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Using Electropalatography (EPG) in the assessment and treatment of developmental motor speech disorders: Linking basic and applied research

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Abstract

Many children experience significant difficulties in developing key aspects of speech. For some, these communication difficulties are compounded by co-occurring intellectual disabilities. This paper presents two case studies from a larger on-going longitudinal study of the effectiveness of using electropalatography (EPG) to address the intelligibility problems experienced by many children and young people with Down's syndrome (DS). EPG, an innovative computer-based tool for assessing and treating speech motor difficulties, enables the speaker to "see" the placement of his or her tongue during speech and to attempt to correct any lingual palatal errors. This visual supplementation of auditory feedback offers potential therapeutic benefits for children with intellectual disabilities, many of whom show relative strengths in visual versus auditory and simultaneous versus sequential processing (e.g. [1]). EPG also provides therapists with an objective measure of articulatory ability. Findings from these two case studies demonstrate the potential utility of EPG in both the assessment and treatment of speech motor disorders in DS.

1 INTRODUCTION

It is estimated that 1 in 10 children will have a speech, language or communication difficulty [2]. For many this is likely to impact on their day-to-day interactions with peers and adversely affect their quality of life [3]. For some children these communication difficulties are exacerbated by a co-existing intellectual disability. In this paper, we look at the use of electropalatography, a novel computer based technology, in assessing and treating the speech difficulties commonly encountered by children who have Down's syndrome (DS).

Traditionally, speech and language therapists (SLTs) have used auditory-based transcriptions to represent the acoustic output of the complex speech production process of their clients, with this in turn used to diagnose the nature and locus of their speech difficulties. This requires the SLT to listen to speech and transcribe what they hear using the International Phonetic Alphabet (IPA). Since it needs no elaborate

instrumentation it can be used anywhere and by all SLTs. However it is not without problems, particularly when assessing motor speech disorders.

It is well documented that auditory-based transcriptions can often be unreliable [4, 5, 6]. In terms of informing diagnosis and directing therapy, transcriptions can also be misleading for a number of reasons. Firstly, the potentially large variation in the skill of the transcriber can lead to inter-rater variability. Moreover, the same listener may perceive things differently on different occasions due to fluctuating attention levels, resulting in poor intra-rater reliability. Another problem is the abstract nature of the speech output. Essentially, most conventional auditory transcriptions are segmentally-based and consist of a series of symbols. Speech is not segmentally based, however, but is a continuous stream of overlapping articulatory events, with instrumental studies showing that discrete boundaries between segments cannot always be accurately identified or even, at times, distinguished [7]. The segmental nature of the transcription can also lead to categorical transcription errors (substitutions) when non-categorical errors (distortions) have actually been made [8] which clearly impacts on the reliability of the transcription. The listener's perception can additionally be influenced if they know what the speech target is, which invariably they do in a test situation.

Another potential limitation arises from the fact that the transcription represents the acoustic output only and not precisely what the articulatory organs themselves are doing. Different articulatory movements and configurations can lead to the same acoustic result (and therefore the same transcription) and these articulatory differences may be important in the precise diagnosis of the speech disorder. An over-reliance on auditory-based transcriptions for disordered speech can therefore be very misleading, especially in complex speech disorders such as those caused by motor disorders.

Given the inherent limitations of auditory-based evaluations, instrumental methods have begun to play an increasingly more prominent role in the clinical management of a range of client groups with motor speech disorders. These benefit from providing more objective, quantitative and reliable data on the articulatory, laryngeal and respiratory activities involved in speech and are better able to represent the continuous nature of speech events. This in turn leads to increased diagnostic precision, is essential for developing and evaluating appropriate evidence-based therapies.

Some instrumental techniques, for example ultrasound, can be used as biofeedback devices in therapy to provide real-time visual and auditory displays of abnormal speech patterns. Thomson-Murdoch & Ward [9] have highlighted how instrumental techniques such as these could enhance clinical management:

- by increasing the precision of diagnosis through more valid specification of abnormal functions that require modification,
- by providing positive identification and documentation of the therapeutic efficiency, through short-term assessment and long-term monitoring of the functioning of the speech production apparatus,

One potentially highly useful instrumental technique is electropalatography (EPG). EPG is a relatively non-invasive technique which visually displays the timing and location of the tongue's contact with the hard palate during continuous speech. The individual is required to wear a custom-made artificial palate (Figure 1) housing 62 electrodes which fits snugly against the roof of the mouth. These electrodes are activated when the tongue touches them and a recording is made every 10msecs. An individual's articulation can be compared to standard patterns for consonants for a

given language (see examples in Figure 2) and errors in production can be noted, both by the therapist and speaker.

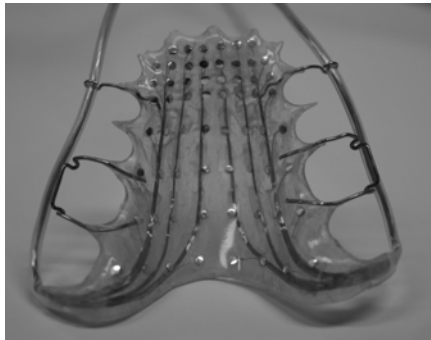


Figure 1. EPG palate

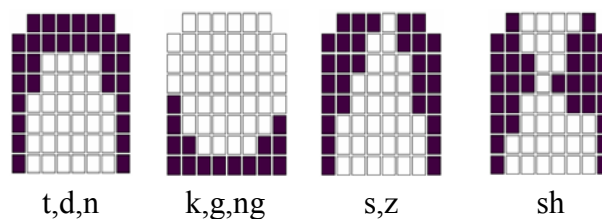


Figure 2. . Examples of standard articulatory patterns for English consonants involving the tongue. Oral cavity is represented from front (row 1) to back (row 8). Black squares indicate activated electrodes showing current positioning of the tongue.

In addition to providing more detailed and reliable data to aid in precision of diagnosis, EPG can also be used to modify erroneous articulatory patterns by using visual feedback. A target articulation pattern characteristic of a particular speech sound is displayed on one side of a computer screen and during a therapy session the client attempts to copy this correct articulation by monitoring his/her own contact patterns in real time on the other side of the screen (see Figure 3).



Figure 3. The client attempts to copy the target articulation which is displayed on the right hand side of the computer screen. The left hand pattern is the client's attempts to match the target

EPG has already been successfully used in the assessment and treatment of a range of speech disabilities (for example, cleft palate, apraxia of speech, functional articulation disorders, cerebral palsy and hearing impairment - see [10] for a comprehensive bibliography of studies in English). Until very recently, however, EPG has not been used with client groups whose speech motor difficulties are potentially confounded by a co-existing intellectual disability.

This is perhaps surprising given that it is well documented, for example, that individuals with Down's syndrome (DS) can demonstrate very significant difficulties with speech production and often present with very much reduced intelligibility (see e.g. [11]). Several studies have suggested that these difficulties are characterised by a delay in phonological development [12, 13, 14, 15, 16]. Stoel Gammon [17] summarised the developmental phonological processes used by children with DS as cluster reduction, final consonant deletion, stopping of fricatives, pre-vocalic voicing, word initial gliding, word final vocalization, and devoicing of word final obstruents. Others have suggested that a purely phonological delay is an over-simplistic view and that many children with DS also show developmental differences in their speech output, such as greater variability in production [18] and unsystematic replacement of final voiceless fricatives by other voiceless fricatives [19]. Roberts and colleagues [20], who collected data from 32 boys with DS aged 4 to 13 years, found additional systematic errors not previously reported, for example palatal fronting, fricative simplification, deaffrication, and lateralisation of sibilants. In addition to phonological processes, researchers are beginning to suggest that children with DS may be demonstrating characteristics synonymous with a diagnosis of childhood apraxia of speech [11, 21]. Other investigators have also been exploring whether difficulties reflect atypical organisation of speech and language or more fundamental executive deficits [22].

Although the nature and origin of the speech errors associated with DS have still to be fully determined, it is generally accepted that these speech problems often lead to significantly decreased intelligibility [21]. In a survey of 937 parents of children with DS, over 95% of parents reported that individuals immediately outside the family experienced difficulties in understanding what their child was trying to say [23]. Buckley and Sacks [24] likewise reported that over half the adolescent girls and approximately 80% of boys in their survey were rated as unintelligible to strangers.

A recent case study of a 10 year-old girl with DS [25] applied EPG-based therapy with a view to resolving an abnormal phonetic process of velar fronting (i.e. substituting velar sounds such as the [k] in "key" with a more anterior sound such as [t]) which had previously proved resistant to conventional speech therapy. The study measured changes in the accuracy and stability of tongue-palate contacts over a 14-week block of therapy. Training with visual feedback enabled the child to modify her incorrect tongue placement for velars and to transfer this skill readily to conversational contexts. Her speech showed fewer articulation errors and significantly increased intelligibility.

These encouraging findings led us to design and conduct a larger-scale longitudinal study of the potential efficacy of EPG in the assessment and treatment of speech disorders in DS. For a number of reasons, EPG seemed particularly suited for investigating speech motor patterns in children with DS and for treating abnormal articulation. First, the link between the child's speech movements and the visual display on the screen is a direct and conceptually very simple one, making complex explanations of what is involved in learning to produce correct articulatory patterns

unnecessary. Second, by utilising visual feedback in the therapy sessions, this link should be more easily accessible to children with DS as their visual processing skills are often described as a relative strength and they are reported to respond better to visual stimuli than, for example, verbal instructions [26, 1]. Third, there is evidence that children with DS particularly enjoy interacting with a computer-generated presentation of simple graphically represented material [27].

2 METHODS

Study Design: The study aims to collect an extensive range of information on speech characteristics in 30 children with DS aged between 8 and 18 years and to evaluate the efficacy of EPG versus non-EPG speech therapy in comparison to change over time in an untreated control group. Initial screening is designed to identify those children for whom meeting task demands would be likely to present significant obstacles to assessment and /or therapy: those whose level of cognitive ability is less than 3 years, those with a significant hearing loss (greater than 40dB even when aided), those with current emotional and behavioural difficulties, and those with a co-existing diagnosis of autism.

Children recruited into the study undergo detailed testing on a battery of standardised and non-standardised speech, language and cognitive assessments, with their speech output also profiled using an EPG-based protocol. Cognitive ability is assessed using the full form of the Weschler Preschool and Primary Scale of Intelligence (WPPSI-IIIUK) [28] which provides verbal, performance and full-scale mental age equivalents (AE). The British Picture Vocabulary Scales-II (BPVS-II) [29] is a well-established tool for measuring receptive vocabulary, has minimal language demands, and covers a wide age range (3 to 16 years). The Clinical Evaluation of Language Fundamentals-Preschool UK (CELF-P) [30] allows calculation of receptive, expressive and general language AE. The Diagnostic Evaluation of Articulation and Phonology (DEAP) [31] includes a measure of consonant production in single words, covering most consonants of English in initial and final word positions. The phonology subtest allows calculation of percentage consonants correct (PCC), percentage vowels correct (PVC), percentage phonemes correct (PPC) and single words/connected speech phoneme agreement (SvC). These DEAP test items, plus 10 repetitions of 10 additional words chosen to sample a further range of important lingual palatal contacts, were all spoken by participants whilst wearing a customised EPG palate and were audio recorded for subsequent phonetic transcription. In contrast to the standard DEAP protocol which allows only perceptually-based analysis, EPG-derived data enables more objective measures of articulatory abilities to be taken.

Following assessment, participants with DS are randomly assigned to 1 of 3 groups broadly matched for cognitive and chronological age. Ten children are being allocated to EPG visual feedback therapy and provided with a Portable Training Unit (PTU) for home practice; 10 will receive traditional articulation therapy (i.e. non EPG-based but delivered by the same therapist); and 10 are being allocated to a no treatment group (while continuing to receive any outside therapy as usual). Treatment for both therapy groups consists of 24 individualised sessions over 12 weeks, with all participants being reassessed on speech, using DEAP data, the Children's Speech Intelligibility Measure (CISM - [32]) and EPG measures immediately following therapy; the no treatment group are reassessed at an equivalent point, i.e. 12 weeks after their initial assessments. All groups are to be reassessed 3 and 6 months

thereafter. This will allow us to monitor any post-therapy changes in progress in the two therapy groups, while controlling for normal developmental changes.

Participants: To date, 57 families with a child with DS have been approached. Thirty eight of the children met our initial inclusion criteria and were screened for suitability, and 28 were subsequently recruited into the study. This paper reports two in-depth case studies, one of an 11 year old girl and one of a 14 year old boy, both presenting with severe but different speech difficulties. Both received EPG therapy. Pre-therapy speech, language and cognitive test results are detailed below, along with their unique and contrasting speech patterns as identified through EPG assessment, both before and after EPG therapy.

3 RESULTS

Child A: Results of pre-therapy cognitive, language and speech testing for child A, aged 11 years 7 months, can be seen in Table 1.

Table 1: Results of pre-therapy assessment for Child A

Test	Score
WPPSI III-UK	VAE 6;10 PAE 4;07 FSAE 5;09
BPVS II	AE 5;05
CELF-P UK	CELF-C AE 3;11 CELF-E AE 3;00 CELF-T AE 3;04
DEAP	PCC 67% AE<3;0
CSIM	Intelligibility 72%

Key: *Cognition (WPPSI III-UK):* VAE = Verbal Age Equivalent; PAE = Performance Age Equivalent; FSAE = Full-Scale Age Equivalent
Receptive Vocabulary (BPVS II): AE = Age Equivalent
Language (CELF-P UK): CELF-C = Receptive Language; CELF-E = Expressive Language; CELF-T = Total Language
Speech (DEAP): PCC = Percentage Consonants Correct
Intelligibility (CSIM): note: age equivalents cannot be calculated for this test

As can be seen in Table 1, assessment of child A’s cognitive abilities indicated greater strengths on verbal test items than on performance items. Language testing highlighted a significant delay in receptive vocabulary and in receptive and expressive language, consistent with a diagnosis of DS. Perceptual analysis of the DEAP, prior to a more detailed analysis of the corresponding EPG data, indicated that 67% of consonants and 95% of vowels were correctly articulated. This equates to an AE of less than 3 years, indicative of a severe speech impairment. Specifically, the SLT noted that /s, z, ʃ, ʒ, tʃ, dʒ/ were distorted and inconsistent in their production, there were voicing errors (e.g. “toe” was heard as “doe”), weak syllables were deleted (e.g. “banana” was produced as “nana”) and consonant clusters were reduced (e.g. “spider” was heard as “baider”). EPG analysis of the DEAP word list and of the additional customised word list confirmed distorted sibilants, specifically characterised by lateral and central plus lateral articulations, and also highlighted a previously undetected

¹ Phonetic symbols will be used throughout this paper as is the convention when reporting on speech sounds - here, /s/ as in sun, /z/ as in zoo. /ʃ/ as in shoe, /ʒ/ as in measure, /tʃ/ as in chew, /dʒ/ as in jelly

high-level of variability in speech production, that is the same word was being produced differently over several repetitions.

Child A received 24 EPG therapy sessions spanning 3 months focussing on achieving correct production of /s/ and /sh/. Only results for /s/ will be reported here. An EPG PTU was used between sessions for home practice.

Pre-therapy EPG patterns for the target /s/ in “sun” are shown in Figure 4. Each single frame shows the midpoint of the segment. The correct articulation for /s/ should have contact down both sides of the palate and a narrow groove at the front (top of the diagram) through which air is channelled, allowing the correct sound to be made (see Figure 4 adult model). The majority of EPG patterns produced by Child A are distinctly different, although 5 repetitions out of 10 were perceived as being correct. Sounds that are perceived to be accurate but are not articulated correctly, or inconsistently articulated, can lead to difficulties in connected speech where rapid and coordinated movements of the articulators are required. At this connected speech level, intelligibility can therefore be severely impaired if articulation is not accurate and consistent.

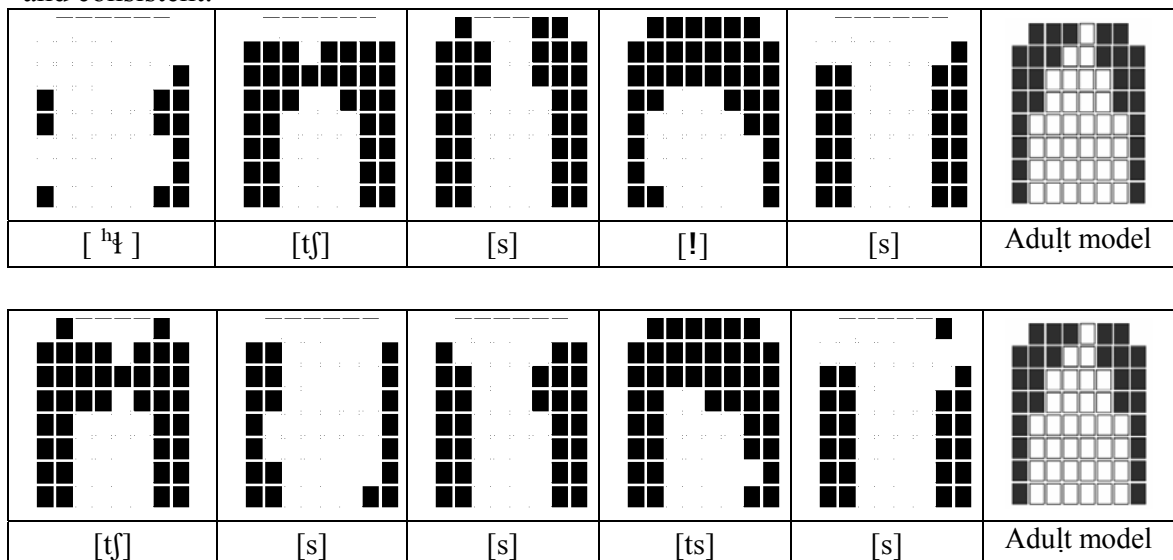


Figure 4. Child A: Pre-therapy EPG patterns for 10 repetitions of the target /s/ in “sun” (correct production is given on the far right and phonetic transcription beneath). Each frame shows the mid point of articulation for each repetition. The symbols [ʰʃ], [!], [ts] indicate productions that sounded distorted. [tʃ], indicated that the /s/ was heard as a “ch” e.g. “chun”

Table 2: Results for Child A from the DEAP and CSIM for the 4 time points

Measure	Pre-therapy	Post-therapy	3 months post-	6 months post-
DEAP (PCC)	67%	75%	78%	89%
CSIM (Intelligibility)	72%	58%	46%	76%

Key: See Table 1

Results for the DEAP and CSIM are given in Table 2 for each of the 4 time points in the study. Corresponding EPG patterns are given for post therapy and 3 months post therapy only since the palate no longer fitted at 6 months (Figures 5 & 6).

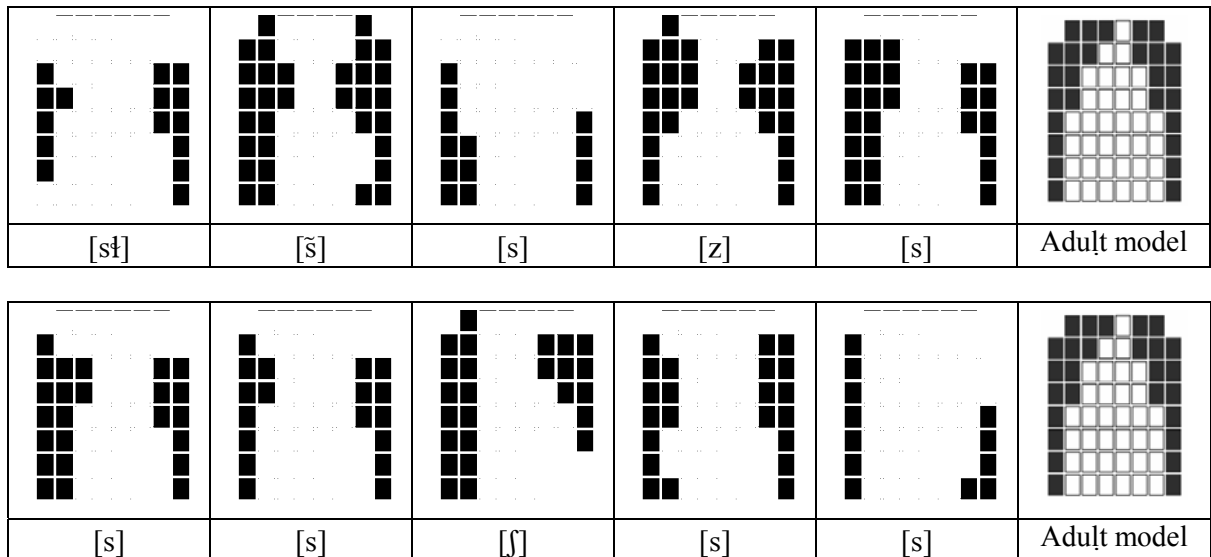


Figure 5. Ten repetitions of the target /s/ in sun immediately post therapy. The EPG patterns demonstrate accurate and consistent lingual palatal contact patterns. Each frame shows the mid point of articulation for each repetition. The symbols [st̥], [s̃], indicate productions that sounded distorted. [ʃ] indicates that the /s/ was heard as a “sh” e.g. “shun”.

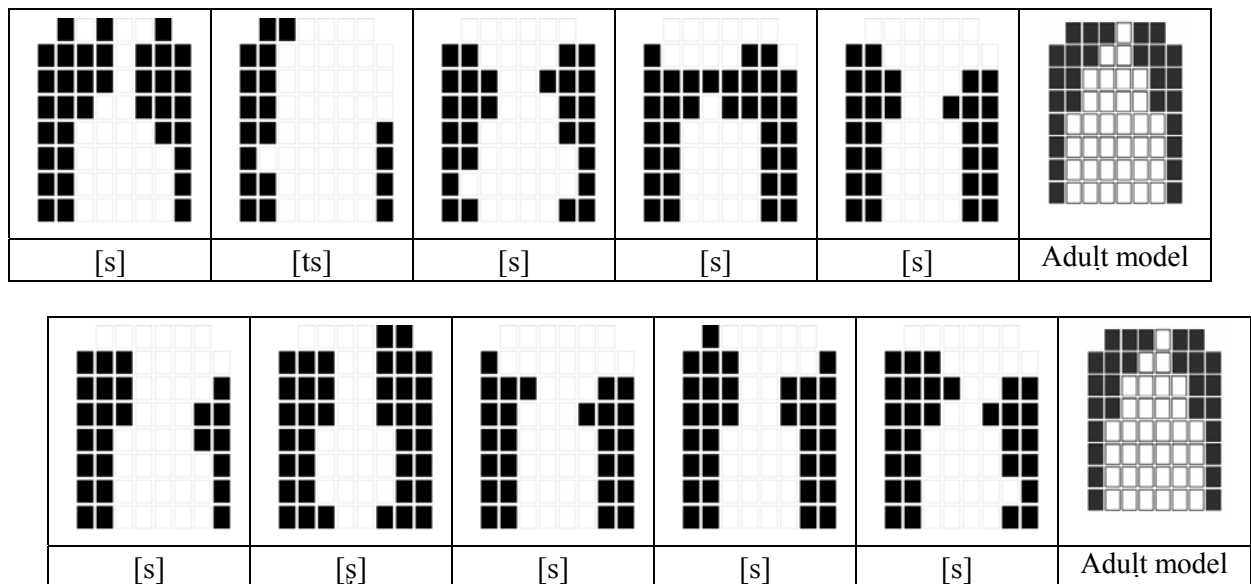


Figure 6. Ten repetitions of the target /s/ in sun 3 months post therapy. The EPG patterns demonstrate mainly accurate and consistent lingual palatal contact patterns. Each frame shows the mid point of articulation for each repetition. The symbols [ts] and [ʃ], indicate productions that sounded distorted.

Variability of productions was also measured using the Variability Index [33]. The calculation gives an EPG prototypical frame where the higher the index the greater the variability (range 0 to 50). The variability of 10 repetitions of /s/ in the phrase “a sun” was calculated pre- and post-therapy. Since decreased variability is associated with increased motor control, a reduction in post-therapy variability would be indicative of an improvement in Child A’s speech. Child A’s productions were also compared to productions from 3 typically developing children. Figure 7 shows how the variability of /s/ reduced from 15.92 to 12.10 immediately post-therapy which is closer to the variability levels seen typical development.

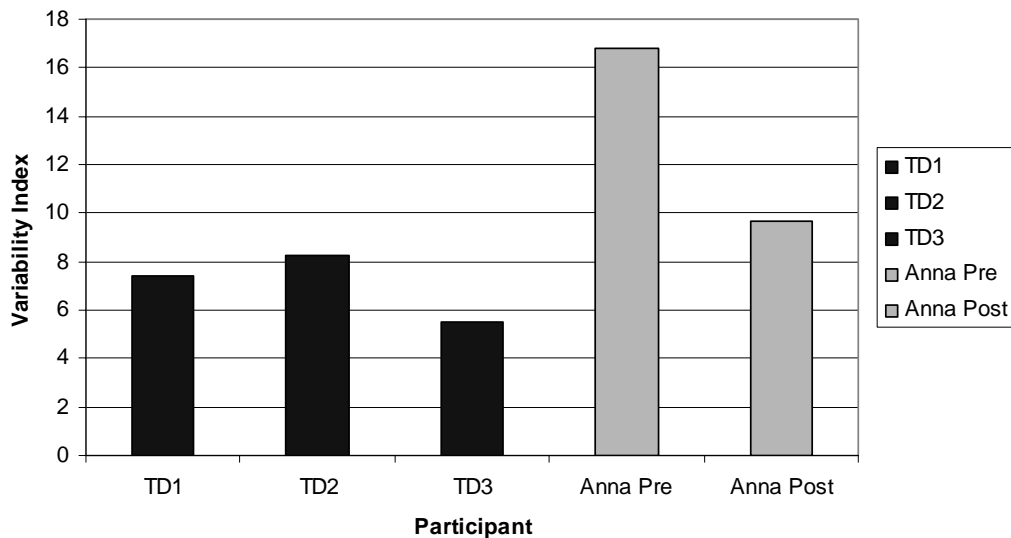


Figure 7. Variability for production of /s/ pre and immediately post therapy compared to 3 typically developing children at a similar developmental stage.

Summary of therapy outcomes: Towards the end of therapy, this child was able to achieve correct lingual palatal placement for /s/ both in single words and in sentences within the clinical setting and these productions were perceived as correct. She was also able to carry over this skill without EPG feedback. The PCC had increased from 67% to 89% which represents an improvement in all sibilants, not just /s/, and her intelligibility as measured 6 months post-therapy had increased from 58% to 76%. Variability had decreased which perhaps indicates improved motor control although it still remains higher than typically developing children. Child A has therefore made significant progress in therapy. However, she continues to present with intelligibility issues, many of which are related to speech rate and voice.

Child B: Results of pre-therapy cognitive, language and speech testing for child B, chronological age 14 years 11 months, can be seen in Table 3.

Table 3: Results of pre-therapy assessment for Child B

Test	Score
WPPSI III-UK	VAE 5;01 PAE 7;02 FSAE 6;02
BPVS II	AE 7;03
CELF-P UK	CELF-C AE 4;10 CELF-E AE 4;00 CELF-T AE 4;00
DEAP	PCC 59% AE <3;0
CSIM	Intelligibility 46%

Key: See Table 1

As can be seen in Table 3, assessment of child B's cognitive abilities showed greater success on performance test items than on verbal items. Language testing highlighted a significant delay in receptive and expressive language although receptive vocabulary was noticeably better. Perceptual analysis of the DEAP indicated that 59% of consonants were correctly articulated. This equates to an AE of less than 3 years. Specifically, the SLT noted a number of features: fronting of /k/ and /g/ so that they became /t/ and /d/; fricatives and affricates (/s, z, sh, ch/) were disordered and showed increased variability; difficulties in the sequencing of sounds in words. EPG analysis of the DEAP and an additional customised list of velar stops in all word positions showed that velars were often produced incorrectly but with type of error variable. Longer words with contrasting places of articulation were particularly problematic due to the greater degree of coordination required.

Child B also received 24 EPG therapy sessions spanning 3 months but in this case the focus was on achieving correct production of the velar stops /k/ and /g/. Only results for /k/ will be reported here. In addition to working on the sounds in isolation, key words were practised (for example, words he was using at school, names, etc), using the EPG to provide a visual map of the correct production. Again an EPG PTU was used between sessions for home practice.

An example of the production of /k/ in "car" as highlighted through EPG is shown in Figure 8 below. This is a complete printout for this sound as opposed to a single frame previously shown for child A because there are changes in articulation taking place throughout the production which cannot be captured by one frame. Whilst there is clearly contact in the velar region (back of palate), child B also made contact at the front of the palate, essentially producing two distinct articulations with some overlap. This was heard and transcribed as a /t/ followed by a /k/.

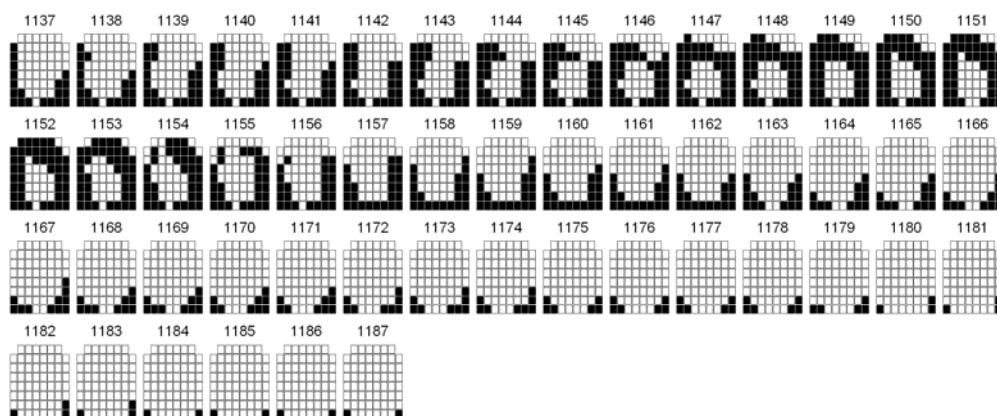


Figure 8: Child B: Complete print-outs of EPG patterns for the /k/ at the beginning of "car". Patterns are read from right to left and each frame represents 10msec. Whilst this speaker begins with the correct velar articulation there is also alveolar involvement resulting in a double articulation which starts at frame 1146 and is released at 1154. The attempt is heard as [tk]. For comparison purposes with earlier figures for child A the midpoint frame is highlighted

Table 4: Results for Child B from the DEAP and CSIM for the 3 post therapy time points

Measure	Pre-therapy	Post-therapy	3 months post-	6 months post-
DEAP (PCC)	59%	65%	73%	65%
CSIM (Intelligibility)	46%	54%	61%	52%

Key: See Table 1

Table 4 shows the results from the DEAP and the CSIM following therapy. Immediately post therapy child B had made gains in both the percent consonants correct as measured by the DEAP (59% pre-therapy compared to 65% post-therapy) and also in intelligibility (single words increasing from 46% to 54%). This trend continued such that at 3 months post therapy further gains had been accomplished (PCC 73% and 61% intelligible in single words). At six months post therapy there had been some slippage although PCC and percent intelligible were still better than pre-therapy and very similar to immediately post therapy. These improvements are also evident in the post therapy EPG recordings at all time points (see Figures 9, 10, 11). There is clear velar articulation in all three examples and no evidence of the fronted pattern that had dominated pre-therapy. All three productions are heard as “car”. The amount of tongue palate contact in the velar region for each production varies (note there is no complete closure in Figure 9 whilst there is in Figures 10 and 11). However this is perfectly acceptable and considered normal.

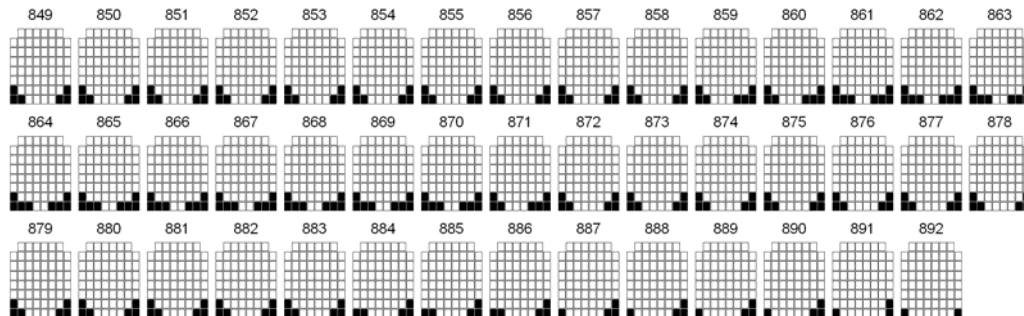


Figure 9: Post-therapy EPG patterns for /k/ in “car”. Whilst full closure is not seen in the velar region this is not unusual in this context.

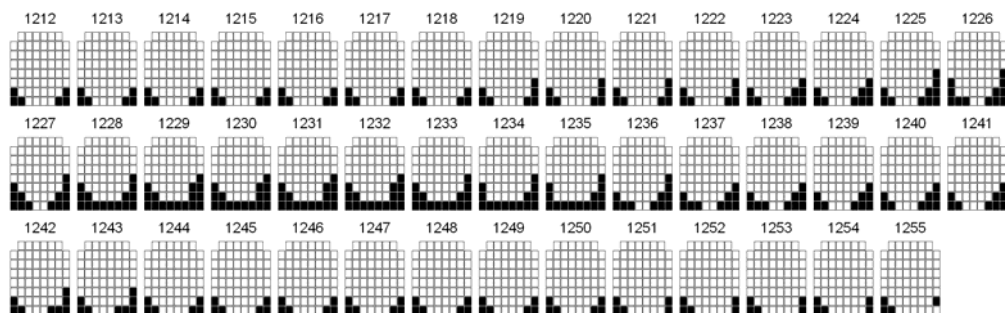


Figure 10: 3 month post-therapy EPG patterns for /k/ in “car”.

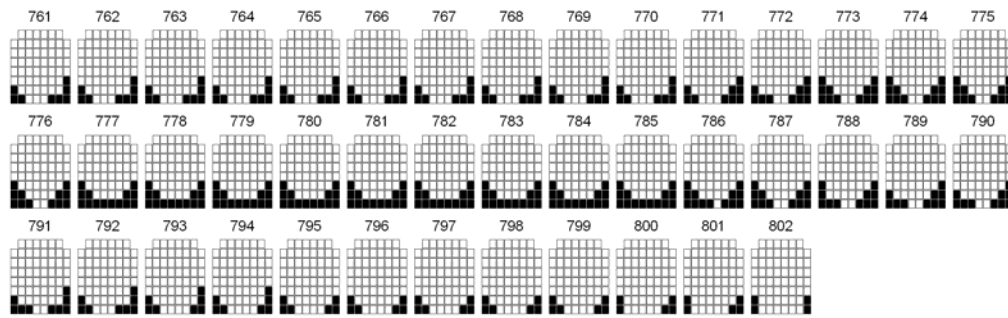


Figure 11: 6 month post-therapy EPG patterns for /k/ in “car”.

Summary of therapy outcomes: Child B was able to achieve correct lingual palatal placement for both /k/ and /g in single words and key words in connected speech. At the 3 and 6 month post-therapy recordings he was able to retain this gain although PCC and intelligibility dropped a little at the 6 month time point. An improvement on pre-therapy was nevertheless still evident and the EPG patterns were correct. Child B has therefore made measureable progress in therapy. However, he continues to present with some disordered speech patterns and can be difficult to understand, especially out of context.

4 DISCUSSION

The findings from the two case studies presented here demonstrate that EPG therapy can influence accuracy of speech production in children with DS, irrespective of whether analysis focuses on variability in production of the same consonant over repeated trials or on the same consonant when produced in the context of different words. Both children made progress and it is likely that the additional visual information provided by EPG supported the learning process for these children with DS. Whilst these are exciting and promising results there are still many questions in need of answering and we need to look at the whole cohort of children in the larger study to begin to understand the effect of EPG training in improving speech intelligibility in DS. For example, from these two case studies we can see that whilst one child’s progress at the end of therapy was furthered 3 and 6 months after therapy had ceased, the other child continued to make gains at 3 months but at 6 months progress has returned to a level comparative to immediately post therapy.

The issue of whether gains made in therapy can be sustained has important clinical implications since if progress is not maintained we need to examine possible reasons for this and reconsider therapy delivery. It may be that therapy needs to be more intensive to provide for additional repetition and practice. It is well documented that children with DS have difficulty stabilising the information they acquire [34] and it has been suggested that this is due to deficits in hippocampal functioning [35]. We therefore need to reflect not only on whether the children make progress in therapy, but also on whether this progress is consolidated or indeed continues once targeted intervention has stopped. In the event of Child B it seems that therapy may not have been intensive enough but that for Child A it was. We need to investigate further timing and delivery of therapy to see if a pattern begins to emerge between child characteristics and therapy outcomes within the group as a whole.

In this paper we have reported on only two children receiving individualised therapy targeting different sounds. Evaluation of this approach as an effective therapy for articulation disorders at a group level awaits completion of all data sets. Whilst the majority of children with DS present with significant difficulties in speech production

these are heterogenic in nature. Some of the difficulties cannot be targeted with EPG since the technique is restricted to those articulations which involve the tongue contacting the hard palate (although these constitute 75% of English consonants). Other constraints also apply. For example, a minimum level of cognitive ability may be required to understand the technique and its relationship between the computer screen and the movements of the tongue in the mouth. Some children may in addition be orally hypersensitive and this might prevent them from being able to tolerate the custom-made palate. Nevertheless we feel this technique represents a new approach to what have previously been considered to be intractable speech problems in children with DS.

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