The efficacy of speech intervention using electropalatography with an 18-year-old deaf client: A single case study

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ABSTRACT

This single case study explored the use of EPG as a therapeutic tool for treating inaccurate articulation of the voiceless alveolar plosive /t/. The participant (M) is an 18-year-old deaf adult who consistently uses hearing aids, and who communicates using a combination of English, Sign Supported English and British Sign Language (BSL). M received traditional phonological therapy targeting his production of /t/ prior to EPG therapy, but without success. He requested further therapy and EPG was offered as an alternative approach. Pre-EPG therapy, M made tongue placement errors for both /t/ and the voiced alveolar plosive /d/. Based on perceptual analysis by M's speech and language therapist, the first author, his productions were inconsistent, though generally perceived as voiceless and voiced velar plosives respectively. The EPG therapy consisted of 6 bi-weekly therapy sessions, each lasting for one hour, targeting M's production of /t/ in familiar words, using the visual feedback from the EPG display. Trained and untrained listeners perceptually analysed audio recordings of words and sentences collected at 3 assessment points. Improvements, both over the course of the EPG therapy and during the follow-up period, were found to be statistically significant. Significantly, M was able to generalise his production skills to untaught words containing both /t/ and /d/. Equally significant was the lack of change in M's production of a control sound, the voiceless dental fricative /θ/. More globally, an improvement was observed in ratings of M's intelligibility in sentences and in his voice quality (assessed impressionistically).

Keywords: deafness, hearing impairment, adult, EPG, voiceless alveolar plosive, voice quality

[1] 'deaf' will be used throughout this article to refer to individuals with any degree of hearing impairment.

INTRODUCTION

Electropalatography (EPG) is an instrumental procedure that records details of the location and timing of tongue contacts with the hard palate during speech (Hardcastle, Gibbon, & Jones, 1991). This technique has been used as a diagnostic assessment tool, for recording and analysing tongue contact patterns for sounds produced in the alveolar, post-alveolar, palatal and velar place of articulation (Friel, 1998; Gibbon, Dent, & Hardcastle, 1993; Gibbon, Hardcastle, & Dent, 1995). As a therapy tool, EPG has been used to target a range of speech production difficulties, including articulation/phonological disorders in children and young adults (Dagenais, 1995; Dent, 1995; Gibbon, McNeill, Wood, & Watson, 2003; Hardcastle, Gibbon, & Scobbie, 1995). It has been used increasingly to treat articulation/phonological disorders in children and adults with cleft palate (Whitehill, Stokes, & Man, 1996; Gibbon, Crampin, Hardcastle, Nairn, Razzell, Harvey, & Reynolds, 1998). Relatively few studies have investigated the use of EPG with adults with speech production difficulties (Bernhardt, Bacsfalvi, & Gick, 2005; Howard & Varley, 1995). In terms of its specific use, EPG has been successfully used to teach production patterns for a range of sounds, including fricatives (Bernhardt, Gick, Bacsfalvi, & Ashdown, 2003; Fletcher, Dagenais, & Critz-Crosby, 1991; Parsloe, 1998), affricates (Bernhardt et al., 2003; Hardcastle et al., 1995; Parsloe, 1998) and plosives (Crawford, 1995; Friel, 1998; Gibbon et al., 1993; Pantelemidou, Herman, & Thomas, 2003; Parsloe, 1998).

EPG provides very precise and accurate visual feedback of tongue-to-palate contact in real time and is used therapeutically to increase a client's ability to monitor and change tongue movements. Many studies report improvement in clients' productions of specific phonemes where traditional therapy has failed to affect change or where skills have plateaued (Bernhardt et al., 2003; Dagenais, Critz-Crosby, Fletcher, & McCutchen, 1994; Pantelemidou et al., 2003; Parsloe, 1998). There is evidence in the literature that EPG therapy can affect change in speech production skills more quickly than traditional therapy (Bernhardt et al., 2003; Dagenais et al., 1994; Fletcher et al., 1991; Parsloe, 1998). There is also some evidence that production skills can be maintained in the short-term (Crawford, 1995; Dagenais et al., 1994; Pantelemidou et al., 2003). However, few longitudinal studies have been carried out to investigate the impact of phoneme-specific changes on intelligibility in connected speech or the long-term maintenance of skills.

Of over 180 clinical EPG studies carried out to date, relatively few document the use of EPG with deaf clients (Gibbon, 2003). This is surprising, as EPG provides clear visual feedback of place of articulation for a range of sounds (Fletcher et al., 1991; Gibbon et al., 1993), which can be particularly problematic for deaf speakers. For certain consonants, a contrast in place of articulation is difficult to discriminate auditorily and difficult to perceive visually, e.g., alveolar *versus* velar consonants.

In the present study, EPG is used as a therapy tool for the remediation of alveolar plosives produced by an 18-year-old profoundly deaf adult (M). Pre-EPG therapy, based on perceptual judgments by a specialist speech and language therapist, M produced voiced and voiceless alveolar plosives with accurate voicing and manner of articulation. His production of these consonants was perceptually inconsistent due to placement errors. Such variability in relation to place of articulation in deaf speakers is reported elsewhere (e.g., Nicolaidis, 2004). In M's speech, based on perceptual judgments, alveolar plosives were occasionally perceived as accurate alveolar approximations, though they were generally perceived as velar plosives. Owing to this perceptual variability, complex articulation, such as double articulation, was suspected. M is unable to discriminate alveolar and velar plosives. He received traditional phonological therapy targeting his production of /t/ prior to EPG therapy, without success. M requested further therapy and EPG therapy was offered as an alternative approach. Crawford (1995) showed that alveolar plosives could be taught to two profoundly deaf children using EPG, in the absence of the ability to perceive the target contrast.

A key aim of the present study was to investigate whether it would be possible for a deaf adult to make phonemic changes to an established phonological system using EPG therapy. A listener judgments experiment was used to investigate whether trained and untrained listeners could detect any improvement in M's production of the voiceless alveolar plosive /t/ at a word level following EPG therapy, and whether M would spontaneously generalise his production skills to the voiced alveolar plosive /d/ at a word level. It examined whether M could maintain production skills one month post-therapy, despite being unable to discriminate the target phonological contrast. A further aim was to investigate whether phoneme-specific changes could result in improvement in intelligibility at sentence level, as judged by listeners. Informal observations of EPG data showing M’s production of treated and untreated sounds in isolation at each assessment point will be discussed in relation to listener judgments.

METHOD

The Participant (M)

A local specialist speech and language therapist referred M to the Department of Language and Communication Science at City University for remediation of his alveolar plosive production using EPG. This therapy was conducted by M’s local specialist speech and language therapist. M was aged 18 years and 5 months at the start of the block of EPG therapy. He has a profound bilateral sensori-neural hearing loss and is a consistent hearing aid user. M wears bilateral analogue hearing aids (Phonak SuperFront PPCL4). He was referred to the speech and language therapy service at the age of 4 years and 2 months and was diagnosed with a profound bilateral hearing loss at the age of 6 years. M has a history of a conductive overlay to his hearing loss. Pre-diagnosis, he was educated in a mainstream nursery and school. From the time of diagnosis, M was educated in a ‘total communication’ hearing impairment unit attached to a mainstream school, in which a combination of speech and sign was used. He received weekly specialist speech and language therapy as part of his educational provision, in order to develop his speech production, speech discrimination, language and literacy skills. M is the fifth child of eight children. He is the only deaf person in his immediate family. M communicates with his family in English, though Punjabi and some Urdu are also used in his home. This study does not address M’s perceptual or articulatory skills in languages other than English. M identifies speech as his primary mode of communication. He is also a fluent user of British Sign Language (BSL).

Pre-therapy, M’s speech discrimination, production and language skills were assessed by the specialist speech and language therapist conducting the block of EPG therapy. M’s speech discrimination skills were assessed using an unpublished assessment devised in Greenwich Teaching Primary Care Trust, based on a ‘listening hierarchy’ documented by Beazley, Frost and Halden (1996). When maximally aided, M is able to discriminate differences in syllable number and all English vowel contrasts. He is able to discriminate contrasts differing in more than one feature (e.g., place and voicing, or manner and place). He is able to discriminate consonants differing in manner only, for example, ‘tea’ versus ‘sea’, and voicing only, for example, ‘Sue’ versus ‘Zoo’. M is not able to discriminate consonants differing in place only, for example, alveolar versus velar voiceless plosives (e.g., ‘tea’ versus ‘key’), i.e. he is not able to perceive the contrast targeted in his EPG therapy.

M’s speech is generally intelligible to familiar listeners in context when they are looking and listening carefully. Articulatorily, M has a fully contrastive vowel system. Based on perceptual analysis by a specialist speech and language therapist, M was able to produce all English consonants contrastively in word initial position, with the exception of the alveolar plosives /t/ and /d/ and the dental fricatives /θ/ and /ð/. The voiceless and voiced alveolar plosives were generally perceived as voiceless and voiced velar plosives respectively. The voiceless and voiced dental fricatives were consistently perceived as voiced alveolar plosives. M often omits word-final consonants, above and beyond the expected lenited /t/ and /l/ associated with his London accent of English and the omission of high-frequency consonants e.g., /s/ and /z/ which is a common feature of deaf speech. In a broad variant of this accent, the dental fricatives may be realised labiodentally (with appropriate voicing), but an alveolar or post-alveolar place of articulation would *not* be expected. M has severely delayed language and literacy skills for his age, and this impacts on the choice of stimuli and research design.

Materials

The following materials were used to collect data for perceptual analysis. The target stimuli consisted of 40 words, selected by the first author in such a way as to probe M’s production of the target sounds in a variety of phonetic environments (see Appendix 1). The words were presented to M in pictorial and written form. Speech in noise (SPIN) test sentences (Kalikow, Stevens, & Elliot, 1977) were used to elicit a sentence-level speech sample, in order to investigate any change in intelligibility in M’s connected speech. M produced 10 high-predictability SPIN Test sentences and 10 low-predictability SPIN Test sentences, randomly selected from larger sets, at each assessment point (see Appendix 2). M was not wearing his EPG plate during these recordings.

Design

A single case study was used to investigate the efficacy of EPG therapy with M. Single case studies have been widely used in speech and language therapy research (see Pring, 2005). They are particularly useful in evaluating therapies, such as that offered here, which are designed to meet the individual needs of clients. This study examined M’s production of words containing /t/ before and after EPG treatment. There is evidence from clinical records (written and audio-visual recordings) that his production had not changed either spontaneously or after a block of traditional phonological therapy. Nevertheless, a group of words containing the untreated sound /θ/ were also monitored to control for spontaneous change in M’s speech sound system during the intervention. Trained and untrained listeners perceptually analysed audio recordings of words and sentences collected at 3 assessment points.

Design of the Listener Judgments Experiment

The design assessed M’s production of 40 words. Ten words containing /t/ were used in the treatment. A further ten words containing /t/ and ten containing /d/ were included but not treated. These were used to examine whether the treatment generalized to other words containing the treated sound and to a related untreated sound. The final ten words contained the control sound /θ/. M was assessed immediately pre- therapy, immediately post-therapy and 1 month post-therapy. The post therapy assessments examined his immediate change with treatment and whether this was maintained one month later. At each assessment, M was asked to produce 40 words. He was also asked to produce 10 high predictability SPIN Test sentences and 10 low predictability SPIN Test sentences (Kalikow et al., 1977). The predictability of SPIN test sentences is determined by whether their final word is predicted from the context of the sentence or not. As M’s language and literacy skills are delayed, the sentences were read to him and he was asked to repeat them. Specific speech material for listener judgments is shown in Appendices 1 and 2.

Recordings of the above stimuli were presented to 10 trained and 10 untrained listeners. Trained listeners had received phonetic ear training and had worked full time as Paediatric speech and language therapists for at least 3 years, regularly carrying out phonetic transcription of disordered speech. Untrained listeners had no phonetic ear-training, were not speech and language therapists and were not regularly exposed to disordered speech. Recordings of M's production of the 120 words (40 from each assessment point) were numbered and placed in a random order using random number tables. They were presented to listeners who were also shown the target word in written form and asked to rate the accuracy of M's production on a scale of 1-4 (1 = very poor, 2 = poor, 3 = good, 4 = very good). Recordings of M's production of the 60 sentences (20 from each assessment point) were also presented in a random order. Listeners were asked, first, to write down what they perceived to be the last word in the sentence. Only accurate responses were scored. Secondly, they gave a rating of the overall intelligibility of each sentence by indicating how much of them they could understand on a scale of 1-4 (1 = none, 2 = part, 3= most, 4 = all). Rating scales were designed specifically for this research project.

Procedure

The Electropalatograph (EPG)

EPG is a multi-sensory feedback approach, in which visual feedback from a computer screen and tactile feedback from the EPG plate are provided simultaneously. The British system (EPG3) used in this study, was developed at the University of Reading, England (Hardcastle et al., 1991; Jones & Hardcastle, 1995). As described by Hardcastle et al. (1991), the system consists of an artificial plate, which is custom made to fit against the individual's hard palate. Prior to EPG therapy, impressions were taken of M's palate and the speech and language therapist's palate, in order that EPG plates could be custom-made. The plate is fitted with 62 electrodes, which are exposed to the lingual surface. Wires connect the artificial plate to the multiplexer, which the participant wears around the neck. The multiplexer interfaces directly with the EPG3 programme on the computer. When the tongue touches any of the electrodes, a signal is conducted to the processing unit. Lights indicate which electrodes the tongue has touched, thus providing visual feedback. As the area of contact between the tongue and the plate is displayed on the computer screen in real time, EPG acts as a biofeedback mechanism.

Therapy

M received 6 therapy sessions, each lasting for one hour; sessions took place bi-weekly. Sessions involved discussion of how the target sound is produced, modelling of the target placement of the sound by the therapist using the EPG equipment, M's production practice using the EPG equipment and generalisation practice without the EPG plate, e.g., monitoring activities. M progressed from producing the sound in isolation, combining /t/ with vowels to create non-words, producing the treated words, to practising these in short carrier phrases and a range of sentences.

Recordings for the Listener Experiment

Audio-visual recordings of M producing words and sentences were taken using a Panasonic NV-DS15B digital video recorder and tripod at approximately 50cm distance from the built-in microphone in a quiet acoustics laboratory. Data was transferred onto a computer and each word/sentence was saved as a separate file, in order that data could be randomised, as described above.

EPG Data

EPG recordings of M's productions of the sounds /t/, /d/ and /θ/ in isolation were collected at three assessment points (immediately pre-therapy, immediately post-therapy and 1 month post-therapy). Informal observations about changes in contact patterns were made (by the first author) before and after therapy. These will be discussed in relation to listener judgments. Although plosive data is normally examined in an intervocalic (or other) context, in this study, the sound was elicited as an isolated segment, i.e. with no following vowel. There is also no accompanying acoustic waveform, which might have provided some data regarding aspiration and corroboration of the temporal data. On the other hand, because the sound does not include any following vowel sound, it may be unambiguously stated that the sound relates to the closure phase of the stop, rather than to any other element.

Participant Self-Ratings of Intelligibility

M completed a self-rating questionnaire immediately pre- and immediately post-therapy. In this questionnaire, designed specifically for this research project, M was asked to respond to the following questions by rating himself on a scale of 1-10:

- How confident do you feel about your speech? (1 = not confident / 10 = very)

- How clear is your speech? (1 = not at all / 10 = completely)
- How well do members of your family understand you? (1 = not at all / 10 = completely)
- How well do your friends understand you? (1 = not at all / 10 = completely)
- How well do people you do not know understand you? (1 = not at all / 10 = completely)

Data Analysis

Data from the listener's responses to words and sentences were analysed statistically. Listeners' ratings of words were analysed using a 3-factor mixed ANOVA in which word type (treated /t/, untreated /t/, untreated /d/ and /θ/) and time (pre, post and 1 month post therapy) were within subject variables and listener group (trained/ untrained) was a between subjects variable. Listeners identification of the final words of the sentences and their ratings of the intelligibility of the sentences were also analysed using 3-factor mixed ANOVAs. In these, sentence type (high predictability/low predictability) and time (pre, post and 1 month post therapy) were within subject variables and listener group (trained/untrained) was a between subjects variable. Strictly, the data from the listeners' ratings of words and sentences is ordinal. In using ANOVA to analyse this data, we accepted Clark-Carter's (1997) advice that parametric tests are permissible with such data when the range of scores produced is sufficiently large, as is the case here where ratings of items are added together.

Informal observations based on EPG data and the participant's self rating of his intelligibility are presented below. These are not analysed statistically.

RESULTS

Listener Judgments of Words

There was a significant main effect of time ($F(2, 36) = 102.25$, $p<0.0001$). A Newman Keuls test (unplanned comparison) found that post-therapy ratings were significantly higher than pre-therapy ratings ($p<0.01$). Surprisingly, 1 month post-therapy ratings were significantly higher than immediately post-therapy ratings ($p<0.01$). There was a significant main effect of word type ($F(3, 54) = 121.250$ $p<0.0001$). A Newman Keuls Test indicated that stimuli were all significantly different from each other. The interpretation of the above results is qualified by a significant interaction (see table 1) between time and word type ($F(6, 108) = 83.56$, $p<0.0001$). An analysis of simple main effects showed that treated /t/, untreated /t/ and untreated /d/ all improved over time. As anticipated the control sound /θ/ did not improve. Table 1 shows that it deteriorated slightly. Surprisingly this deterioration was statistically significant although its small magnitude makes it unlikely that it perceptually reduced M's phonological contrast system.

TABLE 1 about here

Listener ratings for each word type at each assessment point were compared using a Newman Keuls test. As shown in table 1, words containing /d/ scored lower than other word types. The difference was significant when compared to treated /t/ words ($p < .05$) and control /θ/ words ($p < .01$). After therapy treated /t/ words were significantly better than all other word types ($p <.01$) and untreated /t/ and untreated /d/ words were significantly better than control /θ/ words ($p < .01$). At follow up a month after therapy, both treated and untreated /t/ words were better than untreated /d/ words ($p < .01$) and each of these groups of words was better than control /θ/ words.

Listener Judgments of Sentences

As expected, there was a significant effect of sentence type: scores for high predictability sentences were significantly more accurate than for low predictability sentences ($F(1,18) = 276.54$, $p<0.0001$). There was also a significant effect of time of assessment ($F(2, 36) = 58.32$, $p < 0.0001$). A Newman Keuls Test showed that, as in the previous analysis, there was a significant improvement from the pre-therapy to post-therapy assessments ($p<0.05$) and a further significant improvement from the post-therapy to 1 month post-therapy assessments ($p<0.01$).

FIGURE 1 about here

There was a significant interaction between time and stimuli ($F(2,18) = 5.02$, $p=0.01$) reflecting the stronger improvement in the high predictability than the low predictability sentences (see figure 1).

Overall Intelligibility Judgments

The main effect of time was again significant ($F(2, 36) = 16.62$, $p<0.0001$. A Newman Keuls test found no significant improvement from the pre-therapy to the immediately post-therapy assessment but the 1 month post-therapy assessment was significantly better than either of the earlier assessments ($p<0.01$). As expected, high predictability sentences had significantly higher scores than low predictability sentences ($F(1,18) = 60.17$, $p<0.0001$).

The interaction between sentence type and time (see figure 2) was also significant ($F(2, 36) =18.89$, $p<0.0001$). An analysis of simple main effects showed that scores improved with time for the high predictability sentences ($F(2,27) = 34.37$, $p<0.0001$) but not for the low predictability sentences.

FIGURE 2 about here

It should be noted that no differences between trained and untrained listeners were found in any of the analyses.

Voice quality changes, such as reports of M's voice sounding more 'normal' and 'pleasant', were informally reported by a number of the listeners following the listening exercise.

EPG DATA

Treated Voiceless Alveolar Plosive /t/

Pre-Therapy - /t/ produced in isolation

Based on perceptual analysis, pre-EPG therapy, M produced voiced and voiceless alveolar plosives with accurate voicing and manner of articulation with inaccurate place of articulation. The top section of each EPG frame represents the anterior section of the plate, towards the lips; the lower section of each EPG frame represents the posterior section of the plate, towards the pharynx. The sequence of frames (see figure 3) shows articulatory movements over time; the patterns are read from left to right. The following sequence of frames shows M (pre-therapy) using alveolar followed by more posterior articulations when producing the voiceless alveolar stop /t/.

FIGURE 3 about here

Based on informal observations of EPG readings, there appears to be an alveolar phase followed by a more posterior phase during M's productions of /t/ in isolation. M does not make complete closure during the latter phase of his production. Unequivocal evidence for velar closure may not be possible owing to the well known limitations of the EPG for very back articulations, and the alveolar and velar phases may not be simultaneous. However, without question, a back articulation appears to be an integral part of alveolar plosive production, and this unusual finding calls for further investigation. Functionally, a perceived change in M's production of /t/ would require more anterior tongue contact but more importantly, less posterior tongue-to-palate contact on release of the sound.

Immediately Post-Therapy - /t/ produced in isolation

Based on informal observations of EPG data, immediately post-therapy, M produces /t/ in isolation using a higher ratio of activated electrodes in the anterior section of the plate (see figure 4).

FIGURE 4 about here

Activation of electrodes in the palatal or velar regions on the release of the sound when the target is alveolar is likely to shift the perceived place of articulation to velar, i.e. the place most closely associated with the release. This can affect meaning, e.g., in English 'tea' may be perceived as 'key'. Errors in tongue placement from alveolar to post-alveolar or palatal regions are unlikely to result in a perceptually different consonant in English, which has no post-alveolar or palatal plosive. For these reasons, M's immediately post-therapy production is more likely to be perceived as the target sound than pre-therapy productions and this is consistent with listener judgments.

1 month Post-Therapy - /t/ produced in isolation

Based on informal observations of EPG data, figure 5 shows a realisation of /t/ involving alveolar tongue-to-palate contact with minimal palatal or velar contact mid-production or, more importantly, on the sound's release.

FIGURE 5 about here

This improvement in tongue-to-palate contact patterns is consistent with perceptual improvements reported by listeners.

Untreated Voiced Alveolar Consonant /d/

Voiced alveolar plosive /d/

The sound /d/ was incorporated in the study to investigate generalisation of speech production skills to the voiced equivalent of the treated sound. Based on informal observations of EPG data, pre-therapy, M made similar articulation errors in his production of the sounds /t/ and /d/, with strong evidence from EPG of complex articulations with alveolar followed by more posterior electrode activations on the sound's release. Post-therapy EPG readings show many electrode activations in the alveolar and post-alveolar region of the plate. M makes minimal contact in the velar region of the plate, resulting in sounds that are more likely to be perceived as alveolar than velar. The above findings are consistent with listener judgments, which show significant perceptual improvements between pre- and post-therapy productions of words containing /d/. Like /t/ words, /d/ words were rated significantly higher than words containing the untreated control sound, which suggests that M was able to generalise his production skills to the voiced alveolar plosive.

Untreated Voiceless Dental Fricative /θ/ (control sound)

EPG readings of M's productions of /θ/ pre- and post-therapy show tongue-to-palate contact in the alveolar and/or post-alveolar region of the plate. This production pattern is likely to be perceived as an alveolar plosive, and since M frequently makes voicing errors for this sound, it is most commonly perceived as [d]. These observations are consistent with data from listener judgments.

Participant Self-Ratings of Intelligibility

M self-ratings for questions pre- and post-therapy are shown in table 2. Pre-therapy, M gave a mean rating of 5.6 on a scale of 1-10. Post-therapy, he gave a mean rating of 9.2 on a scale of 1-10. M was asked to describe his speech. Pre-therapy, he wrote 'My speech sound difficult when I want to say something like difficult word'. Post-therapy, M wrote 'I think my speech very clear. My 'T' sound is getting better!' When asked to reflect on the use of EPG, M said "If I put the palate in, I can learn really quickly. Then without palate in [speech] is better". M's self-assessment may have been influenced by his wish to please his therapist. However, the above reflections on improvements in his speech following EPG therapy are certainly encouraging.

TABLE 2 about here

DISCUSSION

This study investigated the use of EPG as a therapeutic tool for the treatment of alveolar plosives in an 18-year-old deaf adult. A significant perceptual improvement was observed in M's production of voiceless and voiced alveolar plosives immediately post-therapy, in both treated and untreated words, as measured by listener judgments. Further significant improvement was made in M's production of voiceless and voiced alveolar plosives 1 month post-therapy, indicating generalisation of skills, as measured by listener judgments. More globally, a significant perceptual improvement was observed in M's intelligibility at sentence level between pre-therapy and 1 month post-therapy assessment points, as measured by listener judgments. There were no significant differences in judgments by trained and untrained listeners.

Many listeners informally reported change in M's voice quality following EPG therapy; this was an unexpected outcome. Many studies were carried out in the 1960s, 1970s and 1980s to investigate deaf voice quality, but in recent years this area has been relatively neglected (Wilkinson, 2005). 'Cul-de-sac resonance', observed and described by Boone in 1966, is a 'hollow muffled quality', which often features in a deaf person's voice quality. It involves a pharyngeal focus of resonance which is produced by retracting the tongue toward the pharyngeal wall instead of using a higher, more forward neutral position. This causes a lowering of the second formant frequency, which is usually highly influenced by tongue position. It seems plausible that EPG therapy, by bringing M's tongue forward more consistently and reducing contact in the velar region, has impacted on M's voice quality by reducing tongue protraction and increasing his range of movement. This was not an aim of therapy but may explain improvement in listener judgments of connected speech where the target sound did not feature. It is suggested that future similar studies might include the collection of sustained phonation samples, and a systematic assessment of voice quality, e.g., using the Vocal Profile Analysis (Laver, Wirz, Mackenzie, & Hiller, 1981). Objective analysis of tongue movement, for example, using articulometry, is suggested, in order to investigate this further (Perkell, Cohen, Svirsky, Mathies, Garabieta, & Jackson, 1992).

Based on listener judgments, there is evidence that M made further significant improvement during the follow-up period and generalised production skills to untaught words containing /t/ and /d/. This suggests that during this assimilation period, newly acquired production skills were incorporated into a pre-existing system. Similar findings were reported by Pantelemidou et al. (2003). Newly acquired speech production skills can be described as learnt only when they are used in naturally occurring connected speech. Further investigation is indicated to explore the relationship between phoneme-specific changes and the observed effect on intelligibility. A more natural speech sample is needed to investigate generalisation to connected speech; assessment of M's speech outside of the therapeutic environment would be instructive. A longitudinal study in similar case studies could investigate the maintenance of production skills.

Studies of this type are invariably single case studies, since it is unlikely that sufficient clients can be found to conduct a group study. Clearly, a major limitation of this study was the lack of EPG data, which was due to data loss. As a result, it was not possible to directly compare data from EPG recordings with data from the listener judgments experiment, i.e. there was insufficient EPG data showing productions of target sounds in isolation / words / sentences to conduct meaningful analysis of electrode activation patterns. This is particularly frustrating as, based on informal observations, there is evidence of unusual complex tongue-to-palate contact patterns during M's pre-therapy productions of the alveolar plosives /t/ and /d/ in isolation, with alveolar followed by more posterior tongue-to-palate contact during the closure phase of his productions of the plosives. This phenomenon differs from those previously described in the literature, such as double articulation (Gibbon, 1990) and articulatory drift (Gibbon & Wood, 2002). This unusual finding calls for further investigation. Less significant was the incompleteness of the data regarding velar closure. The collection of acoustic data would undoubtedly have assisted in clarifying details of the unusual articulation observed in this client. Time-amplitude speech pressure waveform data is particularly helpful in relation to identifying the onset of the release phase, and spectrographic data may be used to analyse place of articulation. A small study of plosive production (Abramson & Lisker, 1972) led to more than a quarter of a century investigating the normal production and perception of this class of sounds. The investigation of pathological forms in this and similar studies may generate new and somewhat different research questions.

Despite its limitations, there is evidence from this single case study that EPG is a useful therapy tool for effecting change in the speech production system of a profoundly deaf adult in the short- and medium-term. Listener judgments indicate that significant change continued to occur during the follow-up period. Speech production therapy is often discontinued or de-prioritised with older deaf children and adults in the belief that adults are unable to acquire new phonological contrasts. The effects in the follow-up period are therefore particularly significant in view of the age of the participant.

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Table 1: Listener judgments of words – Simple main effects on the interaction between time and stimuli

	Pre-Therapy	Immediately Post-Therapy	1 Month Post-Therapy	F (2,144)	
Treated /t/	21.95	30.20	34.10	142.35	p<.0001
Untreated /t/	21.15	25.80	33.80	151.45	p<.0001
Untreated /d/	19.85	24.70	28.00	62.17	p<.0001
Control /θ/	22.75	22.55	19.15	15.14	p<.0001
F (3,162)	30.58	207.55	978.98		
	p<.001	p<.0001	p<.0001		

Table 2: Participant self-ratings of intelligibility pre- and post-therapy

QUESTION	Key	Pre-Therapy Rating	Post-Therapy Rating
How confident do you feel about your speech?	1 = not confident / 10 = very	7	9
How clear is your speech?	1 = not at all / 10 = completely	6	10
How well do members of your family understand you?	1 = not at all / 10 = completely	5	10
How well do your friends understand you?	1 = not at all / 10 = completely	5	9
How well do people you do not know understand you?	1 = not at all / 10 = completely	5	8

List of Figures:

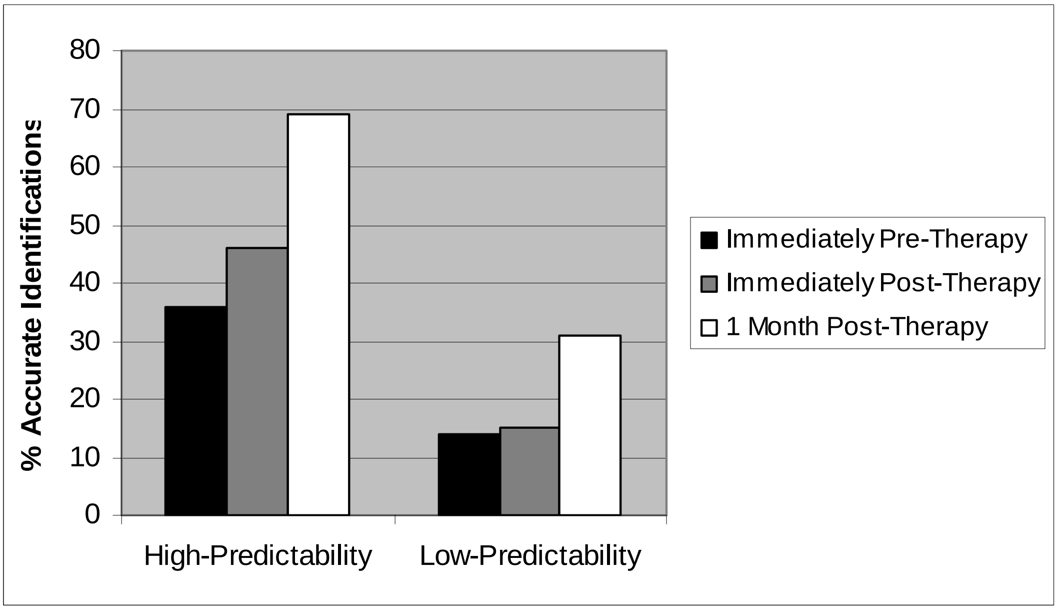

Figure 1: Final word judgments of sentences by listeners (n=20)

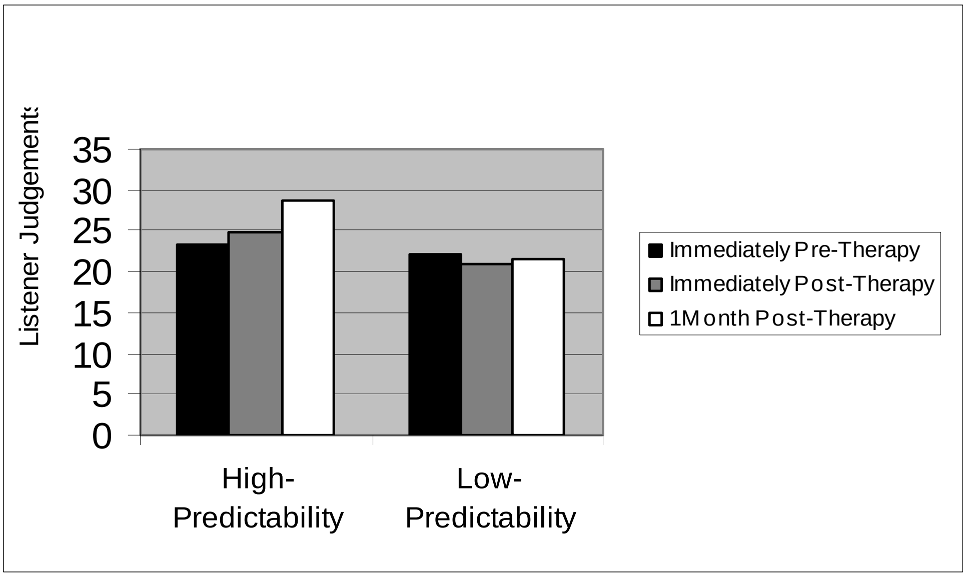

Figure 2: Overall ratings of sentences by listeners (n=20)

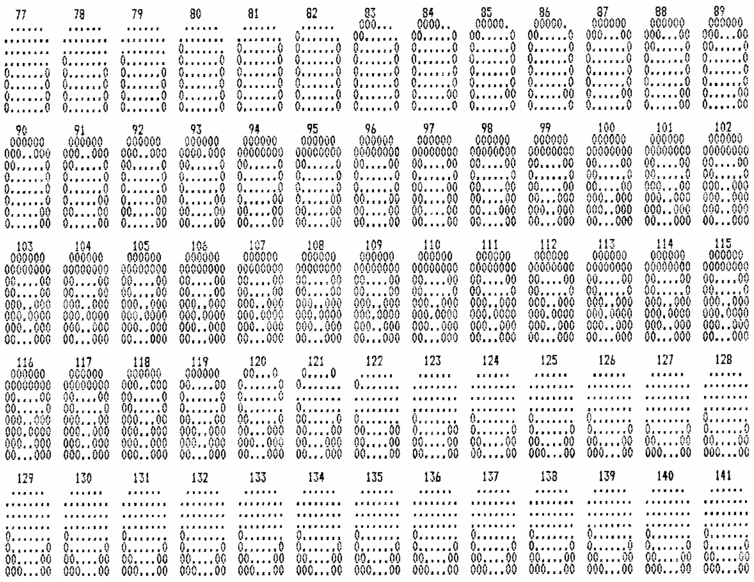

Figure 3: EPG data – Pre-therapy – M’s production of a voiceless alveolar plosive /t/ in isolation

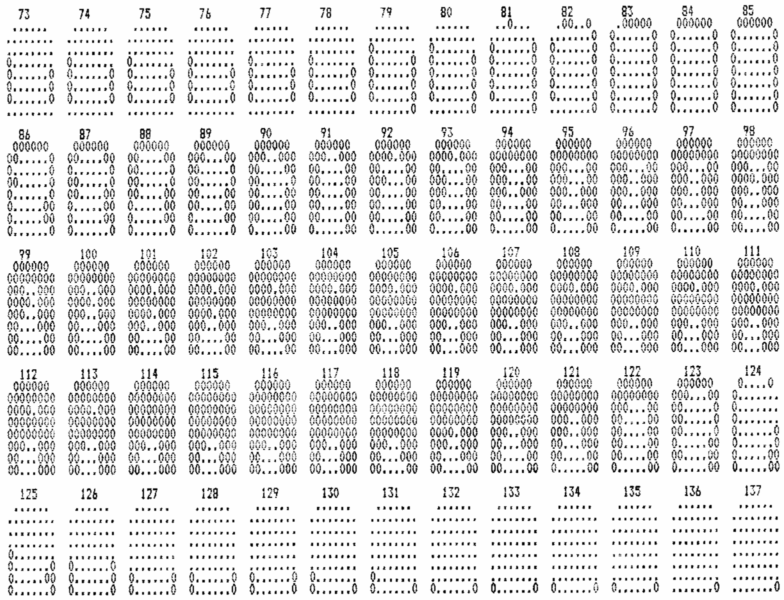

Figure 4: EPG data - Immediately post-therapy

M's production of a voiceless alveolar plosive /t/ in isolation

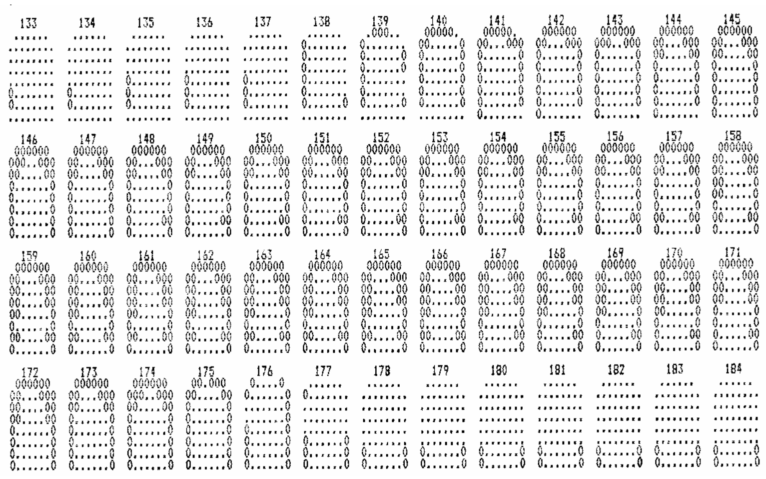

Figure 5: EPG data – 1 month post-therapy

M's production of a voiceless alveolar plosive /t/ in isolation

APPENDICES

Appendix 1: Speech material for listener judgments - Words

Word Lists

As far as possible, word selection was based on the following criteria:

- Monosyllabic words
- Mix of vowels (long, short and diphthongs)
- Mix of CV (consonant-vowel) and CVC (consonant-vowel-consonant) structures
- 6 words with the target sound in word initial position
- 2 words with the target sound in a word final position
- 2 words with the target sound in a consonant cluster (with the approximant /r/)
- Easily represented in pictorial form or as a single letter/number (e.g., T/D/3/10)
- Within the participant's expressive English vocabulary
- All other consonants within the word are within the participant's sound repertoire

Treated /t/ words:

Word Initial - CV	Word Initial - CVC	Word Final	Consonant Cluster
Toy Toe Two	Team Top Type	Night Boot	Train Tree

Untreated /t/ words

Word Initial - CV	Word Initial - CVC	Word Final	Consonant Cluster
Tea Tie Tear	Tap Tin Ten	Write Meat	Tray Truck

Untreated /d/ words

Word Initial - CV	Word Initial - CVC	Word Final	Consonant Cluster
D (dee) Doll Door	Down Deaf Dice	Bird Red	Draw Drum

Untreated /θ/ words

Word Initial - CV	Word Initial - CVC	Word Final	Consonant Cluster
Thigh Thaw	Thief Thumb Thorn Thin	Fourth Bath	Three Throw

Appendix 2: Speech material for listener judgments – SPIN Test Sentences

SPIN Test Sentence Lists (Kalikow et al., 1977)

Assessment Point 1 – Pre-Therapy
Randomly selected from SPIN Test Set 2.4

High Predictability	Low Predictability
How long can you hold your breath?	He had considered the rope.
The guilty one should take the blame.	They knew about the fur.
The king wore a golden crown.	You want to talk about the ditch.
At breakfast he drank some juice.	I want to speak about the crash.
The sport shirt had short sleeves.	The man could not discuss the mouse.
The team was trained by their coach.	We've spoken about the truck.
The doctor charged a low fee.	She has a problem with the goal.
The cookies were kept in a jar.	The old man considered the kick.
Bob stood with his hands on his hips.	We hear she called about the drum.
The girl swept the floor with a broom.	She's glad Jane asked about the drain.

Assessment Point 2 – Immediately Post-Therapy
Randomly selected from SPIN Test Set 2.3

High Predictability	Low Predictability
The hockey player scored a goal.	Mary could not discuss the tack.
The boy gave the football a kick.	Bob could have known about the spoon.
The soup was served in a bowl.	Tom is talking about the fee.
The bomb exploded with a blast.	The old man thinks about the mast.
Ruth poured water down the drain.	David should consider the blame.
The cop wore a bullet-proof vest.	We should have considered the juice.
The workers are digging a ditch.	He hopes Tom asked about the bar.
A chimpanzee is an ape.	Jane has a problem with the coin.
They played a game of cat and mouse.	Bill heard Tom called about the coach.
No one was injured in the crash.	Nancy should consider the fist.

Assessment Point 3 – 1 Month Post-Therapy
Randomly selected from SPIN Test Set 2.5

High Predictability	Low Predictability
Peter dropped in for a brief chat.	Miss White spoke about the film.
The camera is out of film.	Ruth is speaking about the meal.
We heard the ticking of the clock.	Miss White thinks about the tea.
The car drove off the steep cliff.	He doesn't discuss the mop.
Get the bread and cut me a slice.	The boy might consider the trap.
That job was an easy task.	He could discuss the bread.
The car was parked at the curb.	They hope he heard about the rent.
The doctor prescribed the drug.	He was interested in the hedge.
The lion gave an angry roar.	We're glad Ann asked about the fudge.
The gambler lost the bet.	You're discussing the plot.