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Research Report

Intervention for lateral /s/ using electropalatography (EPG) biofeedback and an intensive motor learning approach: a case report

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Abstract

Background: Visual biofeedback using electropalatography (EPG) has been beneficial in the treatment of some cases of lateral /s/ misarticulation. While EPG intervention is motorically based, studies have not commonly employed a motor learning approach to treatment. Furthermore, treatment success is measured primarily by change to EPG tongue–palate contact patterns and listener ratings conducted by speech–language therapists. Studies have not commonly measured articulatory change without the palate *in-situ* using acoustic analysis and non-professional listeners.
Aims: To determine if an intensive treatment programme including both visual biofeedback (EPG) and traditional articulation techniques within a motor learning paradigm would result in functional improvement to /s/ articulation in an 11-year-old girl with persistent lateral misarticulation.
Methods & Procedures: Treatment involved 12 sessions of therapist-delivered treatment over 4 weeks followed by a 6-week home programme. Outcomes of the treatment programme were measured primarily using naïve listener ratings and acoustic analysis of /s/ spectra.
Outcomes & Results: Improvements to both the perceptual and spectral characteristics of /s/ articulation occurred following the treatment programme.

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Conclusions: The study highlighted the benefit of an intensive approach to intervention incorporating both visual biofeedback and traditional articulation approaches. The inclusion of a 6-week structured home-programme was beneficial and resulted in consolidation of treatment gains.

Keywords: articulation, electropalatography (EPG), motor learning, speech disorder, visual biofeedback

What this paper adds

The misarticulation of /s/ is a speech error that is notoriously resistant to traditional treatment. In contrast, some success in the remediation of this speech error has been found with biofeedback-based treatments (i.e. electropalatography (EPG)). The paper examines the response of a single child to an intensive speech intervention that incorporated visual biofeedback (EPG), traditional articulation therapy, and principles of motor learning. It adds to the research delineating the effects of these interventions by measuring treatment outcomes through naïve listeners and quantification of change to characteristics of consonant spectra. The study demonstrates that visual feedback using EPG was useful in achieving accurate tongue–palate contact. When combined with traditional articulation therapy and following an intensive treatment regimen, functional improvement to /s/ articulation was achieved within a short period of time.

Introduction

A common problem encountered by speech–language therapists in paediatric practice is misarticulation of /s/. While this speech error is notoriously resistant to traditional intervention (Gibbon and Hardcastle 1987), biofeedback-based treatment using electropalatography (EPG) has been employed in its remediation with some success (Gibbon and Hardcastle 1987, Gibbon *et al.* 1990, Hickey 1992, Dagenais *et al.* 1994, Dent *et al.* 1995). However, a number of studies have reported poor individual participant outcomes or participants who required extended periods of intervention (Hickey 1992, Dagenais *et al.* 1994, Dent *et al.* 1995). Given such cases, it is useful to examine how the intervention process could be improved and by what criteria 'success' is judged.

First, as the biofeedback technique of EPG is motor-based, it is interesting to note that in a number of cases the service delivery employed contrasted with the principles of motor learning. Specifically, for skill acquisition to occur, treatment should involve multiple opportunities for practise and, in general, shorter, distributed practise sessions as opposed to longer sessions of massed practise (Schmidt and Wrisberg 2004). Furthermore, a structured treatment consolidation phase is important in achieving automation of the learned skill (Correa *et al.* 2003). In the reports of lateral /s/ intervention to date, frequency of EPG biofeedback treatment was stated as once (Gibbon and Hardcastle 1987) or twice per week (Gibbon *et al.* 1990; Dagenais *et al.* 1994) or went unreported (Hickey 1992; Dent *et al.* 1995). Furthermore, a structured home programme and follow-up treatment consolidation period/carryover were absent from some studies (Hickey 1992;

Dagenais *et al.* 1994). It is proposed that if, as thought, children with lateral /s/ exhibit a phonetic basis for their misarticulation, an intensive motor-learning approach to treatment incorporating both EPG and traditional articulation treatment may prove successful within a shorter intervention period. That is, treatment conducted three or more times per week over a short period (e.g. 3–4 weeks), including daily home practise and a structured carryover phase.

Second, the criteria by which treatment success is judged should also be examined. A review of the EPG-based intervention literature indicates that studies have primarily used improvement to, or normalization of, tongue–palate contact patterns as the key indicator of treatment success. Listener ratings, for the most part conducted by trained speech–language therapists, compliment the EPG findings (Gibbon and Hardcastle 1987, Gibbon *et al.* 1990, Hickey 1992, Dagenais *et al.* 1994, Dent *et al.* 1995, Carter and Edwards 2004, Bernhardt *et al.* 2007). To date, there has been limited examination of *functional* change to articulation following EPG-based treatment. That is, improvement to articulation as it would occur in everyday communication, without the palate *in-situ*. With the palate removed, functional change could be quantified in two ways: (1) using the perceptual judgements of naïve listeners', specifically, those without a background in speech–language therapy or phonetics; and (2) spectral analysis of the articulatory production. It would seem that such information would provide a valuable addition to the determinants of success.

On this basis, the present study aimed to determine if an intensive speech therapy treatment programme incorporating visual biofeedback (EPG) and traditional articulation therapy would result in functional improvement to articulation in an 11-year-old child with lateral /s/. In contrast to previous studies, success of treatment would primarily be measured using naïve listeners ratings and quantification of change to characteristics of the consonant spectra.

Methods

Participant

The participant, RB (fictitious initials), was an 11-year-old Australian girl. Parental report indicated that she had received on-going speech therapy intervention for 7 years; however, residual articulation errors remained. For RB, the most distressing of her remaining speech errors was a lateral /s/ articulation and she requested this speech error be the focus of treatment. Both RB and her parents were highly motivated.

Procedure

A single-subject case study was undertaken. Before treatment, articulation was examined to determine intervention targets and provide a baseline for measurement of change in speech behaviours (pre-treatment condition). Treatment was undertaken over a 4-week period. Reassessment occurred immediately following the 4 weeks of treatment (post-treatment condition) and following the completion of the 6-week home programme (post-home programme condition).

Assessment and data analysis

Electropalatography. The Windows EPG (WinEPG) system was used to record tongue–palate contact. RB was fitted with an individually moulded thin acrylic palate, embedded with 62 proportionally spaced touch sensitive electrodes (Gibbon and Nicolaidis 1999). She was provided with the palate approximately 2 weeks before the commencement of the study and asked to undertake daily practice to facilitate adaptation/desensitization to the palate. While RB undertook the daily practice, she disliked the presence of the palate within her mouth reporting that it worsened her articulation and felt 'funny'. Similar experiences have been reported previously (McLeod and Searl 2006).

During assessment, five repetitions of the phrase 'say CV again' were repeated with the EPG palate *in-situ* where C=/s/ or /t/ and V=/i/, /a/, or /u/. This resulted in 15 repetitions of /s/ and /t/ per assessment. It was hypothesized that RB's lateral /s/ production may have resulted from inadequate anterior tongue control and poor lateral bracing. As accurate articulation of /t/ requires that both of these lingual movements are adequate, it was included in the assessment corpus to provide further insight into the underlying cause of impaired /s/ production. The EPG data were analysed using representative frames of contact as per a previous study (McAuliffe *et al.* 2001). For examples of normal Australian English speakers articulation of /t/ and /s/, see McAuliffe *et al.* (2001).

Articulation without the palate in-situ

The list of CV phrases included for EPG assessment was read again following removal of the EPG palate. As the aim of the study was to examine functional change to articulation with a combined EPG and motor learning approach, these data were collected to provide a sample of speech that was indicative of normal articulation across the treatment stages. Both perceptual and acoustic analyses were conducted on the data.

Perceptually, a group of five naïve listeners (i.e. with no training or background in speech–language therapy or phonetics), male (n=3) and female (n=2) aged 29–58 years (mean=41.6 years), rated the participant's articulation of /s/ without the palate *in-situ* in the phrase 'say CV again'. The listeners were blinded to the study purpose. The phrase productions were randomized and listeners were asked to 'rate the clarity of the following phrases where 1=perfect and 5=sloppy' as per Weismer and Bunton (1999). Listeners were asked to pay special attention to the participant's articulation of /s/. The percentage level of agreement between each of the five raters was found to be high (Kreiman *et al.* 1993), with all pair-wise comparisons greater than 80% (mean=91%, range=80–98%).

Acoustically, the CV portion of each phrase recording was subjected to acoustic analysis using a commercially available computer system (Kay CSL 4300 B). The audio signals were digitized at a rate of 22 kHz, using 16-bit of quantitization. Articulatory-acoustic analysis of /s/ spectra including centroid frequency (M1) and skewness (M3) were conducted. These moments reflect the concentration and tilt of the spectral energy distribution respectively during consonant production (Forrest *et al.* 1988) and are considered indicative of the accuracy of consonant articulation. For determination of /s/ spectra, a 50-ms window was positioned at

the midpoint of the consonant amplitude-by-time waveform. The segments were then transformed using the long-term average function of the CSL and a full Hamming window.

Pre-treatment assessment results

Initial EPG assessment results are presented in figure 1a. As per previous studies, electrodes contacted on 80% or more of repetitions are shaded dark grey and those

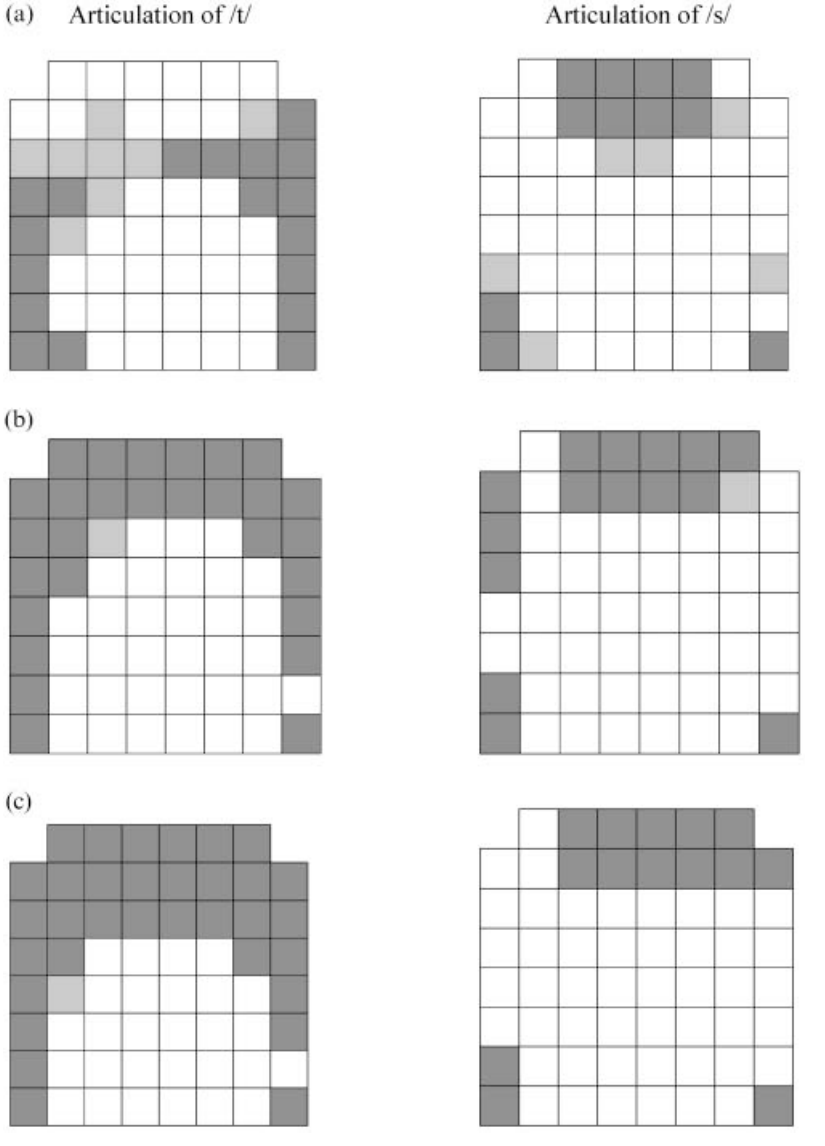

Figure 1. (a) Representative frames for /t/ and /s/ pre-treatment with articulation of /t/ (left) and /s/ (right); (b) representative frames for /t/ and /s/ immediately post-treatment; (c) representative frames for /t/ and /s/ immediately post-home programme.

contacted on 60% or more of repetitions are shaded light grey (McAuliffe *et al.* 2001). For /t/, results indicated that the point of articulation occurred in the mid-palatal region. This was further posterior to normal tongue position for /t/ in speakers of Australian English (McAuliffe *et al.* 2001). Complete closure across the palate, necessary for stop production, was present on only 60–80% of repetitions. Results for /s/ demonstrated a typical lateral /s/ production. Contact occurred in the central alveolar electrodes only. Lateral lingual contact was absent except in the velar region of the palate. It is likely that this impaired tongue–palate contact pattern for /s/ resulted in the perception of imprecise /s/ articulation. Perceptual analysis of /s/ articulation without the EPG palate *in-situ* indicated a moderate level of distortion. It was hypothesized that the consonant distortion resulted from an absence of lateral tongue stabilization and reduced tongue tip control.

Treatment plan

Treatment initially aimed to achieve anterior lateral tongue stabilization and tongue tip control. To achieve these goals, EPG would be used to obtain accurate tongue–palate contact patterns for /t/. A normal tongue–palate contact pattern for /s/ would be shaped from this tongue–palate contact pattern using EPG. For carry-over to speech, an intensive programme of speech therapy intervention was formulated. Overall, this consisted of two steps: (1) a 4-week period of intensive intervention including three sessions with a speech–language therapist per week (12 sessions) and daily home practise; and (2) a 6-week home programme. In step one, EPG would be used to achieve accurate tongue–palate contact. Once an accurate tongue–palate contact pattern was achieved, a combination of traditional articulation principles and visual biofeedback (EPG) would be used to achieve accurate sound production. In this case, traditional articulation therapy includes articulation drills and a step-wise progression from accurate production of the sound in isolation through to accurate production of the sound in words. Movement through the articulation hierarchy would occur when a 90% accuracy criterion was reached. Both part one and two of the treatment programme would emphasize the principles of motor learning and be heavily reliant upon drill, visual biofeedback, and behavioural feedback. The home programme (treatment consolidation phase) was structured and included daily homework tasks incorporating a portable training unit (PTU).

Results

EPG results

Figure 1 shows the results of the EPG analysis. As the treatment programme for /s/ was dependent upon accurate EPG tongue–palate contact patterns for /t/, the EPG results for /t/ are also presented. The results indicate that the participant's EPG pattern for /t/ had normalized following completion of the treatment programme. Immediately following treatment (figure 1b), the EPG pattern was similar to those previously published for normal adults speakers of Australian English (McAuliffe *et al.* 2001). At the completion of the home programme (figure 1c), contact extended into the third row of the EPG palate; however, this was still within the range of normal tongue–palate contact for /t/.

The results for /s/ production did not demonstrate the same level of improvement. Following both the post-treatment and the post-home programme assessments, EPG tongue–palate contact patterns remained disordered. Immediately post-treatment, the beginnings of a fricative groove formation with deviation to the left were evident; however, following the home programme, this lateral stabilization had diminished anteriorly.

Perceptual and acoustic results for /s/ without the palate in-situ

Perceptual analysis indicated a reduction in the perceived 'sloppiness' of articulation of /s/ across the treatment conditions (figure 2). Repeated-measures ANOVA revealed a significant difference across conditions ($F=28.25$, $p<0.001$). Post-hoc testing using alpha-adjusted Holm–Sidak tests indicated that a significant reduction in perceived 'sloppiness' of articulation occurred immediately post-treatment ($t=0.64$, $p<0.05$) and between the pre-treatment and post-home programme conditions ($t=5.74$, $p<0.05$). A trend towards reducing perceived 'sloppiness' was observed between the post-treatment and post-home programme conditions ($t=1.33$, $p=0.05$).

Table 1 contains the results of mean centroid frequency (M1) and skewness (M3) analyses of the /s/ spectral distribution. Repeated-measures ANOVA revealed significant differences across conditions for both measures ($p<0.001$). For M1, all post-hoc tests were statistically significant indicating that M1 increased from pre- to post-treatment ($t=2.78$, $p<0.05$), post-treatment to post-home programme ($t=6.26$,

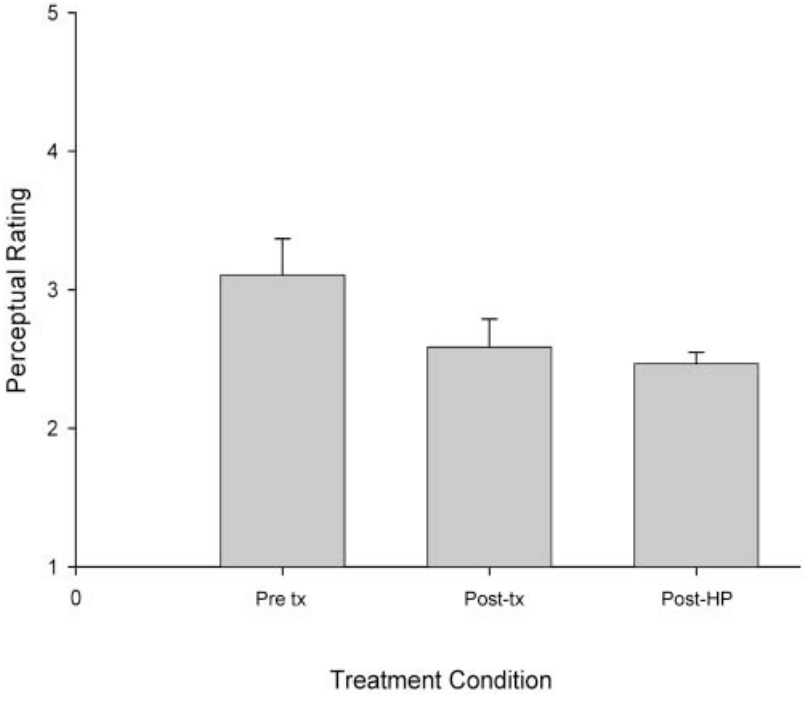

Figure 2. Mean and standard deviation scores on the perceptual rating scale completed by a group of five naïve listeners where 1=perfect articulation and 5=sloppy (Weismer and Bunton 1999).

Table 1. Results of spectral analysis of /s/ articulation (without the EPG palate *in-situ*) over the phases of treatment

Measure	Pre-treatment	Post-treatment	Post-home programme	*F*	*p*
Centroid frequency (M1)	3739 (960)	4691 (979)	6838 (1034)	42.84	<0.001
Skewness (M3)	0.523 (0.49)	0.065 (0.45)	−1.049 (0.56)	52.99	<0.001

$p<0.05$), and again between the pre-treatment and post-home programme conditions ($t=9.04$, $p<0.05$). Post-hoc testing of M3 results indicated statistically significant reductions observed from pre- to post-treatment ($t=2.91$, $p<0.05$), from post-treatment to the post-home programme condition ($t=7.10$, $p<0.05$), and between the pre-treatment and post-home programme conditions ($t=10.08$, $p<0.05$). The relationship between these two measures (Tjaden 1997) is highlighted in figure 3, which plots the M1 and M3 results of each repetition of /s/ at the assessment sessions. Acoustically, the improvement to /s/ production following the home programme phase is apparent.

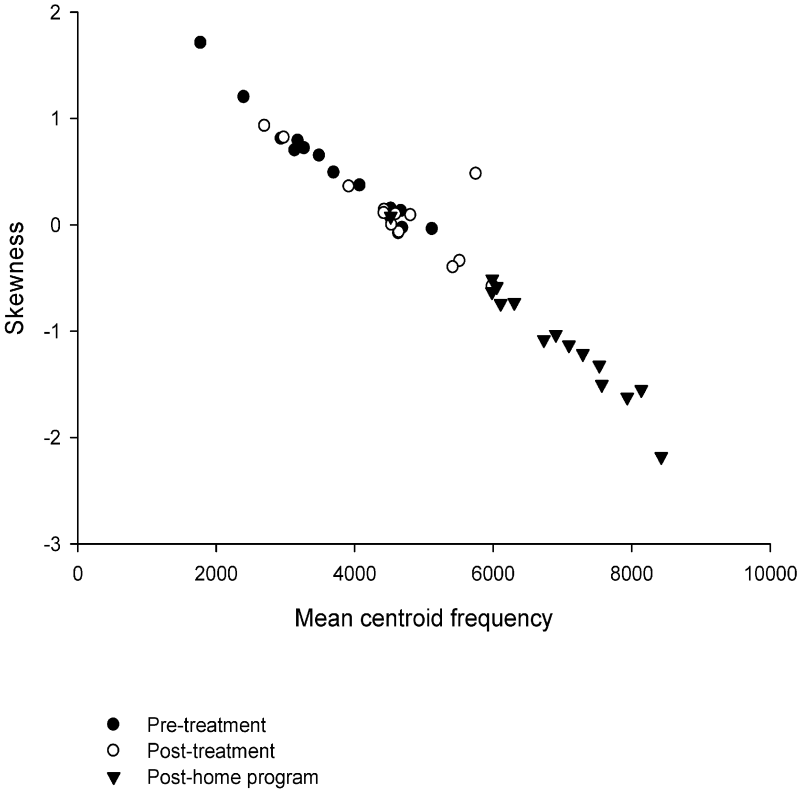

Figure 3. Relationship between mean centroid frequency (M1) and skewness (M3) of the spectral distribution for /s/ at the three treatment phases.

Discussion

The study aimed to determine if a 4-week period of intensive treatment incorporating visual biofeedback and traditional articulation therapy would result in functional improvement to /s/ articulation in an 11-year-old girl. Overall, functional improvement was observed with both the perceptual and acoustic properties of /s/ articulation improving significantly following intervention. The improvements were consolidated following a 6-week period of home practice. However, EPG data were incongruous with these findings, indicating only minimal changes to tongue–palate contact patterns for /s/ following treatment. The reasons for these contradictory findings are discussed.

Perceptually, a significant improvement to /s/ articulation was noted following the initial treatment programme with a trend towards further improvement observed following the consolidation phase. While the participant's articulation of /s/ was not 'perfect' at the end of the intervention period, naïve listeners perceived a significant reduction in the degree of consonant distortion. Furthermore, anecdotal reports from RB, her parents, and her teachers indicated improved /s/ articulation. The acoustic data supported the perceptual finding of improved /s/ articulation. Following completion of the home programme, RB's mean centroid frequency for /s/ resembled previously published data for normal adult female speakers (McFarland *et al.* 1996, Tjaden 1997). The change in mean centroid frequency from 3.7 to 6.8 kHz and increasingly negative skewed distribution suggested that RB was using a more anterior point of constriction and/or a narrower fricative groove for /s/ following the intervention period. Examination of individual tokens (figure 3) clearly demonstrated that a consistent change in mean centroid frequency and skewness of the spectral distribution emerged following the post-home-programme stage that was not present following the completion of therapist-delivered treatment. In the case of RB, the findings highlight the importance of a period of intensive home practise as it allowed for consolidation of initial treatment gains.

While functional measures of /s/ articulation improved following treatment, EPG patterns changed only minimally. Post-treatment, there was evidence of increased lateral stability and a decentralized groove. It was anticipated that the consolidation phase would extend these improvements; however, this was not the case. In discussion of these findings, it should be noted that treatment did not progress as originally planned due to RB's dislike of the artificial palate (even following an extended desensitization period). With the EPG palate *in-situ*, RB was able to modify her tongue–palate contact patterns to resemble normal /s/ of Australian English speakers; however, the normal contact pattern corresponded with distorted /s/ articulation (perceived by RB, the therapist, and RB's family). As a result, once RB could produce an accurate tongue–palate contact pattern for /s/ with the EPG palate *in-situ*, the palate was removed and RB was asked to perform the same lingual movement again to produce /s/. This procedure resulted in the production of a perceptually normal /s/ for the first time after many years of traditional therapy. Therefore, a modified treatment programme was undertaken in which the EPG palate was used at the commencement of each session to produce accurate tongue–palate contact for /s/ and stimulate RB's motor plan. The palate was then removed and traditional articulation therapy techniques employed.

In the light of the modified interventional programme, the lack of change to EPG contact patterns is not surprising. The technique was used successfully to 'kick-start' articulatory modification in a child with an entrenched abnormal tongue–palate contact pattern (Gibbon and Wood 2003). It is asserted that once RB was familiar with the tongue configuration required to produce /s/, she was able to maintain a similar configuration on removal of the EPG palate and, therefore, produce a perceptually acceptable /s/. Similarly, Dagenais *et al.* (1994) reported a lack of change to EPG patterns post-treatment in the presence of improved listener ratings in a participant with lateral /s/. The findings of the current study and the work of Dagenais *et al.* highlight the importance of listener ratings of articulation as an outcome measure in treatment studies.

In summary, visual feedback using EPG was useful initially in achieving accurate tongue–palate contact. The subsequent application of traditional articulation therapy techniques resulted in functional improvement to /s/ articulation that was quantified by naïve listener ratings and acoustic analysis. The improvement was achieved within a 4-week period and consolidated by a 6-week structured home programme, something that had not been achieved in many years of traditional intervention. While only a single-participant case investigation, it is posited that the functional change to /s/ articulation was due to the combination of visual feedback and an intensive motor learning approach to treatment. In particular, the consolidation phase was most beneficial. Once RB could produce /s/ accurately, drill and behavioural feedback were paramount. Future studies employing a combined visual feedback and intensive motor learning approach to intractable speech disorders would be of benefit.

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