Visual feedback therapy with electropalatography (EPG) for speech sound disorders in children

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Abstract

Electropalatography (EPG) is an instrumental technique that detects the tongue's contact against the hard palate during speech and creates a visual display of the resulting patterns. This chapter focuses on EPG as a visual feedback device in therapy for children with speech sound disorders. Tongue-palate contact information is rich in detail and as a result it can be used for diverse research and clinical purposes. Examples of clinically relevant information contained in EPG data are place of articulation, lateral bracing, groove formation, timing of tongue movements and coarticulation. Furthermore, the technique records measurable amounts of contact for sound targets that are frequently produced as errors by children with speech sound disorders (e.g., /σ/, /Σ/, /τΣ/). These features make EPG valuable for both diagnosis and therapy. During EPG therapy, children's abnormal articulation patterns are revealed to them on the computer screen and they can use this dynamic visual feedback display to help them produce normal contact patterns. An attractive property of EPG as a therapy device is that the visual display is relatively intuitive. This means that children can understand the link between the speech sounds they hear and the associated contact patterns displayed on the screen. There is now an extensive literature on the benefits of using EPG in therapy, but the quality of evidence would improve by conducting large clinical trials in the future.

Introduction

Investigating the actions of the tongue during speech poses particular challenges. The difficulties are due to the tongue's inaccessible location within the mouth, its sensitivity, the unique properties of its internal structure, and the speed and complexity of its movements. EPG is a technique designed for just this purpose, in other words, to record tongue movements during speech. EPG (also termed *palatometry* and *dynamic palatometry*) in fact only records one aspect of tongue activity – the location and timing of tongue contacts against the hard palate (Gibbon, 2008; Hardcastle & Gibbon, 1997; Hardcastle, Gibbon, & Jones, 1991). Compared to other instruments currently available for investigating tongue movements in speech, EPG is both safe and relatively convenient to use. Safety is an obvious necessity and convenience is highly desirable when designing instrumental techniques for use with clinical populations. The focus of this chapter is on using EPG for visual feedback therapy, but in preparing the ground for later discussions, there follows a description of the EPG technique and an explanation of its important role in diagnosis.

EPG – the Technique

A number of different EPG systems have emerged in research and clinical use over the past 40 years. A British system – the EPG3 system developed at the University of Reading – has been used in the majority of studies conducted by researchers in Europe and Hong Kong (Hardcastle, Gibbon, & Jones, 1991; Hardcastle & Gibbon, 1997). A new Windows® version of the Reading EPG has recently been developed at Queen Margaret University, Edinburgh, UK (WinEPG™, Articulate Instruments Ltd, 2008). In the past, the Kay Elemetrics Palatometer was used in research carried out in the United States (Fletcher, 1983), although there is now a new EPG system developed by Logmetrix® (Schmidt, 2007). In Japan, the Rion EPG system was the one most widely used until it was discontinued (Fujimura, Tatsumi, & Kagaya, 1973). All EPG systems share some common general features, but differ in details such as the construction of the EPG plates, number and configuration of sensors, and hardware/software specifications (Gibbon & Nicolaidis, 1999; Hardcastle & Gibbon, 1997).

A prerequisite for EPG therapy is manufacturing a special plate, which resembles a dental plate. Each one is custom-made to ensure a perfect fit, and when properly constructed it should fit securely and comfortably against the roof of the mouth. Although relatively expensive to construct, one advantage of having them custom-made is that they can be tailored to fit individuals with unusually shaped hard palates (e.g., cleft palate, Down syndrome), dental anomalies, dentures or dental braces. Figure 1a shows a Reading EPG plate for a typical speaker. The figure shows how the 62 sensors are arranged in a standard configuration of eight horizontal rows placed according to identifiable anatomical landmarks (Hardcastle, Gibbon, & Jones, 1991). The sensors are spaced so that the distance between the front four rows is half that of the back four rows. The high concentration of sensors in the alveolar region allows crucial aspects of tongue-tip articulation, such as grooving during sibilant productions, to be recorded in detail. In the posterior region, the sensors extend to the junction of the hard and soft palates and in the lateral margins they extend to the gingival border.

(a)

(b)

Figure 1. A Reading EPG (artificial) plate for a typical speaker placed on top of a plaster impression of the upper palate and teeth is shown in (a). A single EPG frame, showing a typical contact pattern for alveolar stops /t/, /d/, /n/ is shown in (b), along with the EPG frame row numbers, the phonetic regions of the palate and the part of the tongue that makes contact with these regions.

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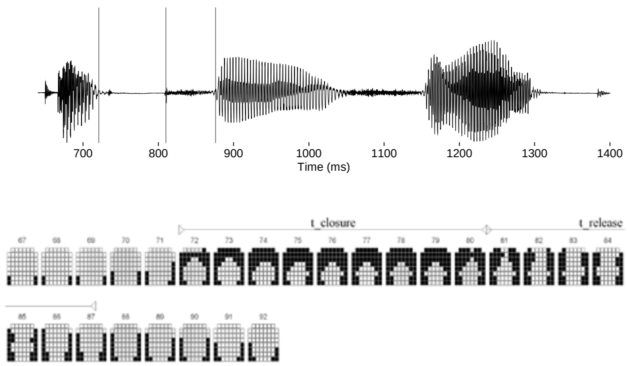
Individual wires from each sensor emerge from the posterior region of the plate in two bundles, exiting at the corners of the speaker's mouth. The EPG plate and a hand-held electrode (providing a small current) are connected to an external processing unit or a multiplexer, which is in turn connected to a computer. A circuit is completed when the tongue surface contacts any of the sensors and the resulting pattern of contact is displayed on a computer monitor. Figure 1b shows a single EPG palatogram, with row numbers 1-8 indicated. Palatograms are schematic displays, which are standard for every speaker regardless of individual differences in the shape and size of the EPG plate. Figure 1b indicates how the schematic palatograms broadly correspond to the phonetic regions of the palate (i.e., alveolar, post-alveolar, palatal and velar) and to the relevant active articulators (i.e., tongue tip and tongue body).

The most recent version of EPG software, the WinEPG™ system (Articulate Instruments Ltd, 2008), can sample at different rates, although usually the EPG is set at 100 Hz with simultaneous sampling of the acoustic signal at 22,050 Hz. The EPG data are displayed as sequences of two-dimensional representations of tongue-palate contact, referred to as palatograms or EPG frames. The EPG data can be stored and analyzed using the Articulate Assistant™ software. Figure 2 shows a dynamic sequence of EPG frames for an alveolar stop /t/ produced by a typically developing 12-year-old child. The figure shows individual palatograms, which are numbered and read from left to right. In this printout, the frames occur at 10 ms intervals, and tongue contact is indicated by filled black squares along the eight horizontal rows.

(a)



(b)

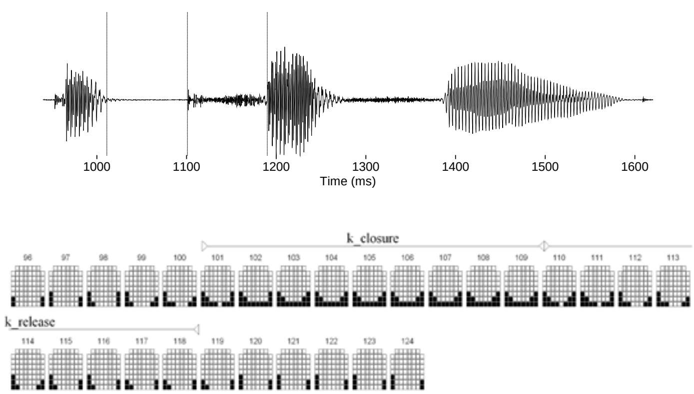


Figure 2. EPG printouts for (a) /t/ in *a toolshed* and (b) /k/ in *a kettle* produced by a typically developing 12-year-old boy. These are full, dynamic EPG printouts, where the top of individual palatograms represents the alveolar region, and the bottom is the velar region located at the junction between the hard and soft palates. The sampling interval is 10 ms.

Figure 2a illustrates contact patterns for the alveolar plosive /t/ in the phrase *a toolshed*. During the stop closure phase (frames 72-80), there is contact along the lateral margins combined with closure across the palate in the alveolar region. This combination of lateral and alveolar contact gives rise to the so-called *horseshoe shape*, which is a characteristic pattern for normal alveolar stops /t/, /d/ and /n/. The closure phase of /t/ in Figure 2a is followed by the release phase, which starts at frame 81. Notice that an /s/-like configuration occurs fleetingly at the start of the release. The patterns for the alveolar stop are in contrast to those for the velar stop in Figure 2b, which shows a /k/ target in the phrase *a kettle* spoken by the same typically developing child. Here, the palatograms during the closure period (frames 102-109) have contact along the posterior lateral margins and closure in the velar region.

Figure 2 illustrates how the sounds /t/ and /k/ are associated with visually distinct, recognizable EPG patterns. In fact, EPG records characteristic patterns in typical speakers for all English lingual phoneme targets, which include /τ/, /δ/, /κ/, /γ/, /σ/, /ζ/, /Σ/, /Z/, /τΣ/, /δZ/, the palatal approximant /j/, nasals /n/, /N/, and the lateral /l/ (for reports of typical adult EPG patterns, see Gibbon, Yuen, Lee, & Adams, 2007; Hardcastle & Gibbon, 1997; Liker & Gibbon, 2008; Liker, Gibbon, Wrench, & Horga, 2007; McLeod, Roberts, & Sita, 2006; McLeod & Singh, 2009). Hardcastle and Gibbon (1997) presented idealized static EPG patterns, which have proved to be useful reference frames, although they are not based on recorded data. More recently, McLeod and Singh (2009) presented comprehensive coverage of EPG patterns for typical and disordered speakers.

Although studies have identified characteristic patterns for consonant targets, typical speakers vary in the overall amount of contact they produce. Gibbon, Yuen, Lee and Adams (2007) conducted a study on normal alveolar stops (i.e., /t/, /d/ and /n/) and found that some speakers had more than twice as much contact as other speakers. This held true despite the finding that all speakers produced characteristic horseshoe-shaped patterns for these targets. Studies of typical velars (Liker & Gibbon, 2007), bilabials (Gibbon, Lee, & Yuen, 2007), and affricates (Liker, Gibbon, Wrench, & Horga, 2007) reached a similar conclusion, namely that some speakers had 2 or 3 times more contact than others. One explanation for this variation is that the amount of contact relates to inter-speaker differences in palatal shape. More specifically, individuals with flatter palates tend to have higher overall amounts of contact than those with more steeply arched palates (Hiki & Itoh, 1986). There are other possible explanations, however. It may be the case that the amount of contact reflects speakers' long-term jaw and tongue settings. In other words, speakers produce high amounts of contact when they articulate because they have high habitual settings. Likewise speakers with low amounts of contact have low settings. Another possible explanation is that the degree of articulatory effort exerted by speakers influences the amount of contact. Here, speakers with higher overall amounts of contact exert more tongue-palate pressure, as a result of increased effort, compared to speakers with lower amounts of contact. Although the precise relationship between speaker characteristics (e.g., anatomy, articulatory settings, speech style) and EPG data is unknown at present, clinicians need to assess whether these characteristics are influencing the EPG patterns produced by children with speech sound disorders.

Varying patterns of contact are registered during bunched and retroflex varieties of /r/, relatively close vowels, such as /ι/, □/I/, □/ε/, /u/, /Y/ and rising diphthongs, such as /εI/, /AI/, /οI/, /αY/, /↔Y/. There is usually minimal contact during open vowels, such as /A/, □/□/. Equally, consonants that have their primary constriction either further forward than the most anterior row of sensors (e.g., dentals, bilabials) or further back than the most posterior row of sensors (e.g., velars in the context of open vowels, uvulars, pharyngeals, glottals), show limited contact. Some EPG contact occurs during these consonant sounds, however, when they occur in the context of relatively close vowels, rising diphthongs (Gibbon, Lee, & Yuen, 2007) or complex clusters (Zharkova, Schaeffler, & Gibbon, under review).

The richness of spatial and temporal detail available in the full dynamic EPG printouts has already been described and illustrated in Figure 2. However, these full printouts can be unwieldy because of the sheer amount of information contained in them. In order to make the information more manageable and for the purposes of statistical processing, it is useful to reduce the data to single numerical indices. These indices may be based on pre-selected frames or even just a single frame (e.g., frame of maximum contact during a stop or fricative) that has been extracted from the full printout. Indices are now available that allow researchers to quantify important aspects of EPG contact patterns, such as place of articulation, amount of contact, symmetry and variability (see Gibbon & Nicolaidis, 1999, for a review). Indices are invaluable when differentiating typical from disordered patterns and when measuring subtle differences between similar contact patterns. To illustrate the latter point, a recent study of typical speakers revealed that oral stops (/t/, /d/) had significantly more contact than the nasal stop /n/ (Gibbon, Yuen, Lee, & Adams, 2007). These oral and nasal targets all exhibited similar horseshoe-shaped EPG patterns, so any differences that existed were subtle and measurable only by statistical analysis of numerical values derived from contact indices.

EPG – its Role in Diagnosis

In clinical practice, EPG assessment data is always used in conjunction with more routinely available assessment procedures for diagnostic purposes. The objective data from EPG is valuable when used alongside subjective data from auditory-impressionistic transcriptions. Although transcription is the most widely and routinely used method for assessing disordered speech, it has well-recognized limitations (Heselwood & Howard, 2008; Kent, 1996). One drawback is that a transcriber can only infer what the visually inaccessible articulators such as the tongue are doing during speech. Such inferences are based on an accumulation of complex cues contained in the acoustic signal. Examples of EPG data presented in later sections will show that inferences about tongue articulation, specifically about placement, can be misleading when based on perceptual judgments alone. Another limitation is that a linear notation system, such as transcription, is not able to measure speech motor control, which may be impaired in some children with speech disorders.

In contrast to transcribed data, EPG gives direct information about important features of tongue articulation (e.g., place of articulation, lateral bracing, groove formation) and can measure some key aspects of motor control, such as speed, spatial (i.e., positional) accuracy, consistency of movement as well as differential control of apical, lateral and posterior regions of the tongue (Gibbon, 1999). Therefore, direct objective measures derived from EPG data make it possible to identify abnormal articulations and speech motor impairments. These measurements can be used for diagnostic purposes as well as for quantifying subtle changes in tongue behavior due to factors such as the normal speech maturational process, disease progression or the effects of therapeutic intervention. EPG data therefore complements transcription data.

Researchers have devised a variety of EPG classification schemes in order to capture the types of EPG error patterns produced by individuals with speech disorders. Hardcastle and Gibbon (1997) suggested that EPG patterns could be classified broadly as follows: (a) those that have predominantly abnormal spatial configurations of tongue-palate contact (e.g., complete tongue-palate contact); (b) those that have abnormal timing (e.g., long durations); and (c) those that are normal in terms of spatial configuration and timing but occur in an abnormal location (e.g., substitutions). Gibbon (2004) devised a classificatory scheme for abnormal EPG patterns that occur in the speech of children with cleft palate. These studies give numerous illustrations of the different types of error patterns, but the most frequently occurring EPG error pattern, the spatial distortion, is illustrated in Figure 3. The EPG data shown in Figure 3 are from four children aged 8 to 15 years; three had distorted spatial patterns associated with articulation disorders and one had normal patterns associated with typical speech development. The patterns are for the /Σ/ target extracted from the phrase *a shop*. All /Σ/ targets produced by the children with disorders were heard by listeners as lateral fricatives [ℜ].

(a)

(b)

(c)

(d)

Figure 3. EPG printouts for four children's productions of /💧/ in *a shop*. (a) shows a printout from a 12-year-old boy with typical speech. (b) (c) and (d) show contact patterns for three school aged children with speech sound disorders. Each child exhibits different EPG patterns, although all were heard by listeners as lateral fricatives [ℜ].

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Figure 3a shows that the child with typical speech produced /Σ/ with lateral contact and an anterior groove configuration. These two features (lateral contact and anterior groove) are absent from the patterns produced by the children with speech disorders. For example, one child (Figure 3b) made extensive contact across most of the palate, similar to an undifferentiated gesture (Gibbon, 1999, and described later in the chapter), during the production of this sound. Another child had a pattern rather like that of an alveolar stop (Figure 3c), but with some asymmetry and incomplete lateral seal on the right side. The incomplete seal indicates where air was escaping into the buccal cavity during the lateral fricative. The third child had contact predominantly in the palatal and velar regions of the palate (Figure 3d). Here there is evidence of a groove in the posterior region of the palate, indicating that air could be escaping centrally as well as laterally during this child's productions of lateral fricatives. Figure 3 shows that children can have substantially different articulations for errors that are represented with the same phonetic symbol, in this case [ℜ]. The perceptual consequences of the different articulation errors were apparently too subtle for listeners to detect.

Although EPG data and transcription provide complementary information in the way described above, data from the two sources can conflict. An example is the phenomenon of covert contrast, where instrumentally measurable differences between target phonemes oppose evidence from listeners' perceptions of phonological neutralization. These differences are measurable from EPG data but are not detected reliably by the human ear (see Gibbon, 2002, for a review of instrumental studies of covert contrast). Kornfeld (1971) captured the point in stating "adults do not always perceive distinctions that children make" (p. 462). Instances of conflicting, also called divergent, information are important in facilitating new insights into diagnosis. For instance, the presence of covert contrasts has been interpreted as evidence that a child has phonological and articulatory knowledge about that contrast (Gibbon, 2002; Gibbon & Scobbie, 1997).

Another type of articulation error, called an *undifferentiated gesture* (Gibbon, 1999), involves tongue-palate contact that lacks clear differentiation between the tongue tip, the tongue body, and the lateral margins of the tongue. As shown in Figure 2, typically developing children produce alveolar stops /t/ and /d/ with finely controlled tongue actions, which combine lateral bracing with an upward movement of the tongue tip to the alveolar ridge. Velar stops /k/ and /g/ have an upward movement of the tongue body, which rises until it reaches the posterior region of the hard palate. In contrast to typical alveolar or velar articulations, undifferentiated gestures involve placement that is not confined to the anterior/lateral regions of the palate for alveolars, or the posterior region for velars. Instead, contact extends across the whole of the palate. Thus, undifferentiated gestures involve simultaneous alveolar, palatal, and velar placement.

Examples of undifferentiated gestures are shown in Figure 3b, and in the case study of Lisa described at the end of the chapter. Lisa produced undifferentiated gestures for specific targets, namely post-alveolar fricative /Σ/, /Z/ and affricate /τΣ/, /δZ/ targets. Some children, however, produce undifferentiated gestures for a much wider range of lingual targets. The widespread occurrence of undifferentiated gestures in a child's speech is interpreted as reflecting that the child has poor coordination between the tongue tip and the tongue body. Furthermore, it reflects a lack of lateral anchorage or bracing, suggesting an overall instability of tongue movement control (Gibbon, 1999). Children who produce undifferentiated gestures across-the-board for lingual targets often have speech features that are frequently reported in the literature as being characteristic of childhood apraxia of speech (Gibbon, 2003a).

As well as having simultaneous alveolar, palatal and velar contact, undifferentiated gestures often have a different place of articulation at the onset and at the release of closure (Gibbon & Wood, 2002). Gibbon and Wood found that the majority of children who produced undifferentiated gestures had perceptually variable placement for lingual stops. They suggested that an abnormal shift in tongue placement during the closure phase, termed *drift*, can lead to conflicting acoustic cues for place of articulation. Drift has been reported to occur in a wide range of speech disorders, including cleft palate (Gibbon, Ellis, & Crampin, 2004; Hardcastle, Morgan Barry, & Nunn, 1989; Howard, 2004) and phonological disorders (Gibbon, 1999). A recent perceptual experiment used computer-generated speech stimuli to investigate the effect of drift on perceptual judgments about lingual place of articulation (Gibbon & Mayo, 2008). The results showed that listeners were significantly more inconsistent when asked to judge placement of stimuli with conflicting cues compared to stimuli with congruent cues. The presence of undifferentiated gestures may explain why some children present with inconsistent speech disorder (Dodd, 1995), which involves extensive perceptual variability in placement for lingual stops.

EPG Assessment – Pre and Post Therapy

An EPG assessment precedes visual feedback therapy because goals of intervention are derived largely from an analysis of pre-therapy data. In addition to an EPG recording, a comprehensive clinical assessment of children's speech and language skills is essential before proceeding with EPG therapy; any etiological or maintaining factors need to be fully explored.

As part of a pre-therapy EPG assessment, it is usual to record a standard word list designed to elicit a range of consonants and consonant sequences in a variety of phonetic contexts (Appendix 1 shows the CLEFTNET word list as an example). Standard word lists provide a screen of children's articulation repertoire or inventory. Initial observations of EPG data from a standard word list usually lead to further recordings that probe specific areas of difficulty. Examples of additional probes are:

- multiple exemplars of problematic targets. Word lists that focus specifically on problematic sounds, eliciting multiple examples in a variety of different phonetic contexts, including different vowel environments, syllable positions, clusters and multisyllabic words.
- non-speech tasks, such as diadochokinetic rates. EPG can measure precisely the speed and accuracy of tongue movements for the alveolar (e.g., /t/) and velar (e.g., /k/) articulations included in maximum performance tasks.
- imitation versus spontaneous productions. EPG can quantify whether children's articulations are more accurate during imitation compared to spontaneous productions, or vice versa.
- minimal pairs that listeners judge to be neutralized in children's speech. These can be elicited in order to determine whether children are producing covert contrasts.
- connected speech. Sentences or spontaneous speech can be elicited to reveal whether children are using normal connected speech processes.
- variability. Multiple repetitions of the same word provide EPG data about articulatory variability of children's productions.

The speech materials are recorded using high quality audio tape facilities, ideally in a sound-proofed studio. It is customary to record some speech material on two occasions, once with and once without the EPG plate in situ. The purpose is to estimate whether the EPG plate is affecting the perceptual quality of the child's habitual speech. EPG assessments are usually undertaken on a minimum of three occasions: the first one taking place before the start of EPG therapy; the second on completion of therapy; and a third on a follow up occasion, usually three months or more after the completion of therapy. If it is practical to do so, it is useful to make short EPG recordings of words containing target sounds at the start of every EPG therapy session. This allows the clinician to monitor progress on a regular basis and to show children their own patterns recorded from previous sessions. Demonstrating improvements in EPG patterns from previous therapy sessions motivates children and reminds them of therapy goals.

Target Populations

Due to the specialist nature of the technique and the cost of buying equipment and making plates, EPG therapy is usually only offered to children in situations where other more widely available intervention options have failed. Children referred for EPG therapy are therefore usually of school age, with complex as well as apparently intractable speech difficulties. These hard-to-treat children often have poor self image and esteem and they can lack confidence due to previous failures. Many have additional literacy difficulties. For these reasons, children undergoing EPG therapy are not typical of children with speech sound disorders reported in the literature, who tend to be younger and have not experienced failure to the same extent as those for whom EPG is recommended. Developing new and effective interventions for older children with persisting speech sound disorders is challenging and one of the most neglected research areas in speech therapy (Smit, 2004).

The pediatric populations that could potentially benefit from EPG therapy include children with speech disorders affecting lingual consonants and high vowels. EPG therapy is not suitable for speech difficulties that are due to abnormal functioning of articulators other than the tongue, such as the lips or velum; these difficulties will need a different approach. Targets that are suitable for EPG therapy are those that register measurable amounts of contact. Gibbon and Paterson (2006) conducted a survey of a large group of children and adults who had undergone EPG therapy. They found that /s/ was by far the most frequently targeted sound in EPG therapy. The post alveolar fricative, /Σ/, and alveolar plosives /t/ and /d/ were also frequent targets, with just under half the group having EPG therapy for these sounds. A somewhat surprising finding was the frequency with which the velar sounds /k/ and /g/ were targets in EPG therapy. Almost a third of the group had EPG therapy for errors affecting velar targets, although Gibbon, McNeill, Wood and Watson (2003) discuss the potential pitfalls of using EPG therapy for these sounds. In contrast, the survey showed that clinicians never used EPG to remediate errors affecting the retroflex /r/ or vowels.

The target pediatric population for EPG therapy is consequently large because almost all speech disorders in children affect sounds that are articulated with the tongue. This is true regardless of the underlying cause (e.g., sensory, language, structural, motor, developmental or cognitive impairments). Although the target population is sizeable, at the present time EPG therapy is not available to most children with speech disorders. Apart from children in the UK with cleft palate who can access the national CLEFTNET initiative (Lee, Gibbon, Crampin, Yuen, & McLennan, 2007), this type of therapy is only available to those living close to specialist EPG centers.

Visual feedback therapy is potentially beneficial for children with speech difficulties that arise from diverse etiologies and that affect lingual articulation. From this large group, children with functional articulation disorders (including phonological disorders) or cleft palate are most frequently selected for EPG therapy. A study by Gibbon and Paterson (2006) found that out of 60 individuals who received EPG therapy over a 10-year period in Scotland, the overwhelming majority were school age children with either functional articulation disorders or cleft palate. Although they have different etiologies, these populations are similar insofar as both can give rise to intractable forms of articulation difficulties. Furthermore, targets that register measurable amounts of tongue-palate contact are vulnerable to errors in both groups (Smit, Hand, Freilinger, Bernthal, & Bird, 1990). Finally, these errors, when they occur in older children, are unlikely to resolve spontaneously and are notoriously resistant to speech therapy (Noordhoff, Huang, & Wu, 1990).

Criteria for Determining Intervention Relevance

Due to the underlying principles of EPG and the strategy of using visual feedback in therapy, two hard-and-fast criteria apply when selecting children. One is that they have abnormal articulation that affects lingual targets and the other is that children have sufficient visual acuity to see the contact patterns displayed on the screen. In addition, clinicians consider the inherent practical and procedural demands of the technique when selecting children for EPG therapy. These additional factors are described in more detail below.

One factor that is taken into account when selecting children for EPG therapy is their age. EPG is not normally used with young children, toddlers or infants, although in Japan, EPG has been used with pre-school children with cleft palate (Yamashita, Michi, Imai, Suzuki, & Yoshida, 1992). Elsewhere, EPG is rarely offered as a therapy option for children until they are over the age of 6-years. Younger children are often not considered for EPG therapy because they may still benefit from other more widely available, and less expensive, intervention approaches. Furthermore, using visual feedback is a relatively demanding form of therapy, requiring children to understand the links between tongue activity and the visual display and to develop conscious control of fine-grain tongue movements. Lastly, success of EPG therapy depends at least in part on a high level of motivation and attention. These cognitive, motor and psychological prerequisites mean that EPG is not considered an appropriate therapy option for pre-school children or children with severe forms of learning or motor disorders.

An additional procedural consideration is that children need to wear the plate during EPG assessment and therapy. For this to be constructed, the child needs to visit a dentist for a dental impression. Most children tolerate having the impression made and the plate's presence in the mouth once it has been manufactured, but some are hypersensitive in this region and therefore may not be suitable candidates for EPG therapy. Children need adequate dentition to retain the plate in the mouth during therapy, which needs to take place at a time in their life when minimal changes in dentition are expected. Changes in dentition during the EPG therapy, such as those due to growth or orthodontic treatment, can result in the plate becoming unusable or at least uncomfortable to wear. This situation is undesirable and can lead to EPG therapy being terminated prematurely. For these reasons, decisions about when to offer EPG therapy are best made in collaboration with dentists or orthodontists.

Theoretical Basis

At the heart of EPG therapy is its facility to provide real time visual feedback of tongue activity. This moment-to-moment (i.e, real time) feedback makes EPG unique and distinct from other approaches to therapy for children with speech sound disorders. In relation to speech disorders, Shuster, Ruscello and Smith (1992) have suggested that biofeedback is effective in situations where details about the articulation of target sounds are difficult to describe to children. The position of the tongue and its movements during speech are exceptionally difficult to describe, making EPG a particularly valuable intervention tool.

Under normal circumstances, individuals do not have precise knowledge or awareness about how their tongues are moving when they speak. Although tongue movements are consciously controlled, they are executed automatically. The internal cues (e.g., tactile, kinesthetic) associated with tongue movements are too subtle for children to perceive clearly or accurately. Although perception of these cues is not a prerequisite to normal speech production or to its acquisition in typically developing children, nevertheless, EPG therapy derives its effectiveness from enabling children to develop conscious control of the internal cues associated with tongue activity.

The predominant theoretical approach underpinning EPG therapy is that it adheres to principles of motor learning (see Strand, 1995; Strand & Skinder,1999, for discussion of these principles). A central tenet of motor learning is to provide learners with knowledge of results, which EPG does in the form of visual feedback of tongue-palate contact. In EPG therapy, children use the visual feedback continuously in the early stages of learning new articulation patterns. As therapy progresses, clinicians gradually reduce the external feedback by withdrawing the visual display. The aim at this stage is for children to learn to rely more and more on internal cues (e.g., auditory and kinesthetic), rather than visual cues, when producing new articulation patterns. Reliance on internal cues is equally necessary when generalizing new articulation skills into everyday speech.

Another key component of motor learning is that children are given opportunities for repetitive and intensive practice. In the context of EPG therapy, practice is used to establish accurate and consistent motor programs for new articulation patterns. EPG therapy sessions therefore frequently contain repetitive drill activities in some form. Furthermore, the portable EPG units described in a later section were designed specifically so that children could benefit from regular practice in between clinical sessions. A final element of motor learning requires grading the motor complexity of tasks, so that new articulation patterns are presented first in simple monosyllables (e.g., CV, VC). More demanding monosyllable structures (e.g., CVC; CCV; VCC) follow, then disyllabic and polysyllabic structures are gradually introduced. Grading complexity in this way is evident in many well established therapy approaches, such as traditional articulation therapy (Van Riper & Emerick, 1984) and the Nuffield Dyspraxia Programme (Connery, 1994).

EPG therapy provides children with visual feedback about their own tongue movements. This information is not available under normal circumstances and it can be revelatory. The following paragraph, written by a 12-year-old boy undergoing EPG therapy, illustrates the impact that this information can have on a child:

> *"it [EPG] has helped me a lot with my speech and confidence. Before [EPG therapy] I couldn't distinguish between the sounds I heard other people make and the way I was trying to repeat them. I really thought I was doing it the same. It surprised me to hear myself on tape, but I still didn't realize what I was doing wrong. Now with the help of EPG, I can see what is happening inside my mouth and where I am putting my tongue, so I know where I am going wrong. I had fallen into some bad habits which I am gradually beginning to eliminate. EPG helps me to try and place my tongue in the right place for the right sound".*

An assumption born out in EPG therapy studies (see later section on empirical basis) is that improving articulation patterns has a direct beneficial effect on speech intelligibility. Vocal tract movements are organized as motor schemas (see Square, 1999) and improving function of one component, such as the tongue, can have far reaching benefits on the functioning of other articulators, such as the velum, located elsewhere in the vocal tract. An example is when improved articulation co-occurs with a simultaneous reduction in abnormal nasal emission in children with cleft palate. Reduced emission after EPG therapy has been noted to occur when compensatory errors, termed *posterior nasal fricatives*, are eliminated as a result of EPG therapy and replaced by anterior oral fricatives. Dent, Gibbon and Hardcastle (1992) reported on a 9-year-old child with a cleft palate who produced /s/ and /z/ targets as posterior nasal fricatives. EPG therapy was successful in establishing near normal EPG patterns for these sounds, which were judged as alveolar oral fricatives without accompanying nasal emission.

In terms of the International Classification of Functioning, Disability and Health (ICF, World Health Organization, 2001), visual feedback therapy is focused directly at the level of impairment of Body Functions. Specifically, EPG therapy aims to improve the physiological functioning of the tongue during speech. Although focusing on Body Functions, clinicians who use EPG recognize the importance of a holistic approach, acknowledging the full range of difficulties experienced by children with speech disorders.

Empirical Basis

There is now a substantial literature reporting EPG therapy for children with speech sound disorders. Gibbon (2003b) found that out of 150 research papers on the clinical applications of EPG, half investigated cleft palate or functional articulation disorders, with a substantial number reporting neurological disorders and hearing impairment. Speech disorders in children arising from a wide range of etiologies have been investigated, including: functional articulation and phonological disorders (Carter & Edwards, 2004; Dagenais, Critz-Crosby, & Adams, 1994; Gibbon & Hardcastle, 1987; McAuliffe & Cornwell, 2008); cleft palate (Fujiwara, 2007; Gibbon & Hardcastle, 1989; Hardcastle, Morgan Barry, & Nunn, 1989; Michi, Suzuki, Yamashita, & Imai, 1986; Yamashita, Michi, Imai, Susuki, & Yoshida, 1992; Whitehill, Stokes, & Man, 1996); neurological disorders (Gibbon & Wood, 2003; Hardcastle, Morgan Barry, & Clark, 1987); hearing impairment (Bacsfalvi, Bernhardt, & Gick, 2007; Dagenais & Critz-Crosby, 1991; Nicolaidis, 2004); and Down Syndrome (Gibbon, McNeill, Wood, & Watson, 2003).

Although a large number of EPG therapy studies exist, there are limitations in the quality of the evidence about effectiveness. In terms of levels of clinical evidence, the quality is low, at levels III or IV according to the SIGN Guidelines (Scottish Intercollegiate Guidelines Network, 2008). Most are non-analytic studies (e.g., case reports, case series) or expert opinion, reporting a small number of children as single cases or small groups. Such studies are useful as descriptive accounts of therapy for that individual, but it is not possible to generalize the results. Another limitation of current studies is that none so far has included an adequate control group. Lee, Law and Gibbon (2008) conducted a Cochrane review of studies on EPG therapy for individuals with cleft palate and concluded that there is currently no evidence from randomized trials to support or refute the effectiveness of EPG in speech therapy and that there is a need for high quality, randomized trials to be undertaken in the future. By linking all the specialist cleft palate centers throughout the UK together – as in the CLEFTNET network – it becomes realistic, as well as desirable, to conduct larger scale research projects than has been possible in the past (Lee, Gibbon, Crampin, Yuen, & McLennan, 2007).

Practical Requirements

The practical requirements of EPG therapy, such as how EPG plates are constructed, have been discussed already in previous sections. Some important additional comments are added here. EPG plates are custom-made and relatively costly to construct, although new cheaper types are now under development (Wrench, 2007). Children therefore need to learn to take care of plates and become familiar with inserting and removing them before and after therapy sessions. There is also the issue of adaptation to the plate. Most adults with normal speech adapt in a short period to wearing the plate, allowing them to speak naturally with it in place (McAuliffe, Lin, Robb, & Murdoch, 2008; McLeod & Searl, 2006). Children also need time to become accustomed to wearing their plate before EPG therapy can begin. Some find that wearing and speaking with it in place is strange or even uncomfortable at first. A sign of insufficient adaptation to the plate is excessive salivation. Children will usually adapt gradually, increasing the time they wear the plate, until they can wear it comfortably for about 2 hours at a time. Once this is achieved, they are ready for the pre-therapy EPG recording and therapy sessions can begin. Most children adapt within a few days.

Speech-language pathologists are currently familiar with using computers as part of their clinical practice and in general do not have difficulties learning how to use the clinical functions of EPG. Speech-language pathologists need to develop skill and confidence in using EPG, however, and can develop these by attending training workshops. An ideal context for clinicians to learn how to use EPG is as part of a collaborative network, such as CLEFTNET (Lee, Gibbon, Crampin, Yuen, & McLennan, 2007). The CLEFTNET initiative represented a novel form of EPG service delivery – it linked the cleft palate centers throughout Scotland to Queen Margaret University, Edinburgh, through an electronic network. EPG data collected in specialist cleft palate centers throughout the UK were sent to Edinburgh, where experts conducted detailed analysis leading to a precise diagnosis of each individual's specific articulation difficulty. Therapy guidelines were drawn up based on the EPG analysis and sent to the specialist clinicians who provided therapy for the children. The initiative provided regular workshops and ready access to technical support. The project also analyzed and archived EPG data sent electronically from the participating centers. EPG materials for use by those involved in the project were developed including: new speech material for EPG recordings (see Appendix 1), an EPG brochure, information sheets, patient consent forms, and EPG data analysis reports. Regular two-day EPG workshops were organized, taking the form of self-directed hands-on tutorials with the WinEPG™ software (Articulate Instruments Ltd, 2008), lectures about the clinical use of EPG and clinical case discussions.

Key Components

During a typical EPG therapy session, a child and a clinician sit side-by-side in front of a computer screen, as shown in Figure 4. New versions of software give the clinician flexibility in terms of the amount of information and the content of the EPG screen displays. Usually the screen shows dynamic (i.e, real time) and static displays alongside each other, as in Figure 4. EPG has the facility for two multiplexers to be connected, one for the child and one for the clinician, with a switch to toggle between the two. When the clinician is connected, it is possible to demonstrate normal contact patterns on the dynamic display. When children are connected to the EPG equipment, they can see their own tongue contact patterns. It is also possible to capture or *freeze* a target pattern onto the static display. A target pattern for a velar articulation is shown on the right hand side of the computer screen in Figure 4. Pre-recorded target static patterns can be stored in the computer and retrieved when needed.

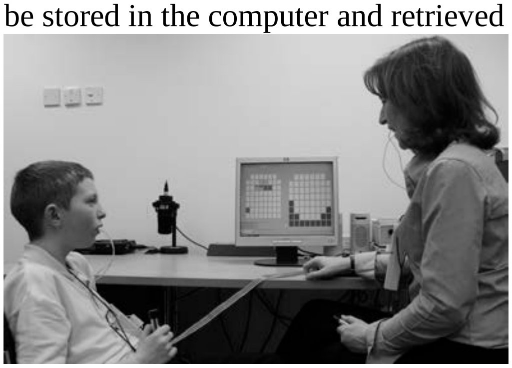

Figure 4. A typical EPG therapy session. The clinician and child both wear EPG plates and are connected to the computer display. The EPG pattern on the right shows a static therapy target for a typical velar sound, /k/. The child is attempting to copy this velar pattern. The display on

the left is “live” (i.e., real time), giving the child moment-to-moment visual feedback of his attempts to produce the velar pattern.

At the beginning of intervention with EPG, the clinician demonstrates typical EPG patterns and explains to the child, using appropriate terminology, the relationship between tongue patterns (as displayed on the EPG screen) and the resulting speech sounds. The clinician also ensures that the child understands how the visual display relates to his or her own tongue and hard palate. Although visual feedback of tongue articulation makes EPG intervention unique, clinicians use a variety of other standard intervention strategies (e.g., modeling, demonstrating, cuing, reinforcing) alongside feedback within therapy sessions.

The target EPG pattern that the child attempts to copy in therapy resembles a normal pattern. The word *resembles* is emphasized here because it is necessary for the pattern that the child attempts (the therapy target pattern) to be tailored for each child. The clinician identifies appropriate therapy target patterns based on the shape of the child’s palate, knowledge of typical patterns and whether the target pattern results in a perceptually accurate speech sound. Some children with abnormally shaped palates produce a perceptually accurate /s/ with a wide anterior groove. In these cases, the /s/ therapy target pattern may resemble a typical /s/, but with a wider groove than would be expected in a typical speaker. Therapy targets are rarely precisely defined in terms of individual sensors that must, or must not, be contacted. Instead, targets are defined in terms of having important elements of typical contact patterns, such as an anterior groove for /s/ or contact in the posterior region for /k/. Furthermore, therapy targets need to be flexible in terms of amount of contact, given the extensive individual differences in the amount of contact produced by typical speakers for all lingual sounds. During therapy sessions, the clinician is careful to ensure that speech sounds associated with therapy target patterns are perceptually accurate.

Children with strongly habituated error patterns can find learning new articulations difficult. A useful strategy in eliminating entrenched patterns is first of all to introduce new patterns in the absence of other speech features, such as airstream or voicing (Hardcastle, Gibbon, & Jones, 1991). In these situations, the child is encouraged to articulate silently, focusing on achieving a consistently accurate target EPG pattern, with appropriate airstream and voicing added at a later stage. Once new patterns are stable and consistent, visual feedback is gradually withdrawn. A first step is removing visual feedback from the child, but keeping the EPG plate is situ. This is possible by arranging the computer screen so the clinician but not the child can see it, or alternatively by unplugging the EPG plate. The former option has the advantage that the clinician is able to check that the child can maintain the correct contact pattern without visual feedback. At a still later stage, the goal is for the child to articulate a perceptually accurate sound after the plate is removed from the mouth.

Assessment Methods

Making clinical decisions, such as identifying therapy goals and their sequencing, is the responsibility of the clinician. Decisions are based on the conceptual framework that the clinician adopts and the assessment results for individual children. For example, a clinician adopting a phonological orientation might introduce new articulation patterns in terms of how they function as systematic and rule-governed aspects of language. For a child who exhibits the phonological process of backing alveolar targets to velar place of articulation, /t/ may be introduced alongside /k/, perhaps within minimal pairs, in order to emphasize the alveolar-velar phonological contrast and to avoid overgeneralization.

Goal selection is usually straightforward for children with articulation difficulties affecting only a few targets, such as lateralization of sibilant targets. Goal selection is more complex for children with multiple articulation errors. In these cases, a clinician may focus EPG therapy on developing an underlying skill, such as speech motor control. A goal of therapy here may be to increase overall tongue stability; this is appropriate for children with evidence of undifferentiated gestures. A number of researchers have suggested that control of the lateral margins of the tongue is essential for normal speech production, because lateral anchorage gives stability to the whole of the tongue (Fletcher, 1992; Stone, Faber, Raphael, & Shawker, 1992). One way to increase tongue stability is to establish reliable patterns of lateral contact for lingual consonants, such as /t/, /d/ and /n/ and this may be an intervention goal for some children. A final example is where a clinician may aim to increase consistency in tongue-palate contact patterns in children demonstrating a high amount of variability. A limited number of targets may be introduced during initial stages of therapy, with a greater range of targets introduced once earlier targets are consistently articulated.

Researchers and clinicians in the CLEFTNET project developed a systematic way of determining EPG therapy goals (see Lee, Gibbon, Crampin, Yuen, & McLennan, 2007, for details and a case illustration). Goals were formulated on the basis of a summary of an EPG analysis of pre-therapy assessment data. An analysis report included a table summarizing children's EPG patterns for each target phoneme, with error patterns classified according to a scheme developed by Gibbon (2004). This is followed by a set of therapy guidelines and EPG printouts illustrating the child's error patterns. Setting therapy goals in CLEFTNET is based on identifying any correct as well as incorrect error patterns. Patterns that are variable, notably those produced correctly in some phonetic contexts but not others, are identified. Goals are selected where a pattern is achievable and already in the individual's articulation repertoire.

Analysis of pre-therapy EPG data often reveals facilitative contexts, which involve placing the target in specific phonetic environment so that components of a preceding or following sound facilitate production of that target (Kent, 1982). The concept of facilitative contexts has a long tradition in speech therapy (e.g., McDonald, 1964), although its application in EPG therapy is unique in identifying contexts that facilitate specific tongue-palate contact patterns . The case study of Lisa presented at the end of the chapter illustrates how a facilitative context was identified and used successfully in EPG therapy for this child.

In order to identify potential facilitative contexts, it is necessary first of all to assess the full range of articulations in an individual's repertoire. The next step is to identify contexts in which the child can already spontaneously produce articulation features (e.g., alveolar placement, lateral contact, velar placement, an alveolar groove). These contexts are then used to facilitate articulations that are incorrectly produced (e.g., retracted placement, minimal EPG contact, no anterior groove). For example, some children with cleft palate are able to articulate the nasal stop /n/ with a typical horseshoe-shaped pattern, but have abnormally retracted placement for the oral stops /t/, /d/. Facilitation is possible because /t/, /d/, and /n/ all have similar EPG patterns in typical speakers. The idea is to use a child's correct (i.e., /n/) productions to facilitate correct productions of articulation errors (i.e., /t/, /d/). This is achieved by placing correct and incorrect articulations next to each other in adjacent contexts, such as in *mi<u>nt t</u>ea*, *wi<u>nd</u>y* etc. In these sequences, for successful production of /t/, /d/, the child needs to hold constant the alveolar placement (facilitated by /n/) during production of the following /t/ or /d/.

The main aim of intervention when using EPG for visual feedback therapy is to enhance children's speech intelligibility by improving articulation patterns for lingual targets. To achieve this aim, children first need to modify abnormal articulations using visual feedback, then to retain newly learned articulations without feedback, and finally to use newly learned articulation in everyday speaking situations. The process of monitoring progress for children in EPG therapy involves shifting the emphasis away from learning new articulation patterns with the aid of visual feedback to using them spontaneously outside the clinic setting. Achieving carryover of newly learned skills is challenging for many children. Gibbon and Paterson (2006) found that although most children undergoing EPG therapy had improved articulation to some extent, most experienced difficulties generalizing to everyday speech. These authors concluded that clinicians need to adopt specific strategies to promote generalization and maintenance when using EPG in therapy. Davis and Drichta (1980) reached a similar conclusion when they reviewed earlier biofeedback techniques used in the clinical management of speech disorders; they highlighted the need to demonstrate in future research that skills learned in the clinical setting were carried over into other speaking situations.

In the past, the frequency and location of EPG therapy sessions were determined by practical considerations, such as the distance to be travelled in order to attend therapy. Frequent practice of new articulation patterns using EPG for feedback was often impossible for those living at a distance and therapy was sometimes discontinued because it was too far for children to attend on a regular basis. A device that has proved successful in overcoming this practical difficulty has been the EPG portable training unit (Fujiwara, 2007; Gibbon, Stewart, Hardcastle, & Crampin, 1999; Jones & Hardcastle, 1995). The major design features of these units are that they are small, comparatively inexpensive, lightweight and simple to operate. The portable units allow visual feedback therapy to take place close to, or in, children's homes, so increasing opportunities for practice and avoiding the need to travel long distances for therapy sessions.

Figure 5. A child receiving visual feedback therapy with a portable training unit.

A wide range of factors can affect rate of progress in intervention for speech sound disorders, and this applies equally to visual feedback therapy with EPG. The case study of Lisa, described at the end of the chapter, is an example of a child for whom EPG therapy was successful after only seven clinic sessions. It remains unclear why some children respond positively to EPG therapy after just a few sessions, whereas others require many sessions over an extended period before making any tangible progress (Dent, Gibbon, & Hardcastle, 1995; Gibbon & Paterson, 2006; Michi, Suzuki, Yamashita, & Imai, 1986; McAuliffe & Cornwell, 2008). Irrespective of the number of sessions required to succeed, all children need sufficiently high levels of attention and motivation to learn new articulation patterns, to practice them until they become automatic and then to use them outside the clinic setting. In terms of attention and motivation, an advantage of computer-mediated procedures, such as EPG, is that some children are more inclined to persist with tasks when performance is measured objectively (i.e., by a computer) rather than when it is judged by another person (i.e., the clinician) (Volin, 1991). A factor likely to facilitate generalization is plenty of support from family, friends, teachers and others in the child's life. These people play an important role in providing encouragement and opportunities for children undergoing EPG therapy to practice new articulations in everyday life.

Many factors can affect progress in EPG intervention, but we lack knowledge about the most critical variables for predicting and maximizing progress. A study by Carter and Edwards (2004) found that it was difficult to predict which children out of a group of 10 with functional disorders would make maximum improvement in EPG therapy. Baker and Bernhardt (2004) discuss a number of variables that can affect response to therapy for speech sound disorders. These factors include those to do with the child (e.g., age, type and severity of speech disorder, degree of motivation), intervention (time in therapy, therapy approach) and therapist characteristics (e.g., ability to motivate child, experience in intervention). Although any of these factors may affect progress in EPG therapy, the precise impact of any one of these on an individual's progress is difficult to determine.

Children from Culturally or Linguistically Diverse Backgrounds

The importance of normative EPG data from children's own linguistic background has been highlighted already and clinicians need to be aware of regional variations when judging whether a child's tongue-palate contact patterns are typical or abnormal. Knowledge of regional variation is equally important in determining target patterns for children to emulate during therapy. There is already an extensive literature on typical EPG patterns, and although most report data from adults, an increasing number report data from typically developing children (Cheng, Murdoch, Goozée, & Scott, 2007; Fletcher, 1989). Fletcher (1989) reported EPG data from nine children with typical speech development age 6 to 14 years. A general finding for all lingual consonants was that amount of contact decreased as children got older. This decrease in contact was paralleled by relatively fine-grained articulatory adjustments, such as a shift to a more posterior placement as children grew and an overall reduction in the length of midsagittal contact of lingual targets. Fletcher interpreted these findings as showing that during the school years articulation accuracy and precision continued to develop.

Many lingual targets, consonants and vowels, that register measurable amounts of tongue-palate contact show variation depending on regional, cultural and linguistic backgrounds (see McLeod, 2007). One example where children's background needs careful consideration is in their use of glottal stops. Glottal stops can be used in place of voiceless plosive /t/, and sometimes also /p/ and /k/ in typical speakers; this is observed in many varieties of English and is part of normal English speech in specific phonetic contexts (Wells, 1982). The EPG patterns associated with the targets /t/ or /k/ will be entirely different from those associated with glottal stops. It is therefore critical when interpreting EPG patterns to distinguish between glottal stops that are a normal part of everyday speech from those that are abnormal due to, for example, compensatory articulations in cleft palate speech or as abnormal substitutions in phonological disorder or childhood apraxia of speech.

Case Study

Lisa[1], a 9-year-old girl, was referred for EPG therapy because of distortions affecting sibilant targets /s/, /z/, /Σ/, /Z/, /τΣ/, /δZ/. Lisa had an unusual history of speech development insofar as she produced a variety of different distortions for sibilant targets during the pre-school period. At the age of 18 months, her mother noticed that Lisa produced /s/ in the word *soap* with a nasal quality. At 3;01 years, an assessment by a speech-language pathologist revealed that Lisa realized all sibilant targets with *phoneme specific nasality* (Peterson-Falzone & Graham, 1990). This abnormal nasality was functional – velopharyngeal abnormality was ruled out at this time based on an oral examination by an otolaryngology consultant, combined with perceptual evidence of adequate oral pressure for all obstruent sounds, apart from attempts at sibilant targets.

By 4;07 years, Lisa’s speech had changed spontaneously (she had not received any intervention during the pre-school years) but remained problematic; there were now two different types of distortions evident for sibilant targets. Alveolar sibilants /s/, /z/ were still realized with phoneme specific nasality, but /Σ/, /Z/, /τΣ/, /δZ/ targets were now lateral fricatives and affricates. At this stage, Lisa received therapy using a traditional approach in order to eliminate the abnormal nasality affecting /s/, /z/ targets. Therapy was partially successful; nasality was eliminated, but these targets became interdental fricatives instead. These various distortions affecting sibilants--namely nasality, lateralization and interdental placement--could have been associated with an early conductive hearing loss. A loss was identified when Lisa was 3-years old, and consisted of a 40dB loss in the right ear and a 20dB loss in the left ear. The hearing loss had resolved by 4;0 years.

Lisa was referred for EPG therapy when she was 9½ years old. From a perceptually based phonetic transcription made at this time, it was evident that her speech had not improved spontaneously since she had been assessed 5 years previously; /s/, /z/ were consistently interdental fricatives and /Σ/, /Z/, /τΣ/, /δZ/ were consistently lateral fricatives and affricates. Lisa perceived her speech difficulty as serious and viewed it as having a detrimental effect on her quality of life and as limiting her participation in some activities. Prior to undergoing EPG therapy, a speech-language pathologist attempted to modify Lisa’s distorted productions using traditional methods, with no success.

Figure 6 shows Lisa’s pre-therapy EPG patterns for sibilant targets alongside patterns from a typically developing child of a similar age. These are composite EPG frames taken at the temporal midpoint during words containing fricatives, affricates and stops (from the CLEFTNET word list, Appendix 1, Section D, Minimal Pairs). The left column in Figure 6 shows the typical child’s patterns for /s/, /♠/, /t♠/, /t/ (for the affricate, the stop /t’/ component is shown separately from the fricative /♠’/ component). As can be seen from the next column in the figure, pre-therapy EPG data showed that Lisa’s patterns for /s/, /z/ were abnormal, involving minimal tongue-palate contact and only a few sensors showing contact in the periphery of the palate. These EPG patterns fitted with listeners’ perceptual impressions of interdental placement. Her EPG patterns for /s/, /z/ contrasted dramatically with her EPG patterns for the lateralized

[1] This case was adapted from Hailstone (2003)

distortions of /Σ/, /Z/, /τΣ/, /δZ/ targets; these had extensive contact across the palate similar to undifferentiated gestures described by Gibbon (1999).

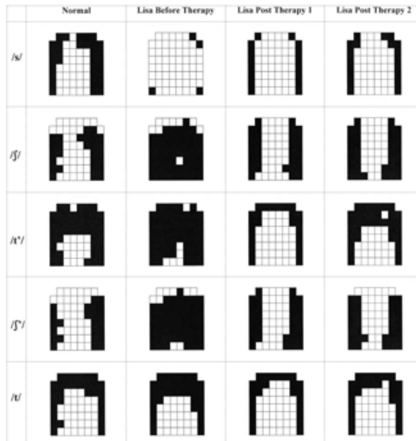

Figure 6. Lisa's EPG patterns before therapy, after 7 weeks of EPG therapy (Post Therapy 1) and 3 months later (Post Therapy 2). Patterns for a typically developing child of the same age are in the left column for comparison. The figure shows patterns for /s/, /♠/, /t♠/, /t/ (for the affricate, the stop /t'/ component is shown separately from the fricative /♠'/ component). These are composite EPG frames, taken at the midpoint of the target sounds, with sensors contacted >50% registered as black squares.

Excessive amounts of contact have been noted to occur during lateralized distortions of sibilant targets, although as Figure 3 demonstrated, much variation occurs in the articulation patterns that can underlie this type of articulation error. It is noteworthy that Lisa's EPG patterns for /τΣ/ and /Σ/ were similar in having extensive contact across the palate. A final observation is that Lisa had normal tongue contact for /t/, suggesting that she had developed independent control of the lateral and apical regions of the tongue. Lisa's normal articulations of /t/ were additionally relevant in providing a potentially facilitative context for /s/. Recall that normal /t/ articulations show an /s/-like groove at the start of closure release (see frame 81 in Figure 2a).

Lisa had 7 once-weekly EPG therapy sessions with a speech-language pathologist based in her local community clinic. In addition to these clinic-based sessions, Lisa was also given a portable training unit, which allowed her to practice at home on her own or with the help of her mother. Therapy aimed to correct her abnormal articulations of all sibilant targets. The focus of the initial sessions was to ensure that Lisa understood how sibilant targets were articulated in typical speakers. The link between articulation and the visual display on EPG was explained. Terms such as *side contact*, *horseshoe shape* and *groove* were introduced. The clinician and Lisa discussed the differences between EPG printouts of normal patterns and Lisa's own printouts. They agreed upon the aims of therapy.

During these early sessions, the clinician used the EPG visual feedback display to demonstrate typical EPG patterns, and for Lisa to gain confidence using the technique. The first target for therapy was /s/, which was selected on the basis that a facilitative context had been identified. This meant that she could already produce a normal /s/-like configuration, albeit for a different target (i.e., at the release of /t/). Lisa felt encouraged by her discovery that she could already produce key features of articulations that had proved so difficult previously. She was able to modify /t/ patterns quite easily using visual feedback, so that they contained an anterior, central groove for /s/ when prolonging the release of /t/ (e.g., *tssssss*) and in facilitative contexts such as in words containing /ts/ (e.g., *hats)*. Importantly, the fricative that Lisa produced when prolonging the release phase of /t/ was judged perceptually as a normal /s/.

Once Lisa could produce normal EPG patterns consistently for /s/ targets, they generalized readily to /z/ targets. Later sessions focused on producing normal tongue contact patterns for /Σ/, /Z/, and then /τΣ/, /δZ/. Using visual feedback, Lisa was able to modify her now normal /s/ articulation in order to produce the more retracted and wider groove that is characteristic of /Σ/. In each session, visual feedback was provided until Lisa could produce target patterns consistently, at which point the feedback was withdrawn by covering the screen or unplugging the multiplexer. Once Lisa could produce target patterns without visual feedback, she was encouraged to remove the plate and practice without it in situ.

After 7 sessions of EPG therapy, Lisa could produce typical EPG patterns (see post therapy patterns in Figure 6) for all sibilant targets and these were judged as perceptually normal. She continued to receive traditional therapy for several months following EPG therapy to help her to carry over these newly learned articulation patterns into everyday speech. The final column in Figure 6 demonstrates that Lisa maintained progress when a third EPG recording was made three months later.

Future directions

Gibbon (2007) has proposed that, instead of children using the EPG display to provide biofeedback of their own tongue movements, they could actively engage in observing articulation patterns produced by another speaker to enhance their learning of new articulation patterns. This *observation window* would consist of the "live" (i.e., real time) EPG display. This form of therapy would involve the child observing the dynamic display of contact patterns produced by the clinician during speech. There are good theoretical reasons why observing another speaker's motor actions might enhance the effectiveness of articulation therapy. For example, visual information is a central component of therapy in the integral stimulation approach developed by Strand and Skinder (1999). Integral stimulation, recently renamed *Dynamic Temporal and Tactile Cueing* (Strand, Stoeckel, & Baas, 2006), requires that the child imitates utterances modeled by the clinician, with an important component being that children focus their visual attention on the clinician's face. The tongue's actions are hidden from view under normal circumstances, however. It may be that information about the clinician's tongue activity contained in an *observation window*, such as the EPG display, may facilitate therapy by providing details about articulation that are not normally available.

Some support for the beneficial role that observation plays in enhancing motor behavior comes from the theory of mirror neurons (Rizzolatti & Arbib, 1998). These specialized neurons make it possible for people to enhance their learning of complex motor skills by watching the performance of others. Kent (2002) suggested potential applications of the theory of mirror neurons to speech pathology, outlining that this theory provides compelling reasons why additional visual information facilitates the accuracy of motor performance. One practical advantage of this approach is that it does not require that children have individual EPG plates constructed. This idea requires investigation in future research.

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Appendix 1 CLEFTNET Speech Word List

A. Repetition *Repeat the following sounds*

1. pa pa pa…
2. ba ba ba…
3. ta ta ta…
4. da da da…
5. ka ka ka…

6. ga ga ga…
7. la la la…
8. fa fa fa…
9. va va va…
10. Ta Ta Ta…
11. Δa Δa Δa…
12. sa sa sa…
13. za za za…
14. Σa Σa Σa…
15. Za Za Za…
16. tΣa tΣa tΣa…
17. dZa dZa dZa…

B. Rote *Now count from 1 to 10*

C. Sentences *Now say these sentences*

1. Naughty Neil saw a robin in a nest.
2. Tiny Tim is putting a hat on.
3. My Daddy mended a door.
4. I saw Sam sitting on a bus.
5. Funny Sean is washing a dirty dish.
6. Cheeky Charlie's watching a football match.
7. Jolly John's got a magic badge.
8. Happy Karen is making a cake.
9. Baby Gary's got a bag of Lego.
10. The puppy is playing with a rope.
11. Bouncy Bob is a baby boy.
12. The phone fell off the shelf.
13. The hamster scrambled up Stewart's sleeve.
14. The nasty boy tossed the basket into the box.

D. Minimal pairs *Please say these words*

1. a sip □ a shoe
2. a tore □ a chop
3. a Sue □ a sheet
4. a top □ a chip
5. a sore □ a shop
6. a team □ a chew
7. a sob □ a shore
8. a tip □ a cheat
9. a seat □ a ship
10. a tomb □ a chore