment, one child displayed a stricture of complete closure consistent with a palatal stop for the target consonant initial /t/, which was perceptually perceived as a fricative. This intriguing mismatch between the perceptual judgement and the EPG data was seen several times among the children in this study: a perceptually judged velar stop before EPG treatment was presented by the EPG data with no velar closure and an initial /t/ was perceptually judged as a dental /t/ but with the EPG data showing velar contact. The tongue placement sometimes generates acoustic cues that may be difficult for a listener to interpret. This mismatch between listener perceptions and speaker behaviours has also been observed in other clinical studies, for example, Gibbon et al. (2004).

The results of this study, such as changes in COG and AT values after treatment compared with before, confirm the observation from the qualitative analysis of the EPG frames that the children's articulatory placement was retracted before treatment and changed towards a more normal anterior place of articulation after treatment. A previous case study has reported similar outcomes using EPG in therapy for velar fronting in a child with articulation disorders associated with mild cerebral palsy (Gibbon and Wood, 2003). In their study, important diagnostic features of the child's articulation disorder were found. The EPG technique detected subtle signs of impaired speech motor control, such as asymmetric patterns, even if a degree of asymmetry is commonly found in typical speech, and long closure durations. Furthermore, valuable diagnostic data, such as a retracted oral place of articulation and 'double articulation', were found in the children in this study.

The analysis of COG and AT values for the children in this study also revealed significant changes for initial and medial targets to a more adequate anterior lingual placement after EPG therapy. There was, however, no significant improvement in the production of some of the targets in the final position. A similar finding was reported by Platt, Andrews, and Howie (1980). They made a perceptual analysis of the articulatory performance of a group of 50 adults with cerebral palsy. The articulation errors were more frequent for consonants in word-final positions; for example, phoneme omissions occurred three times more frequently in final consonants than in initial consonants.

All the children in this study displayed a retracted oral place of articulation before treatment for most of the target consonants. One finding that has been made in perceptually based studies is that retracted oral articulation (backing) is a rare and deviant characteristic of disordered child speech (e.g. Hodson and Paden, 1981). Hodson and Paden studied children with unintelligible speech and found that retracted/backed articulation tended to occur in the least intelligible children. The retracted lingua-palatal contact patterns may be one of a number of factors that cause reduced intelligibility in children with dysarthria and cerebral palsy.

The findings from the brief examination of articulatory timing among the children in this study revealed that there were large differences both within each participant and between the participants when it came to the duration of the closure phases for the target consonant initial /t/, both before and after treatment. This compares well with the data from a study by Morgan Barry (1993). In that study, a difference relating to segmental timing was found for word-initial obstruents among six neurologically disordered participants compared with four typical adult English speakers. More work needs to be done to find out more about articulatory timing both for normal speech and for speech among individuals with speech disorders associated with cerebral palsy, as well as other causes.

In this study, the children had a fairly short phase of adapting to the EPG plate, but, as McLeod and Searl have pointed out (2006: 204), 'when the device is used for speech training, the point is not for the user to be totally intelligible, natural or undistorted when wearing the appliance. What is more important is that the user is intelligible and natural when not wearing the appliance . . .'. The speech training with the EPG plate will help the user to learn more about the different aspects of speech production.

Limitations and Implications of this Study for Future Research

There were limitations to this investigation that can be used to focus future research. First, EPG recordings should preferably be made repeatedly before, during and after treatment to produce more important data on the changes that result from the treatment and the stability of maintenance. An extended sample for an analysis of spatial patterns and, in particular, a systematic investigation of the temporal patterns would be valuable in order to understand the articulation in individuals with dysarthria related to cerebral palsy. Furthermore, more perceptual analyses based on listener judgements, a detailed perceptual analysis of articulation accuracy and intelligibility should preferably be included. The analysis and interpretation of combined data of this kind could lead to more accurate diagnoses, which would in turn lead to more focused, specific and effective interventions for articulation disorders associated with cerebral palsy.

Conclusions

The results of this study have added to existing knowledge about the articulatory characteristics of tongue placement for /t/, /d/, /n/ and /s/ in dysarthric speech associated with dyskinetic and spastic cerebral palsy. For example, EPG data revealed that a retracted place of articulation and double articulation are frequent speech errors and it appears to be important to explore the temporal features of the articulation to increase our understanding of the characteristics of speech production associated with cerebral palsy. EPG was considered to be a valuable instrument for the description of articulation patterns in children with cerebral palsy and articulation disorders and also to document changes after speech therapy.

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