Investigation into the effectiveness of Electropalatography in treating persisting speech sound disorders in adolescents with co-occurring (Developmental) Language Disorder

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Abstract

This study aimed to assess the effectiveness of Electropalatography (EPG) intervention in targeting specific phonemes/words in seven adolescents aged 14:10-18:06 with co-occurring speech sound and language disorders. Progress on individualised targets versus controls was evaluated following intervention undertaken as part of the participants' usual speech and language therapy provision. As a group, the participants showed significantly greater progress on their targets than controls, indicating that the EPG intervention was effective. However, performance varied between participants, targets and school terms. Factors that may have influenced the effectiveness of intervention include spending more time on targets and focusing on a specific phoneme. Overall, the results suggest EPG should be considered as an intervention approach for this client group, even in the late teenage years.

Keywords: Electropalatography, Speech Sound Disorder, Developmental Language Disorder, intervention, school-aged children

Electropalatography (EPG) has been used as a visual biofeedback tool in the assessment and treatment of speech sound disorders for the past 40 years, answering the 'pressing need' for a method of achieving detailed objective information as to the activity of articulators during disordered speech (Hardcastle et al 1987, p.171). Visual biofeedback uses instrumentation to provide the user with real-time feedback as to the position, shape and movement of their tongue (information traditional methods cannot provide), so they can compare their articulatory efforts with a target and modify their productions, thus developing and consolidating new articulatory patterns (Lee, 2021). The client is empowered with the ability to see and amend their production (Schmidt, 2007). Other visual bio-feedback approaches include Ultrasound and Electromagnetic Articulography, with increasing research comparing the efficacy of different approaches (Cleland et al, 2013; Mauszycki & Wambaugh, 2020) and some research suggesting visual biofeedback is more effective than traditional intervention in establishing motor patterns (Gibbon & Paterson 2006).

For EPG, the client is required to wear a specially manufactured orthodontic palate containing electrodes, which when connected to a computer via a multiplexer (a unit worn around the neck), causes corresponding contacts to light up on the display when the tongue makes contact (Hardcastle et al, 1991). EPG intervention is based on the principles of motor learning theory whereby the client uses immediate feedback on their performance to modify production or form a new motor pattern (Maas et al, 2008). Speech can be viewed in real time or recorded and played back for more in-depth analysis. Target phonemes can include those that create sufficient tongue-palate contact to be registered by the display, including consonants /l, t, d, n, k, g, ŋ, s, z, r, ʃ, ʒ, ʧ, ʤ/ along with some high vowels including / i, ɪ, ɛ, ʊ, u/ (Dagenais, 1995).

EPG offers an alternative approach for treating residual speech errors that traditional methods have been unable to resolve (Gibbon and Lee, 2015), perhaps for children with severe and persisting speech sound errors that have not responded to traditional speech intervention approaches (Ruscello, 1995). EPG is not suitable for every child, with individual differences and characteristics likely to affect success (Hitchcock et al 2017), and selection criteria needed to identify suitable candidates. This includes having sufficient visual, auditory, motor and cognitive skills to be able to interpret the display and adjust tongue position in response to feedback (Carter and Edwards, 2003), along with physical, physiological, psychological and personal factors and metalinguistic awareness (Morgan Barry, 1989).

A further limiting factor in the use of EPG is the expense associated with purchasing the specialist equipment and manufacturing and maintaining an individual palate for every client, resulting in few services being able to offer the approach. This has limited research into its effectiveness and makes gold standard Randomised Control Trials difficult. Thus, research into EPG tends to be on a relatively small scale, based on individual or series of case studies.

Previous studies suggest that EPG is useful for a range of client groups who had limited success using traditional methods (e.g., Carter and Edwards, 2003), including children and young people with cleft palate, (e.g., Gibbon et al 2001, ages 5-18), Down Syndrome (e.g., Wood et al 2019, ages 8:03-18:09), hearing impairment (e.g., Martin et al, 2007, single case study aged 18) and articulation disorders (e.g., Lundeborg & McAllister, 2007, single case study age 5). Studies of children diagnosed with dyspraxia (e.g., Morgan Barry, 1989, ages 9-adult) have also shown good progress but a significant amount of input may be required (Lundeborg & McAllister 2007).

There is currently no published research regarding use of EPG with participants with speech sound disorders and co-occurring language disorder. Many children with a language disorder also present with speech sound disorders, requiring input targeting both language and speech. Such children, in addition to their speech sound disorder may encounter additional challenges to those experiencing speech sound difficulties in isolation, for example, following instructions as to where to place their tongue, or in their ability to discriminate between different phonemes. However, children with DLD (a subset of those with language disorder) have relative strengths in visuo-spatial working memory (Lum et al, 2012) and, in other areas of language learning (e.g., grammar), they appear to benefit from interventions that provide visual support (Balthazar, et al, 2020). Thus, visual representations provided by the EPG display may well support the learning of target patterns for speech, as it utilises an area of relative strength. This has also been suggested as a possible contributor to the success of EPG intervention with children with Down Syndrome (Wood et al, 2019).

In this study we investigate the effectiveness of EPG intervention for children and young adults with severe and persisting speech sound disorder and co-occurring language disorder, by comparing their progress on targeted versus control phonemes and/or words. We hypothesised that the participants would make significantly more progress towards individualised pre-specified patterns on their targets than their controls.

Method

This study was carried out within the normal speech and language therapy provision in a specialist educational setting in the UK for children and young people aged 7-19 years with severe language disorders, the majority of whom meet the criteria for DLD. Many of the students in the specialist provision present with co-occurring speech sound production difficulties of varying severity. Students are selected for EPG intervention when progress using traditional intervention approaches is limited, but it is felt that progress might be greater with a visual biofeedback approach. Certain criteria must be met before considering EPG intervention. The student must:

- have sufficient attention to attend to the screen for the duration of the intervention session - judged by the student's core SLT who had a good understanding of their attention capabilities through work in both intervention sessions and in the classroom.
- be able to interpret the EPG display - assessed during a demonstration by the lead SLT for EPG, using their palate. Occupational Therapists also comment on the student's visual-spatial skills.
- be likely to be able to keep the palate in their mouth for the duration of an intervention session. For students with evidence of oral hypersensitivity, a training palate may be trialled prior to committing to the manufacture of a full palate.
- have no changes in dentition expected and no orthodontic work planned (checked with student's dentist). Oral mechanism exams are also conducted as part of the assessment process.

EPG has been used in our provision for nearly 30 years, with participants achieving the targets set as part of the usual termly target setting system. However, evidence of progress against targets is insufficient to conclude that an intervention has been effective, due to the potential influence of other factors such as maturation, or practice effects. To control for factors unrelated to the intervention (and therefore to allow stronger conclusions about effectiveness), for a period of 18 months, every time a target was set for a participant receiving EPG intervention, a control measure was also administered. Thus, we could control for some non-intervention related factors by comparing progress on targets versus controls.

Providing intervention for all participants and comparing progress within-participants on targets versus controls was preferable to having non-intervention baseline periods, or a control group due to cost, time and ethical issues around manufacturing, fitting and adjusting expensive palates for any non-intervention periods.

The data were analysed some time after they were collected and equipment failure meant that some were no longer analysable. The final dataset therefore involved seven participants who each received intervention for a minimum of one and a maximum of three school terms. A school term varies between 12 and 16 weeks.

Participants

The seven participants (aged 14:10-18:06 at the first testing point), all attended the specialist provision and received EPG intervention for speech sound production (in addition to individual and group SLT sessions targeting language, communication and life skills). Given the age of the participants, their diagnoses had been given before the recent changes to terminology in the area of language disorders. The primary diagnosis or diagnoses for the participants are shown in Table 1 along with age, previous EPG experience, standardised speech and language assessment results, specific targets and controls, time in EPG intervention and delivering SLT. More details about each participant are given below. Some participants would meet the new criteria for DLD (Bishop et al 2017), others had additional diagnoses, but would still meet the broader criteria for Language Disorder. Four attended the college part of the provision and three attended the school. All presented with a severe speech sound disorder and had previously received traditional forms of intervention prior to commencing EPG. All participants met the provision's criteria for receiving EPG and had received EPG intervention prior to the start of this study (length of time listed in Table 1) and thus were familiar with the approach. Several of the participants had been using EPG for some time and some had progressed from being unintelligible to unfamiliar listeners to being mostly intelligible. All participants consented to their data being used and discussed in this study.

INSERT TABLE 1 ABOUT HERE

Participant 1 (aged 18;2) had a diagnosis of verbal dyspraxia in addition to severe speech and language disorder. Upon starting at the school had been unintelligible to most listeners and had multiple speech sound errors. He had 4 years' experience using EPG prior to this study targeting primarily alveolars, /n,t,d/. In this study, he moved on to /s,z,ʃ/, following the hierarchy described by Dagenais (1995), whereby stop consonants are targeted, first, followed by fricatives and then affricates, (a hierarchy followed for all participants). He also made errors with affricates /ʧ/ and /ʤ/.

Participant 2 (aged 17;5) had used EPG for two terms prior to this study (the least of any participant) to target specific phonemes /s/ and /z/. These were his only speech errors, but EPG intervention had been delayed due to the prioritisation of orthodontic work.

Participant 3 (aged 18;6) presented with several additional diagnoses alongside severe speech and language disorder, including unilateral hearing loss and velopharyngeal insufficiency. His hearing impairment affected his discrimination between similar phonemes. His intelligibility to unfamiliar listeners was poor, but had improved greatly since commencing EPG. He had received the most EPG intervention of all the participants (5 years) with previous targets including alveolar phonemes /n,t,d/ to reduce velar contact, a possible compensatory strategy for velopharyngeal incompetency, which contributed to his unintelligibility. He had achieved previous success on individual phonemes in isolation, syllables, and in different positions within words.

Participant 4 (aged 17;2) had additional diagnoses of Mosaic Turner Syndrome, (MTS) dyspraxia and dysarthria in addition to speech and language disorder. She presented with a high arch roof of the mouth, as common in MTS, and had received successful surgery to reduce velopharyngeal insufficiency prior to this study. She had received prior EPG intervention for 3 years and a term. A particular difficulty had been achieving velar phonemes /k/ and /g/, which had formed the majority of previous intervention.

Participant 5 (aged 15;10) presented with a range of additional medical diagnoses alongside speech and language disorder. Speech errors were limited to /s,z,ʃ,ʒ/, but these were entrenched with slow generalisation. The participant had received prior EPG intervention for 3 years, targeting these errors at the phoneme and word level.

Participant 6 (aged 14;10) presented with severe dyspraxia of speech and right sided hemiplegia and before commencing EPG had used an electronic communication device to support his expression due to severe unintelligibility. He presented with a range of speech errors targetable through EPG and had received prior EPG intervention for 2 years and 2 terms targeting alveolar /n,t,d/.

Participant 7 (aged 16;1) had a diagnosis of ADHD in addition to severe oral and verbal dyspraxia, with periods of ill health in the years prior to this study, involving time off school. She had received prior EPG intervention for 3 years, primarily targeting alveolars /n,t,d/. She presented with large number of speech errors and had been unable to achieve the same level of consistency on previous targets as other participants.

Equipment

Recordings were made using the LinguaGraph Electropalatography (EPG) system and icSpeech Professional software, (Rose Medical Solutions, 2016). The palates were manufactured by a dental technician experienced in the manufacture of EPG palates, using a dental impression taken by a consultant orthodontist. The palates were in the style of the Reading system, whereby 62 electrodes are arranged across eight rows and eight columns with placement of electrodes matched to anatomical landmarks. Participants were all accustomed to wearing their palates and confident in using the software.

Assessment and identification of targets versus controls

At the beginning and end of each term, recordings were made for each participant of both their target and a control, on which they received no intervention. Targets and controls were a list of words either in isolation or within sentences. Targets were specifically chosen for each participant based on the clinical judgement of their SLT in discussion with the participant regarding the next priority area and included either a specific single phoneme, or phonemes that shared the same pattern on the EPG display. The number of phonemes targeted varied depending on the individual participant’s specific speech errors and progress on previous targets. The specific words included in the targeted word list were practised within sessions, thus progress on targets relates to the specific targeted words rather than generalisation to other words with the same phonemes. Controls were chosen to be phonemes or words not worked on directly within sessions, that were thought unlikely to be affected by the intervention. and were ideally phonemes produced with a different tongue position.

However, where the participant had only a few speech errors, it was difficult to identify controls where generalisation from work on the target was unlikely. Any unfamiliar words were modelled for the participant to repeat back. Targets and controls for each participant for each term are shown in Table 1 and are discussed in more detail below.

Participant 1 was working towards his driving theory test, thus driving related vocabulary containing /s/ and /z/ formed his target words for the first term of the study. Control words containing the same sounds were unfamiliar to him; thus, it was thought unlikely progress would generalise to these. Terms 2 and 3 targeted /s,z/ and then /ʃ/ respectively, all in everyday functional words including names and places. Affricate /ʤ/ was an additional speech error and everyday functional words containing /ʤ/ were used as the controls in terms 2 and 3.

Participant 2 targeted /s/ and /z/ across the 3 terms of this study, as these were the specific speech errors that had been resistant to traditional intervention methods. As other phonemes treatable using EPG were accurate, control items consisted of untreated words containing /s/ and /z/. Term 1 targeted everyday functional words containing /s/, with control words from other college courses that were largely subject specific and unfamiliar to him and thus thought unlikely to generalise. Term 2 targeted words with multiple occurrences of /s/ with the control list comprising similar untreated words, many of which were unfamiliar to him and thus thought unlikely to generalise spontaneously. Term 3 targeted /s/ and /z/ within vocabulary from his motor mechanics course, with control items including untreated words from the course.

Participant 3's target for Term 1 incorporated different phonemes targeted previously in EPG sessions within his course vocabulary (animal management). Control words were from other courses. Term 2 focused on /t/ in word medial and final positions as well as in clusters, (identified as a significant barrier to his intelligibility). Control words contained word initial /s/, previously targeted with limited success.

Participant 4's targets for term 1 included a range of alveolar and velar phonemes in functional, everyday words. Untargeted control words included the same phonemes. The subsequent term reverted to targeting /k/ specifically, perhaps the biggest barrier to intelligibility, with control items consisting of current course words containing /s/.

Participant 5 was in Year 11, so with a busy timetable leading up to his national exams, EPG sessions were limited to once weekly. Intervention targeted /s/ in all word positions within sentences, having worked on /s/ at the word level in previous EPG targets, with control items consisting of untreated words containing /s/ in sentences.

Participant 6 targeted word initial /s/ in everyday functional words, with word initial /ʤ/ in high frequency words acting as controls.

Participant 7 targeted word initial /t/ in everyday words, with word initial /s/ words acting as controls.

EPG analysis

The first author analysed target and control data to judge success in production against pre-specified target patterns. These were not necessarily a canonical pattern, but one judged to be achievable by the participant during the intervention period and likely to lead to a more perceptually acceptable production, although a perceptual rating was not conducted. Recordings were played back using icSpeech software (Rose Medical), providing audio and visual display of the tongue-palate contact during speech. Recordings were carefully analysed by comparing attempts at the target or control phoneme with the pre-specified target patterns, using the frame with the closest match. A document was created with a screen shot of the pattern and its exact time in the recording, see Figure 1.

FIGURE 1 ABOUT HERE

Intervention

All participants except one received 2x30 minutes of weekly EPG intervention during each term; Participant 5 received 1x 30 minutes weekly, due to taking his national exams imminently and thus needing to spend more time in class. The lead SLT for EPG delivered intervention for all three terms of Participant 1's intervention and term 1 for Participant 3. She had 10 years' experience delivering EPG on 3 different systems, had received direct training from the manufacturers on the system used in the current study and had provided input into the development of its software features. SLTs working in the college delivered intervention for participants 1,2,3,4. The EPG lead provided an hour-long induction training in the use of EPG, jointly devised target areas and the intervention plan with the SLTs and provided ongoing support as required during the intervention, ensuring some uniformity of approach. The SLT assistant (SLTA) delivered sessions for participants 5,6,7 in the school. She had previously provided EPG intervention for a year following training from the EPG lead of several hours plus weekly jointly delivered sessions. At the time of this study, she had weekly liaison sessions with the EPG lead as it was felt she was sufficiently experienced to deliver sessions independently.

The first session of term for all participants involved recording both target and control items, with intervention on targets provided in subsequent sessions. A typical intervention session began by practising the target phoneme in isolation, aiming to match the target pattern on screen. Once an accurate production was achieved, the phoneme was practised at the syllable level, followed by word level in the target position using the target pattern onscreen initially before recording and reviewing attempts. The order of words targeted was decided by the treating SLT, with no set number of trials prescribed. The final session of the term involved re-recording the target and control items.

Results

Group analysis

The violin plot in Figure 2 shows percentage correct on targets versus controls, pre- and post-intervention (combined across the terms and participants). This indicates that targets (in black) improved from pre- to post-intervention while controls (in grey) showed less change.

FIGURE 2 ABOUT HERE

To further investigate these apparent differences, we analyzed the data using logistic regression. This is a type of general linear model that is used for a binomially distributed dependent variable (e.g., correct versus incorrect), and accounts for random effects, such as differences between individuals. We predicted the proportion of correct responses with the fixed effects of time (pre- vs post-intervention) and type (targeted vs control) and their interaction. The proportion of correct responses for controls at pre-intervention was used as the reference, so the model evaluates to what extent the proportion correct in all other combinations of type and time differs with respect to controls at pre-intervention. The model also included a random intercept for delivering SLT and participants as well as participant-by-condition slopes to model individual differences in initial performance and progress (especially important given that each participant had different targets and controls). Each random and fixed effect was added individually and its effect on the model fit evaluated using model comparisons. Only those effects that significantly improved the model's predictive ability were included in the final model. All analyses were carried out in R version 4.0 using the lme4 package (version 1.1-23).

The model with the best fit included both fixed effects (time and type), their interaction and the random effects of participants and participants-by-condition (time and type, but not SLT, which did not improve the fit). The results of the final model are shown in Table 2. The lack of significant effect of type shows that the frequency of correct responses did not differ pre-intervention between targets and controls. The effect of time was also not significant, indicating that for the controls the frequency of correct responses did not differ significantly between pre- and post-intervention. However, the highly significant interaction of type and time shows that the effect of time on targets was significantly different from its effect on controls, where the frequency of correct responses increased to a greater extent from pre- to post-intervention for targets than for controls.

TABLE 2 ABOUT HERE

Individual results

The percentage correct pre- and post-intervention on targets and controls for each term and each participant are shown in Figure 3. Whether time (for both controls and targets combined) or the interaction between time and type were significant was analysed using logistic regression. P-values for these are shown in Figure 3, with significant results in bold.

FIGURE 3 ABOUT HERE

A significant interaction of time and type can be interpreted as evidence that the intervention was effective and specific to the area targeted. A main effect of time, but with no significant interaction, could be due to effective intervention which generalised to the control, or it could be due to non-specific effects such as maturation (unlikely given the age of the participants), or a practice effect; such a finding is therefore difficult to interpret.

None of the individual participants showed a significant interaction in their first term of intervention, although the main effect of time was significant for Participants 1, 3 and 4. However, in the second term, one (Participant 4) showed an interaction of time and type, with two others (Participants 1 and 3) showing a main effect of time. The two participants who had a 3rd term of intervention (Participants 1 and 2), both showed significant interactions of time and type (and main effects of time).

Participant 1 showed significantly higher scores at post-intervention than pre-intervention during all three terms, with a steeper slope for targets, although the interaction was only significant in term 3. Thus, we can conclude that intervention was effective in term 3. In terms 1 and 2, the main effect of time could be due to generalisation to the controls. Term 1's controls were untreated words including the target phoneme and thus generalisation might perhaps be expected. The control phoneme for term 2 /ʤ/ was also the control for term 3, although 40% of the words were different. He displayed limited alveolar contact for the /d/ phase of the affricate. Controls improved in term 2, perhaps due to generalisation of alveolar contact for target /s/ to the initial phase of /ʤ/. Conversely, the decrease in controls in term 3 could be due to the more posterior tongue contact required for target /ʃ/, translating into fewer correct tongue positions for the initial phase of /ʤ/.

Participant 2 also showed a significant interaction in term 3, whereas scores on both targets and controls during term 2 showed only a non-significant increase and progress in term 1 was minimal. Term 3 was the autumn term; the longest when both /s/ and /z/ were targeted in course words and compared to the same phonemes in untreated course words. Intervention in terms 1 and 2 only targeted /s/. One possible reason for the greater progress seen in the final term could be that target words were vocabulary that would have been encountered regularly, not only in his motor mechanics course but also in preparation for his driving theory exam. When compared with term 2's target, term 3 had a lower initial accuracy level, meaning there may have been more scope for improvement, although this was not seen in term 1 where scores remained low throughout.

Participant 3 did not show any significant interaction in either term but showed a significant main effect of time in both terms. Target phonemes for term 1 were also scored in the control words, thus generalisation could be a factor. The control for Term 2 was /s/, which although produced in a different manner to target /t/, involves a similar tongue contact pattern. Thus, perhaps increased alveolar contact for /t/ generalised to /s/.

Participant 4 showed a significant interaction in term 2 and, in term 1 a main effect of time, but no interaction. As targeted phonemes were also scored in control words in term 1, there may have been generalisation. Term 2 was also the longer autumn term and the target was also limited to a single phoneme, rather than consolidating work on multiple phonemes previously targeted as in term 1.

Participant 5 showed little indication of benefit from intervention. Due to other commitments, only one EPG session a week was possible, amounting to 100 minutes of intervention which was considerably less than for any other participant. This was also the only participant to target a phoneme at the sentence level.

Participant 6 had one term of data and the interaction approached significance, due to small gains on the target (word initial /s/) and scores on the control (word initial /ʤ/) decreasing, especially accuracy in the second phase of the affricate, perhaps due to practice of alveolar placement for /s/ during intervention.

Participant 7 did not show any significant interaction between target and control, but appeared to show some increase with both, although this did not reach significance. Her additional diagnoses and experience of ill health may have limited the amount of progress made.

Discussion

This study aimed to assess the effectiveness of EPG intervention in targeting specific phonemes in adolescents with co-occurring speech sound and language disorders. We compared progress on targets versus controls following intervention undertaken as part of the participants' usual speech and language therapy provision. Participants were aged 14:10-18:06 at the start of the intervention, which are comparable ages to studies investigating effectiveness of EPG with other client groups.

A group analysis comparing progress with intervention on the targets versus controls across all participants and terms indicated that intervention with EPG was generally effective as the frequency of correct responses increased to a greater extent from pre- to post-intervention for targets than for controls. However, when analysed at an individual level, the response of the seven individuals varied, both between individuals and for some individuals across terms. Participants 1, 3 and 4 showed general progress during the first and second terms (with a main effect of time). For Participant 4 in the second term, an interaction indicated greater progress on targets than controls. The two participants who had a third term of intervention (Participants 1 and 2), also showed significant interactions. Thus, at a group level (with greater power), it appears that EPG intervention is effective. At an individual level (with less power), it is harder to draw conclusions. Certainly, for Participants 1, 2 and 4, in one term the analyses indicated a clear effect of intervention (where targets improved more than controls). The interaction for Participant 6 almost reached significance, thus drawing strong conclusions regarding the (lack of) effectiveness in this case would be unwise. Where the results showed a main effect of time but no interaction (Participants 1, 3 and 4 in the first term), it is also hard to draw conclusions. Such results could be obtained from a successful intervention that generalised to the controls, or from non-specific effects of maturation and practice. It was however clear that Participants 5 and 7 showed little sign of benefitting from the intervention.

Previous studies have highlighted the importance of considering individual characteristics when evaluating success of EPG intervention (Hitchcock et al, 2017) and indeed it is useful to consider the range of physical, physiological, psychological and personal factors proposed by Morgan Barry (1989). Five of the seven participants had a diagnosis of dyspraxia, (Participants 1,2,4,6,7). Specific studies of children with dyspraxia have shown they can make progress on their speech production using EPG (Morgan Barry, 1989; Lundeborg &

McAllister, 2007), but this progress may take more time than children whose primary difficulties are in articulating specific sound segments or those with a reduced sound system.

Results from Participants 2 and 4 reflect this finding, with better results on later targets and those with a greater number of minutes of intervention. Indeed, the greater number of sessions and hence total amount of intervention available in the longer autumn term seemed to lead to greater success in general, with Participants 2,3 and 4 all achieving greater success that term. In contrast, Participant 5 had the lowest minutes of intervention and made the least progress. Participant 5 was also the only one to target the phoneme in words at the sentence level which may also have contributed to his limited progress. Recalling accurate tongue position for specific phonemes becomes more difficult as additional words, and hence multiple tongue positions and coarticulatory effects are added to the utterance. It may be this particular target would have benefitted from more sessions to provide more frequent practice for this trickier skill. Indeed, Hitchcock et al (2017) highlight the possible need for a longer timeframe to reset a speech pattern that has become a habit over the course of years.

Four participants had additional diagnoses affecting their overall health (Participants 3,4,5,7) including three with specific medical syndromes (Participants 3,4,5) and two (Participants 3 and 4) presenting with velopharyngeal insufficiency. Morgan Barry (1995) suggested EPG may not be as successful for participants with velopharyngeal insufficiency. This is perhaps seen in Participant 3's ongoing intervention to reduce velar contact, which is likely to have represented a compensatory strategy for velopharyngeal incompetence. However, Participant 3 did still make progress on his targets with possible generalisation to the control produced with a similar tongue placement, whilst Participant 4, who had successful surgery to improve velopharyngeal insufficiency prior to the current study, also showed evidence of progress when targeting velar /k/. Participant 4 also achieved a significant interaction when one phoneme was specifically targeted. This was the same for Participant 1 who also showed a significant interaction in the term when he targeted a single phoneme. Conversely, Participant 2 achieved significant interaction for a term where he targeted two phonemes sharing tongue placement /s,z/ , but this may have been influenced by having the longest time spent on his target in the autumn term, as previously highlighted.

Controls were included for each target in an attempt to isolate the effects of intervention, a feature that has been largely absent in previous investigations into EPG effectiveness. However, the results from some participants suggest there may have been some generalisation of progress on targets to the controls, for example, Participant 1 in term 2, Participant 3 in term 2 and Participant 7 in term 1. While this indicates that this experimental design was not ideal, it also indicates that EPG may be an effective means of treating multiple speech errors. In the examples seen in this study, there is a possibility of generalisation of progress to speech sounds made with a similar tongue placement to the target. However, these hypotheses need to be evaluated in more rigorously designed studies, preferably with control participants.

The intervention was delivered by five different individuals (four SLTs and one SLTA), all of whom had received training and on-going support from the EPG lead. The different people delivering the intervention did not appear to affect the results, as the random factor of SLT did not contribute to the final model. Thus, with the level of training and support provided, it appears a range of SLTs and indeed SLTAs can deliver effective EPG intervention.

The current investigation suggests there are multiple factors to take into consideration when identifying possible indicators for success when using EPG. Previous studies have suggested that EPG may be most beneficial in the establishment phase of learning new articulatory patterns, (Gibbon and Paterson, 2006). However, the progress shown by these participants suggest that perhaps the visual feedback provided by EPG can continue to support children with severe speech sound disorder who also have a severe language disorder to improve their speech production accuracy.

Potential candidates for EPG intervention are likely to be children and young people with residual speech sound disorders that have not resolved through traditional methods alone and who may have additional diagnoses impacting their ability to access this highly specialist intervention approach. When planning intervention, a higher number of sessions and focus on a single phoneme may yield better outcomes. Our results suggest there may be a generalisation effect, specifically to phonemes that share a place of articulation with the target, however, results must be treated with caution due to the design of the study.

Limitations and future directions

The primary limitation of this project was the use of control items or phonemes for experimental control. Where an interaction between time and type was shown, we could draw conclusions regarding the effects of intervention on progress with the targets versus controls. However, when the controls also showed progress, this could either be because the intervention was very successful and generalised to controls, or because the effects shown were only due to practice or maturation (i.e., the intervention was not effective). Given the age of the participants, maturation is unlikely, but we cannot rule out practice effects.

Other methods of experimental control were considered but were not deemed feasible in our clinical setting, given the small numbers of students using EPG and the time and expense of manufacturing palates. Having (waiting) control participants or baseline periods would have required fitting and manufacturing palates for participants who would then not use them for intervention, at least for a period. If intervention were then delivered later, expensive and time-consuming adjustments may then have to be made to the palates before intervention could start. Thus, control areas seemed to be the only viable method of experimental control for this study. It would also be useful to conduct a follow up assessment to ascertain long-term effects of EPG intervention, although the practicalities of ensuring a well-fitting palate after a period of non-use can be problematic.

As this was a project undertaken as part of usual working practice, it was also subject to limitations and disruptions associated with working within an educational environment. Total intervention time was not consistent across participants, dependent on the length of the term and other timetable commitments. As participants received EPG intervention from their named SLT (4 different SLTs) or the SLTA, uniformity in the structure or content of the sessions could not be guaranteed, although this did not appear to affect the results.

Conclusion

EPG has been successfully used with a range of clients over the past 40 years, but due to the highly specialist equipment involved and cost of manufacturing and maintaining a well-fitting palate, careful consideration must be given as to the likelihood of success. On average, EPG appeared to be effective for the adolescents in this study with persisting speech sound and language disorders with participants showing significantly greater progress on their targets than controls. However, performance varied between participants, targets and terms. EPG appeared particularly effective when delivered for more sessions and with a focus on a single phoneme. Overall, the results suggest EPG should be considered as an intervention approach for children and young people with severe speech sound and language disorder, even in the late teenage years. However, further research using more robust controls is warranted to gain a clearer understanding of the effectiveness of EPG intervention.

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Table 1: details of Participants, their targets and controls

Participant, age at start of study, sessions per week and amount of previous experience using EPG	Diagnoses	Standardised language score on TOAL Spoken Language at start of intervention	Term	Target	Minutes intervention received on target	SLT/ SLTA	Control
1: 18;02 2x 30 mins weekly for 4 years	Severe Speech and Language Disorder Severe verbal dyspraxia, dysfluency	78	Term 1: Summer Year 1	/s/ & /z/ in all word positions	370	SLT1	/s/ & /z/ in all word positions (control words)
			Term 2: Autumn Year 2	/s/& /z/ WI	450	SLT1	/ʤ/ WI
			Term 3: Spring Year 2	/ʃ/ WI	350	SLT1	/ʤ/ WI
2: 17;05 2x 30 mins weekly for 2 terms	SLI, (Specific Language Impairment) verbal dyspraxia	78	Term 1: Spring Year 1	/s/ in all word positions	480	SLT2	/s/ in all word positions (control words)
			Term 2: Summer Year 1	/s/ in all positions in complex words	360	SLT2	/s/ in complex (control) words
			Term 3: Autumn Year 2	/s/ & /z/ in all word positions	580	SLT2	/s/ & /z/ in all word positions (control words)
3: 18;06	Goldenhaar Syndrome, unilateral hearing loss, severe Speech and Language	59	Term 1: Summer Year 1	/t, d, n/ in all word positions	500	SLT1	/t, d, n/ in all word positions (control words)

2x 30 mins weekly for 5 years	Disorder, velopharyngeal insufficiency		Term 2: Autumn Year 2	/t/ WM, WF & clusters	680	SLT4	/s/ WI
4: 17; 02 2x 30 mins weekly for 3 years and 1 term	Mosaic Turner Syndrome, severe SLI, profound speech disorder, dyspraxia, dysarthria, velopharyngeal incompetence	63	Term 1: Spring Year 1	/t,d,n,k,g, l, ʤ, ʧ/	520	SLT3	/t,d,n,k,g, l, ʤ, ʧ/ (control words)
			Term 2: Autumn Year 2	/k/ in all word positions	660	SLT3	/s/ in all word positions
5: 15;10 1 x 30 mins weekly for 3 years	Neuro-carido-facio-cutaneous Syndrome, Arnold Chiari 1 malformation, Neurofibromatosis type 1-subtype Watson's Syndrome, SLI, speech sound disorder, dysarthria	74	Term 1: Spring Year 2	/s/ in all word positions	100	SLTA	/s/ in all word positions (control words)
6: 14;10 2x 30 mins weekly for 2 years and 2 terms	Severe speech and language disorder, dyspraxia of speech, semi-paralysis of the tongue (right-sided hemi-plegia)	Core Language: SS: 52 (CELF-4) Unable to complete TOAL due to difficulty completing written element	Term 1: Spring Year 1	/s/ WI	360	SLTA	/ʤ/ WI
7: 16;01 2x 30 mins weekly for 3 years	Severe SLI, severe oral and verbal dyspraxia, ADHD	65	Term 1: Spring Year 1	/t/ WI	420	SLTA	/s/ WI

WI=Word Initial, WF=Word Final, WM=Word Medial

Table 2: results of logistic regression

	Final model		
Predictors	*Odds Ratios*	*95% CI*	*p-value*
type [target]	1.12	0.52–2.43	0.765
time [post-intervention]	1.84	0.99–3.42	0.054
type [target] * time [post-intervention]	2.68	1.60–4.47	**<0.001**
Random Effects			
σ^2	3.29		
$\tau_{00\ \mathrm{ID}}$	0.48		
$\tau_{11\ \mathrm{ID.type:\ target}}$	0.80		
$\tau_{11\ \mathrm{ID.time:\ post\text{-}intervention}}$	0.40		
ρ_{01}	-0.81		
	0.94		
ICC	0.18		
N_{ID}	7		
Observations	52		
Marginal R^2 / Conditional R^2	0.104 / 0.265		

Figure 1: Example of data analysis, comparing production of target phoneme to pre-specified target pattern

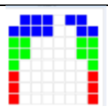
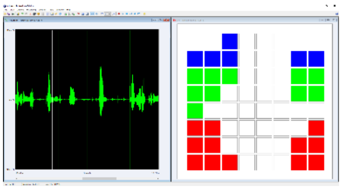
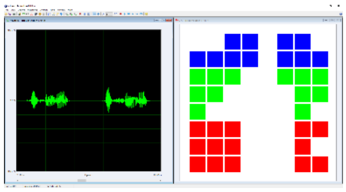
Participant 2	Target pattern for /s/ and /z/: gap of 1 in Row 1 or 2: 	
passenger	Before intervention  Time: 12.98	After intervention  Time: 23.80 (Target pattern achieved)

Figure 2: violin plot showing distribution of target and control scores pre- and post-intervention

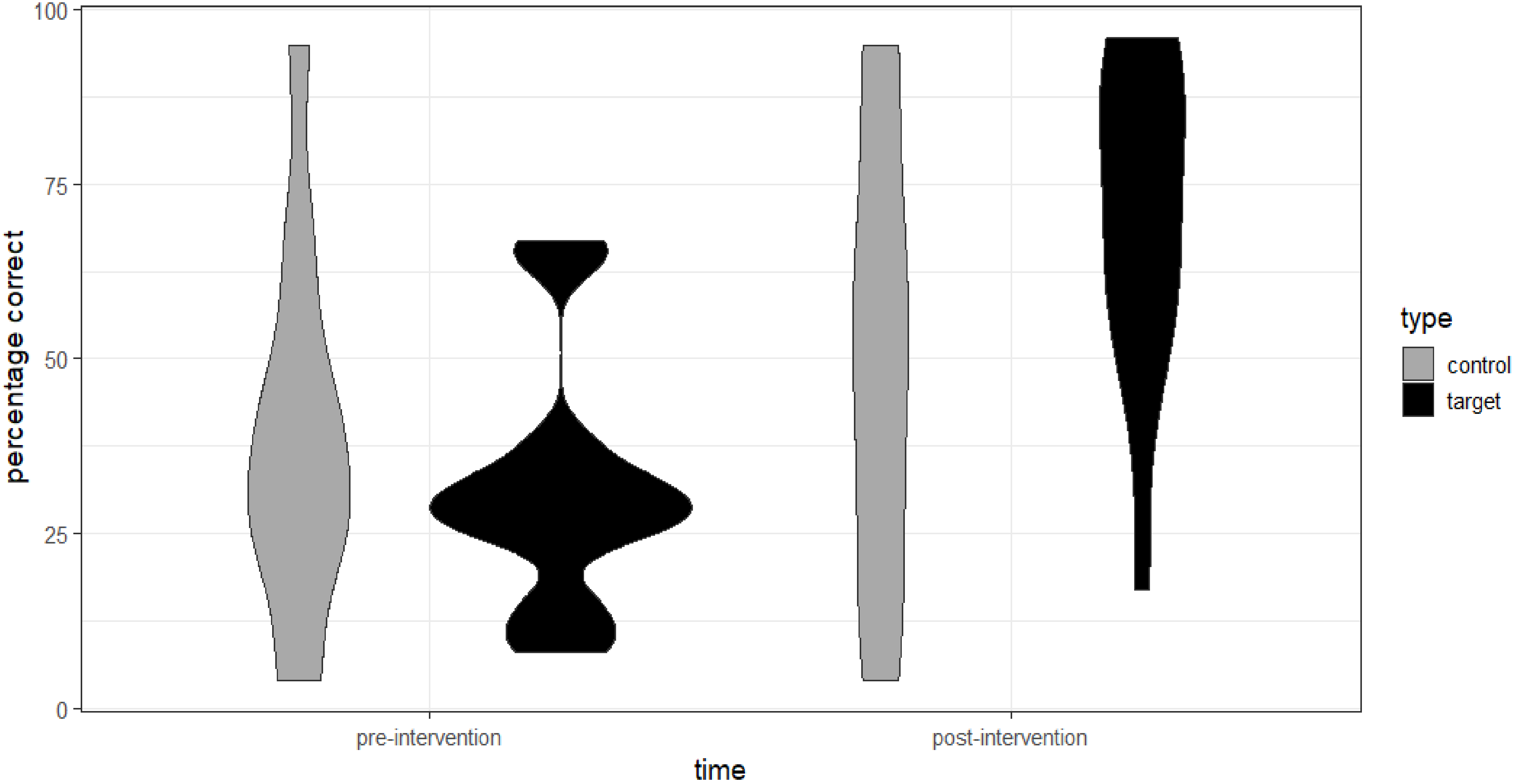


Figure 3: individual results for targets and controls at each term. Significance of main effect of time and interaction of time and type (control vs target) shown on each plot, with significant results in bold.