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Title:

Clinical application of usage-based phonology: Treatment of cleft palate speech using usage-based electropalotography

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Running Head:

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Clinical application of usage-based phonology: Treatment of cleft palate speech using usage-based electropalatography

ABSTRACT

Purpose: To investigate whether a novel electropalatography (EPG) therapy, underpinned by usage-based phonology theory, can improve accuracy of target speech sounds for school-aged children and adults with persistent speech sound disorder (SSD) secondary to cleft palate +/- lip.

Method: Six consecutively treated participants (7 – 27 years) with long-standing speech disorders associated with cleft palate enrolled on a multiple baseline (ABA) within-participant case series. The usage-based EPG therapy technique involved high volume production of words. Speech was assessed on three baselines prior to therapy, during weekly therapy, at completion of therapy, and 3-months post-therapy. Percent correct of target phonemes in untreated words and continuous connected speech was assessed through acoustic phonetic transcription. Intra- and inter-transcriber agreement was determined.

Result: Large to medium treatment effect sizes were shown for all participants following therapy (15 – 33 sessions). Percentage of targets correct for untreated words improved from near 0% pre-therapy, to near 100% for most target sounds post-therapy. Generalisation of target sounds to spontaneous connected speech occurred for all participants and ranged from 78.95% - 100% (*M* = 90.66; SD = 10.14) 3-months post-therapy.

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Conclusion: Clinically significant speech change occurred for all participants following therapy. Response to the novel therapeutic technique is encouraging and further research is indicated.

Introduction

Electropalatography (EPG) is an instrumental technique used to assess and treat individuals with speech sound disorder (SSD). EPG detects tongue-to-palate contact during speech by way of a custom-made plate containing sensors that fits to the roof of the speaker's mouth. Resultant patterns of lingual contact are viewed on a screen in real time (Gibbon & Wood, 2010; Gibbon, 2004; Lee, 2021). EPG is used to treat a range of lingual speech errors. For example, where /t/ is produced as [k], /s/ produced as [ɬ], or where non-lingual speech sounds are accompanied by lingual contact, such as /p/ produced as [p͡k]. EPG is typically used with school aged children and adults with long-standing SSD who have not responded to more conventional speech-language therapy, such as traditional articulation therapy (Cleland & Preston, 2020). A limitation of traditional therapy methods is that many articulatory gestures, such as tongue movements, are hidden within the vocal tract. Such articulatory gestures can be difficult to identify, describe and facilitate using conventional therapy methods (Cleland & Preston, 2020). EPG therapy has the advantage of being able to provide the speaker and clinician with specific, real-time information on tongue-palate contact for such "hidden" sounds. However, because EPG intervention requires specialist equipment and specialist training, and because the speaker needs to have stable dentition for the duration of treatment, EPG is usually a "second-line" therapy.

EPG therapy is clinician-led and normally consists of individual sessions lasting 30 – 60 minutes (Cleland & Preston, 2020). The visual feedback provided by EPG is used to identify

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atypical speech sound productions and to elicit more typical production of target sounds. Therapy typically commences with elicitation of single sounds in isolation. Therapy then progresses in a hierarchical fashion, in the manner of traditional articulation therapy (Van Riper & Emerick, 1990), i.e., production of the speech sound in syllables, words, sentences, and finally production of target speech sounds in connected speech. Speech production in the early stages of therapy typically involves repetitive drilling of speech targets. As speakers progress with therapy, the visual feedback provided by EPG is gradually reduced (Cleland & Preston, 2020).

A number of studies have looked at the effectiveness of EPG therapy with individuals with SSD secondary to cleft palate +/- lip. To date, therapy studies include within-participant studies and a small number of group studies (see Lee et al., 2009 for a summary). These studies suggest EPG therapy can result in acquisition of target speech sounds for many people undergoing this type of therapy. However, methodological limitations have been identified with some studies (Lee et al., 2009; Lohmander et al., 2010). Limitations include small numbers of participants in group studies and lack of inter- and intra-rater reliability with perceptual speech outcomes. In addition, few experimental studies have reported on generalisation and maintenance of learning to everyday speech. Clinical experience suggests generalisation and maintenance of speech gains following EPG therapy and other visual biofeedback therapies can be particularly difficult (Cleland & Preston, 2020; Gibbon & Paterson, 2006). Gibbon and Paterson (2006) surveyed speech-language pathologists' views on EPG therapy outcomes for children with SSD in Scotland over a 10-year period. Speech-language pathologists returned questionnaire for 95% of the patients who had EPG plates made for them in Scotland over this time (n = 71). Of those undergoing EPG treatment (n =

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60), 12.5% of patients achieved total success, while 41.1% showed "moderate success, where some or all sounds targeted in therapy showed improvement and were used in some speaking contexts" (p 283). Further, a total of 19% showed "slight improvement in some speaking context" (p 283), while 12.5% showed no change in any speaking contexts. Reported difficulty with generalisation and maintenance is not surprising given the very entrenched SSDs in those typically receiving EPG therapy. Nevertheless, if these therapies are to be used, significant clinical change must be shown to justify their use. Thus, development of the EPG therapy paradigm to achieve lexical and functional generalisation, and maintenance of such generalisation, is needed.

Crucial to any speech-language therapy paradigm, including EPG, is the theoretical basis of the treatment technique (McLeod & Baker, 2017). Teaching episodes, and frequency of these teaching episodes, stem directly from whatever theory underpins the treatment. In addition, should a client not respond in the predicted way, a robust theory can direct the therapist to other teaching episodes. Likewise, a client's response to therapy can contribute to further theoretical development, either by providing support for the theory or by identifying apparent theoretical shortcomings. For most individuals with SSD, the ultimate aim of therapy is to improve or normalise speech sound production and to integrate this change into everyday talking in a lasting way. Consequently, key to any therapy paradigm is a theoretical basis which explains how transfer of learning and maintenance of this learning may be achieved. Snowling and Hulme (2011) describe such explanatory theories as "causal" models and argue for the importance of such models in the remediation of speech, language and reading difficulties.

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This study used usage-based phonology as the theoretical underpin for EPG therapy. Usage-based phonology is a theory of phonology which to date has had comparably little clinical application and has not yet been applied to cleft palate speech. However, this theory is well known in the general linguistic literature (Docherty & Foulkes, 2013; Vihman & Keren-Portnoy, 2013). Moreover, usage-based phonology may be appealing to clinicians as a single "causal" theory which provides an explanation for speech learning over time, including transfer and maintenance of learning. Usage-based phonology describes an emergent model of phonology where speech sound processing, acquisition and change come about through speech use (i.e., speaking and listening) and the subsequent cognitive associations made following these speech usage events (Bybee, 2001, 2010). Various writers detail slightly differing usage-based models (e.g., Bybee, 2001; Pierrehumbert, 2001). However, all hold onto the basic tenets described above. The usage-based theory underpinning the therapy reported in this study stems from the seminal work of Bybee (2001; 2010), Vihman and colleagues (Vihman & Keren-Portnoy, 2013) and Menn et al. (2013) and can be briefly summarised as follows. At birth, a baby's mind is like a blank slate linguistically. Individual experiences with vocalising and listening lead to first phonology and first words. Auditory experiences of speech lead to auditory memories, while vocalisations lead to motor memories. Similar memories are grouped together, i.e., motor memories arising from an individual's successive production of a particular word over time will be grouped together, while auditory word memories will be grouped together. Frequency of speech usage is important. Frequently produced vocalisations produce increasingly entrenched motor memories. Likewise, frequently heard speech produces increasingly entrenched auditory memories. When an individual goes to produce a word, they typically engage the most frequently used neuromotor memory used previously. For the infant

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developing typical speech, initially the basic phonological unit is the "word" or meaningful unit. Over time, representations for parts of words arise from sub-neural connections. Each time an individual hears a word or produces a word, words with similar speech sounds are aroused to an extent creating sub-networks of neurological representations. The mechanism by which generalisation occurs is surmised as the operation of this neural network. For example, change to an articulatory gesture in a treated word, such as /s/ in "see" will arouse other (untreated) words, such as "seat", "so". This leads to the updating of articulatory gestures in untreated words with time and practice. According to usage-based theory, the basic mechanisms for phonological change in the young child is the same as the mechanisms for change in the school-aged child/adult, i.e., speech usage in communicative contexts. The caveat is that the school-aged child or adult will have a greater number of existing motor and auditory memories onto which new speech experiences are associated, compared to a younger child. Another key concept of usage-based phonology is "gradience" (Bybee, 2001, 2010). This refers to the stepwise phonetic change with articulatory gestures than can come about over time. For example, realisation of the phoneme /tʃ/ in the word "chair" may show a stepwise change over time from [t] to [ts] then finally to [tʃ]. According to usage-based theory, this stepwise change occurs due to the gradual refinement of neuromotor and auditory memories with speech usage. Usage-based phonology contrasts with generative linguistic models and related constraint-based linguistic theory (Chomsky, 1972; Prince & Smolensky, 1997) which underlie much SSD therapy (Williams et al., 2010). Unlike usage-based theory, generative theory assumes a degree of innate, abstract language knowledge, present at birth.

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In this study, the authors used usage-based phonology theory, as summarised above, to formulate six novel therapeutic premises (see Table 1). Following on from these premises, teaching episodes were developed for this study and included:

1. High volume speech production, with the focus on single word production.
2. Specific feedback on articulatory gestures in words using EPG visual feedback.
3. Production of low frequency words in the early stages of therapy, followed by production of high frequency words in the later stages.

Insert Table 1 about here

Aim

The aim of this study was to investigate whether a novel EPG therapy, underpinned by usage-based phonological theory, could improve accuracy of target speech sounds for school-aged and adult participants with persistent SSD secondary to cleft palate +/- lip. Specific research questions were as follows:

1. Acquisition and lexical generalisation: Does the usage-based EPG technique improve accuracy of targeted phonemes in treated words post-therapy, and does this improved accuracy generalise to untreated words?
2. Functional generalisation/impact on quality of life: Does improved accuracy of target phonemes:
    a. generalise to continuous, connected speech, and
    b. result in improved ratings of speech understandability and speech acceptability and improved ratings of impact on quality-of-life, post-therapy?

Method

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Participants

Participants were recruited from a UK regional cleft lip and palate service. Inclusion criteria were: (1) persistent lingual speech sound difficulties secondary to cleft palate +/- lip (including submucous cleft palate), (2) unresponsive to at least two episodes or more of more widely available speech therapy in the past, (3) aged 7-years and over at the time of enrolment onto study, (4) suitable dentition so that an EPG plate could be fitted and worn during speech practice, (5) normal velopharyngeal function or mild signs of velopharyngeal insufficiency (VPI), and (6) no significant learning disabilities. The final study sample consisted of six participants. A flow chart of study recruitment is shown in Figure 1. Table 2 summarises the demographic information of the six participants.

Insert Figure 1 and Table 2 about here

Ethical approval

This study received ethical approval from the North West – Greater Manchester East Research Ethics Committee (17/NW/0235).

Design

A multiple baseline (ABA) within-participant design (Ebbels, 2017; Morley, 1994) was used. Following recruitment, participants underwent an initial assessment to identify target lingual speech sounds. Participants then completed three baseline assessments, at least 3-weeks apart to ensure speech sound errors were static (i.e., Phase A: No treatment). Participants were then offered weekly usage-based EPG therapy (i.e., Phase B: Treatment). All therapy was carried out by the first author, a speech-language pathologist. Individual speech sounds were worked on in turn at word level, i.e., speech target one was the focus

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of therapy at word level, before moving onto speech target two, and so on. Treatment continued until all speech sound targets were remediated and were being produced in the participant's everyday speech, or the participant's progress had plateaued, and no further gains were being seen. All auditory-perceptual speech assessment was made from video recordings. None of the participants received any other therapy for their speech for the duration on the study.

Target Selection

Initial assessment involved the Great Ormond Street Speech Assessment (Sell et al., 1999) and the phonological subtest of the Diagnostic Evaluation of Articulation and Phonology (Dodd et al., 2002). Table 1 summarises participants' main cleft speech characteristics at word level together with therapy speech targets.

Following initial assessment, a list of 16 treated and 16 untreated words for each speech sound produced in error was developed for each participant. Treated and untreated words were matched for word position, word length, vowels contained within the word, and word frequency. In terms of word frequency, for each of the 16 words, eight words were low frequency (i.e., occurring less regularly in the English language) and eight were high frequency (i.e., frequently occurring words in English). Low and high frequency words were established from a spoken and written word frequency corpus published by Leech et al. (2001). Words with a frequency of less than 100 (rounded frequency per million-word tokens) were classified as low frequency words, while words with a frequency of more than 100 were classed as high frequency words. Treated words were used in therapy, while untreated words were never used in therapy and were used to measure lexical generalisation and maintenance. The same word lists were used at each assessment point

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for direct comparison across assessment points. Word lists can be seen in the supplementary material (Table 4).

Therapy

The WinEPG system (Articulate Instruments Ltd, 2008), and Reading-style EPG palates (Wrench, 2007) were used in this therapy. In the first session the speech-language pathologist explained and demonstrated how the EPG system worked. EPG visual feedback was then used to facilitate more typical production of a problem speech sound. As an example of the visual feedback provided by EPG, Figure 2 shows an illustration of a lateral production of /s/, together with an illustration of a typical /s/ using EPG. Facilitation of more typical production of a target speech sound, with accompanying EPG feedback, occurred at word level in the space of one session. Initially, exact production was not a requirement; over the space of several sessions stepwise phonetic change was encouraged with word production. For example, initially a [t] for a /s/ target within a word might be accepted, then a heavily aspirated [t^h] accepted, before moving onto a [s]. The participants/participants' carers were counselled that these initial productions were intermediate steps towards a match with the adult realisation. Low frequency words were practiced to an accuracy of 80% (typical production, or very close approximation), before moving on to high frequency words. EPG feedback was gradually reduced with practice. When the participant was able to produce the target sound typically, or a very close approximation, at high frequency word level without EPG visual feedback, the research moved onto another target sound. Once all speech sounds were produced at word level without EPG feedback, practice moved onto production of the target sounds at connected sentence level. This therapy was drill-based and an average of 250 production trials (SD =

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14.85) occurred in each 50 to 60-minute therapy session. Throughout therapy, more typical productions were encouraged, while less typical productions were discouraged, in the manner of operant learning (Skinner, 1976). Initially this feedback was very specific, over time this feedback became less specific and less regular. Participants were expected to practice targets at home. This home practice included use of a portable EPG machine (Articulate Instruments Ltd, 2008).

Insert Figure 2 about here

Outcome Measures

Response to therapy was measured through auditory-perceptual transcription of speech, ratings of speech understandability and speech acceptability, ratings of quality of life and EPG metrics. EPG metrics and the outcomes from EPG assessment are reported elsewhere (Patrick, 2021). Perceptual speech, speech understandability/acceptability, quality of life measures reported in results are listed in Table 3.

Insert Table 3 about here

Two independent cleft specialist speech-language pathologists phonetically transcribed participants' production of untreated words and made a judgement of speech understandability and speech acceptability using scales developed by Henningsson et al. (2008) at the three baseline assessments and the two assessments post-therapy. These listeners were blind to assessment time-point. When transcribing production of untreated words, the independent speech-language pathologists made a tick beside words perceived as typical. Words perceived as inaccurate were phonetically transcribed using narrow phonetic transcription using symbols of the International Phonetic Association chart and its

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extensions [IPA] (2019). This phonetic transcription was used to calculate percentage of targets correct (%TC): Total number of target sounds correct was tallied and was then divided by the total number of target sounds in the word list. All phonemic errors and phonetic distortions were marked as incorrect, apart from dentalisation of alveolars or very mild interdental production of alveolars. Using Henningsson et al. (2008) 's scales, the speech-language pathologists rated speech understandability as: always easy to understand; occasionally hard to understand; often hard to understand; or hard to understand most of the time. Speech acceptability was graded as: normal; mild deviation; moderate deviation; or severe deviation. Parents and spouses completed the Intelligibility in Context Scale, ICS (McLeod et al., 2012) and the quality-of-life assessments were completed by the participants. Child participants completed the Speech Participation and Activities of Children, SPAA-C, questionnaire (McCleod, 2004). Participants aged 17-years and over completed the Quality-of-Life Instrument, QoL-dys (Piacentini et al., 2011). The QoL-dys is a patient-reported quality of life measure that was developed for adults with dysarthria. QoL-dys was selected in the absence of a quality-of-life measure for adults with articulation distortions and/or substitutions secondary to the cleft condition at the time this study was submitted for ethical approval. All other assessment measures (e.g., initial assessment, all assessment carried out during therapy) were completed by the treating speech-language pathologist and the first author. Percentage of targets correct in connected speech samples was calculated in the same manner as the untreated words: the connected speech sample was phonetically transcribed; the total number of target sounds correct was tallied and then divided by the total number of target sounds in the connected speech sample.

Statistical Analysis

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The magnitude of response to therapy was examined statistically using an effect size index. Effect sizes (*d*) for production of untreated words were calculated using an adaption of the standard mean difference described by Gierut et al. (2015). In this study, the difference between the mean of pre-therapy assessment of untreated words and the mean of post-therapy assessment of untreated words was divided by the pooled standard deviation for pre-therapy assessments. Effect size was designated as small (> 1.4), medium (> 3.6), or large (> 10.1) using the benchmarks proposed by Gierut et al. (2015) for children with "functional phonological disorders". These benchmarks were chosen in the absence of any benchmarks for cleft palate speech and were the closest benchmarks that could be found.

The Wilcoxon signed- rank test was used to determine any differences in number of target sounds correct in low frequency words versus number correct in high frequency words.

Reliability

Inter-rater agreement was calculated on a point-by-point basis. Percentage of agreement by the two independent listener's phonetic transcription of target sounds was 91.09%. Both independent speech pathologists transcribed and rated a random 20% of speech data at least one month following original transcription. Intra-rater agreement for phonetic transcription of target sounds was 92.08% for the first independent rater and 96.96% for the second. Inter-rater agreement for speech understandability and speech acceptability ratings was 60%. Lower levels of agreement with these scales means caution is needed in interpreting the speech understandability and speech acceptability ratings in this study. Twenty percent of the researcher's transcriptions and ratings were transcribed and rated by the two independent speech-language pathologists to produce inter-rater agreement for the treating speech-language pathologist. Percentage of agreement with transcription of

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target sounds was 89.75% with the first independent rater and 91.39% with the second rater. Intra-rater agreement for 20% of speech data for the researcher's transcription of target sounds was 97.07%.

Results

Figure 3 shows percentage of targets correct in untreated words at the three baselines and the two assessments post-therapy. Using the benchmarks described by Gierut et al. (2015), in this study large effect sizes occurred for 17/25 target sounds, medium effect sizes were shown for 7/25 target sounds and 1/25 target sounds showed a small effect size. Although based on functional phonological disorders, these benchmarks appeared reasonable descriptions of therapy gains for study participants.

Insert Figure 3 about here

Table 4 shows percentage of targets correct in the 2-minute connected speech sample of all participants at the three baselines, at assessment immediately post-therapy, then at assessment 3-months post-therapy. Use of target sounds in continuous connected speech ranged from 78.94 – 100% (M = 90.66%).

Insert Table 4 about here

Table 5 shows ICS scores (McLeod et al., 2012) for participants at initial assessment, baseline three, end of therapy and maintenance assessment. Table 6 and Table 7 shows independent speech-language pathologists' ratings of speech understandability and speech acceptability respectively at the three baselines, at completion of therapy and at maintenance assessment using scales devised by Henningsson et al (2008). Speech understandability/intelligibility in context relates to how well a listener can understand

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another person's speech in a particular communicative context (Hustad et al., 2015). Speech acceptability relates to how close an individual's speech is to their peers, or the degree to which a person's speech draws attention to itself, outside the context of the spoken message (Henningsson et al., 2008). All participants showed improved ratings of speech understandability and speech acceptability, apart from participant one.

In relation to quality-of-life, for two of the adults, speech sound difficulties were reported to be having a notable impact on their everyday functioning pre-therapy (score of 62/160 and 66/160 respectively). Post-therapy scores were reduced in the direction of improved quality-of-life (score of 41/160 and 22/160 respectively). For the third adult, quality-of-life was not particularly affected by this participant's speech sound disorder (score of 18/160 on initial assessment). The Speech Participation and Activities for Children, SPAA-C (McLeod, 2004) was administered to the three child participants. Two of the child participants reported that their SSD was not impacting on their everyday functioning in any way, and this situation was unchanged post-therapy. For the other child participant, quality-of-life was affected by this participants' SSD. Pre-therapy, this participant felt her talking was different to other people. She said she felt happy talking to her mum and dad, her best friend, and teachers, but did not like talking to less familiar people. Post-therapy, all ratings improved, and she reported that she felt happy with her speech in all speaking situations.

Insert Tables 5, 6, and 7 about here

Differences in percentage of targets correct in low frequency words and high frequency words was examined at word level (treated and untreated words) and connected speech level (2-minute connected speech sample). The Wilcoxon signed-rank test showed no difference in percentage of targets correct in production of low and high frequency words

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after five sessions (Z = -.53, p = .593) after ten sessions (Z = .00, p = 1.000) for all participants. However, a difference was shown in percentage of targets correct in low and high frequency words in connected speech towards the end of the acquisition stage of treatment. A Wilcoxon signed- rank test showed significant difference between percentage of targets correct in low and high frequency words (Z = -2.20, p = .028). This significant difference suggests participants had more difficulty producing target sounds in words occurring with high frequency in connected speech, compared to words occurring with low frequency during the acquisition phase of treatment.

Cumulative therapy (average production dosage per session x number of sessions) for participants treated within this research was: 3,750; 6,250; 6,000; 6,500; 8,250; and 5,000 respectively (see Figure 1). These figures do not include practice done at home.

Additional tables and figures relating to results can be found in supplementary material (adult participants' scores of the QoL-dys measure; differences in percentage targets correct for low frequency and high frequency words in treated and untreated words and in continuous connected speech).

Discussion

The aim of this study was to describe and evaluate participants' response to a novel usage-based EPG therapeutic technique. All participants acquired accurate or more accurate lingual speech sounds in untreated words following therapy. Further, all participants showed generalisation of target sounds to connected speech, though to varying degrees. Individual's use of target sounds in connected speech ranged from 78.94% - 100% (M = 90.66).

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Acquisition and lexical generalisation

Prior to therapy, all participants in the study had received many sessions of conventional speech therapy and had been unable to improve their speech production at sound level. For 5/6 participants in this study, this acquisition of target lingual speech sounds was rapid, with more typical speech production occurring in treated words within one to two sessions of therapy. Rapid acquisition of lingual speech sounds for some patients has been reported in EPG therapy studies involving individuals with cleft palate speech (Gibbon et al., 2001; Stokes et al., 1995; Whitehill et al., 1996), and with EPG therapy studies involving other client groups (Gibbon et al., 2003; Martin et al., 2007). For example, Gibbon et al. (2001) reported on 8/12 individuals with long-standing cleft palate speech who had more normal tongue-palate contact patterns for /t/ and /s/ following four sessions of EPG therapy. Martin et al. (2007) reported on an 18-year-old client with profound sensorineural hearing loss who achieved lexical generalisation of /t/ and /d/ within six sessions of EPG therapy. This study supports other authors (Cleland & Preston, 2000; Lee, 2021) who suggest the benefit of EPG over conventional speech therapy lies with the provision of specific, real-time information on tongue-palate contact.

Functional generalisation

The ultimate goal of any therapy for SSD is functional generalisation of target sounds, i.e., use of target sound/s in everyday, continuous speech, in all speech settings. Functional generalisation has proven problematic for individuals undergoing EPG, in the past (Cleland & Preston, 2020; Gibbon & Paterson, 2006; Lee et al., 2009). In this study, all participants showed generalisation of target sounds to continuous connected speech. Individual's use of target sounds in connected speech ranged from 78.94% - 100% (M = 90.66). These findings

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can be compared to Gibbon and Paterson's (2006) survey of 60 patients undergoing EPG therapy in Scotland, as previously described. In Gibbon and Paterson's survey, EPG therapy produced total success for 12.5 % of patients, moderate success for 41.1%, slight success for 19%, while 12.5% showed no change. Using Gibbon and Paterson's taxonomy for success, in this study 33% of participants showed total success (participants two and three), 50% showed near total success (participants one, five and six), 16% showed moderate success (participant four), while 0% showed no change.

According to ICS ratings, all participants could make themselves understood to people who were familiar to them (e.g., family), despite 5/6 participants having speech sound errors resulting in loss of phonemic contrast, and 2/6 having many affected consonants. This finding is in line with other research showing higher speech understandability scores for people familiar with the speaker (Flipsen, 1995; McLeod et al., 2012), and perhaps reflects consistency with participants' atypical speech sound production, so that familiar people can "tune into" their speech. Despite scores in the mid- to high- range for familiar listeners, improvements in ICS scores were shown on re-assessment post-therapy for all participants apart from participant one, i.e., the scale was sensitive to improvements with speech sound production for 5/6 participants.

Speech-language pathologists' rating of speech understandability and speech acceptability showed all participants had improved ratings post-therapy, apart from participant one. On baseline assessment, participant one's reduced understandability and acceptability was attributed to atypical speech sound productions (lateral production of lingual sibilants). Post-therapy reduced ratings were attributed to posterior nasal turbulence which for this participant had increased over the course of therapy. It could be speculated that improved

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midline frication for lingual sibilants increased intraoral air pressure, thereby influencing velopharyngeal closure, and manifesting in increased posterior nasal turbulence. It should be noted that lower levels of inter-rater were shown with the speech understandability and acceptability rating scales (60% inter-rater agreement). This suggests that the speech-language pathologists were applying slightly different criteria when using these scales, so caution is needed in extrapolating these findings. These scales may benefit from further development, e.g., better quantification of the descriptors used. Use of visual analogue scales and word recognition tests are alternatives to measurement of speech understandability and acceptability (Miller, 2013). However, these tools are also associated with lower inter- and intra-rater agreement (Miller, 2013). Lower agreement with different measures highlights the complexity of speech understandability and acceptability in terms of defining and measuring these holistic outcomes. Development of tools to measure these aspects of speech remains a challenge for researchers (Hustad et al., 2015; Miller, 2013; Whitehill et al., 2011; Yorkson et al., 1996).

Measurements of change to daily activities and general satisfaction with speech following therapy have been slow to appear in therapy studies involving people with cleft palate speech (Howard & Lohmander, 2011). However, over the past 10 to 15-years there has been a growing awareness of the importance of measurement of these wider outcomes with this client group (Howard & Lohmander, 2011). Consequently, quality-of-life measures have been developed for use with both children and adults with cleft palate +/- lip (e.g., Rees et al., 2016; Skirko et al., 2013; Sischo & Broder, 2011). In particular, the Velopharyngeal Insufficiency Effects on Life Outcomes (VELO) has been used to examine quality-of-life in patients with velopharyngeal insufficiency (VPI) secondary to the cleft

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condition (Skirko et al., 2013). Generally, studies suggest improvement with aspects of speech related to velopharyngeal function, such as resonance and nasal airflow, is associated with improved quality-of-life (e.g., Bruneel et al. 2019; Pedersen et al. 2021).

In this study, 2/3 children's reported quality-of-life was not particularly affected by their SSD as measured on the SPAA-C and reported quality-of-life was largely unchanged post-therapy. For one child (participant five) this may have been because her SSD was relatively mild. In addition, because of their age, these two children may have lacked ability to report their own feelings. If so, a proxy measure involving their parents may have been useful. For the third child, reported quality-of-life on the SPAA-C was notably affected by her SSD and reported quality-of-life improved following therapy. This child had the most extensive SSD of all three children and was also the oldest.

For the three adult participants, 2/3 (participant two and participant four) felt that their SSDs notably affected their quality-of-life, and both reported improved quality-of-life following therapy, as measured by the QoL-dys instrument (Piacentini et al., 2011). This improvement was most marked for participant four, who, for this case series, had the poorest outcome in terms of percentage of targets correct in connected speech. Pre-therapy, self-ratings of quality-of-life for the remaining adult were not overly affected by her SSD and this remained the case post-therapy. However, discussion with this participant's family indicated her SSD had notably impacted on her quality-of-life. Other quality-of-life instruments may have provided more sensitive measures, such as the recently developed CLEFT-Q (Wong Riff et al., 2019).

Support for the usage-based phonology theoretical model

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Participants' target speech sound acquisition, lexical generalisation, functional generalisation and related improvements with speech understandability /acceptability and quality-of-life are encouraging and provide some support for the theoretical model underpinning therapy. Specific aspects of the applied theoretical model anticipated to result in therapy gains included a high number of word production trials and manipulation of low and high frequency words.

High number of word production trials

The theoretical model predicts that any change with speech sound production will require speech production practice of words. It is assumed that auditory input on its own will not result in changes to speech production. This is because the usage-based model is a two-lexicon model, with each word having separate neuromotor and auditory memories (Bybee, 2001, 2010; Menn et al., 2013). Further, according to the theoretical model, articulatory gestures become increasingly entrenched with use (Bybee, 2001, 2010; Menn et al., 2013). Thus, the usage-based model also predicts that, in general, greater amounts of production practice will be needed for school-aged children and adults, compared with younger children.

This study involved a high dose of production trials within sessions (250, on average). Participants received between 15 – 33 sessions (M = 24) over a five to 16-month period (M = 9). Cumulative therapy (production dosage x number of sessions) for participants treated within this research ranged from 3,750 - 8,250 (M = 5,958, SD = 1,511). These figures do not include practice done at home. Thus, as predicted by the theoretical model, the school-aged and adult participants in this study required a large amount of production practice to achieve full/near generalisation of target sounds into continuous connected speech.

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At present, total cumulative therapy needed to remediate an SSD, whatever the aetiology, is largely unknown (Baker & McLeod, 2011; Sugden et al., 2018). The reason for this is two-fold. Firstly, SSD therapy studies, including cleft therapy studies, have rarely provided comprehensive details on dosage (Sugden et al., 2018). Secondly, few studies report of the entire duration of treatment, that is, from initial assessment to discharge (Baker & McLeod, 2011; Sugden et al., 2018). Hitchcock and colleagues (2019) examined treatment intensity in published reports of visual biofeedback therapy for SSD. Therapy included EPG, ultrasound, and visual acoustic biofeedback. Participants with a structural anomaly, e.g., cleft palate +/- lip, were excluded from this review. Cumulative therapy involving production trials could be calculated for 18 of the 29 studies and this ranged from 840 – 5,117. However, whether or not this represented total duration of therapy (i.e., therapy to discharge) was not stated in this analysis. These authors found a weak, but statistically significant, correlation between cumulative therapy and treatment outcomes, with higher cumulative therapy being correlated with better speech outcomes. Future cleft therapy studies, and SSD therapy studies in general, need to provide details of cumulative therapy, ideally for total duration of therapy (i.e., to discharge). In doing so, comparisons amongst therapy studies will be possible.

Word frequency

The usage-based model adopted in this study predicts speech targets in low frequency words (i.e., words occurring with low frequency in the English language) would be easier to learn compared with high frequency words (i.e., words occurring with high frequency in the English language). This is because low frequency words have less entrenched neuromotor memories, while high frequency words have highly entrenched neuromotor memories

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(Bybee, 2001, 2010; Menn et al., 2013; Vogel Sosa & Bybee, 2008). Consequently, in this therapy research, low frequency words were taught first, followed by high frequency words. This prediction of a word frequency effect contrasts with generative theory (Chomsky, 1968). Generative theory views a child's underlying lexical representation as innate and as approximating the target. Rules operate to produce surface forms (Chomsky, 1991). For example, a child who produces [ku] for "two" is assumed to have some kind of representation for [tu] in their mental lexicon, despite their misarticulation of the word. According to the generative stance, misarticulation occurs with the linking of the lexical representation and the depiction of the target sounds in the phonological system (Storkel, 2018). Thus, a word frequency effect would not be predicted by generative theory.

In this study, a significant difference was seen in percentage of targets correct in low versus high frequency words in connected speech samples for all participants during the acquisition and lexical generalisation phases. Participants were much more likely to produce high frequency words in error in continuous connected speech. This would suggest that a strong word frequency effect was operating in connected speech, and again provides some support for the theoretical model.

It was also predicted that high volume production of high frequency words in the later stages of therapy would advance generalisation. According to the usage-based model adopted in this research, words occurring with high frequency will have strong sub-neural connections with other word tokens (Menn et al., 2013). Applying this phonological theory, it is this sub-neural network that produces system-wide change, and consequently generalisation to non-treated tokens. Other research examining word frequency provides some support for use of high frequency words in boosting speech sound learning (Gierut &

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Morrisette, 2012; Gierut et al., 1999; Morrisette & Gierut, 2002). However, whether the generalisation seen in this study was facilitated by a focus on high frequency words at the later stage of therapy can't be determined with the current study's research design. Also, according to the usage-based theoretical model, any production practice will arouse similar speech tokens, thereby developing and updating the sub-network of representations. Since large volumes of production trials were executed by study participants per session it may be that sheer volume of production trials was the key factor in achieving generalisation and maintenance of speech change following therapy, rather than production of high frequency words at the later stages of therapy.

Usage-based phonology and motor learning theory

Recently, schema motor learning theory has been used as a theoretical rationale for visual feedback therapy such as EPG and ultrasound (Cleland & Preston, 2020). However, to date no published EPG intervention studies have utilised motor learning theory. The usage-based therapy used in this study has parallels with therapy motivated by schema motor learning theory (Maas et al., 2008). Both focus on the motor execution of speech and the need for a high number of production trials during therapy sessions. However, usage-based phonology theory differs from schema theory in several fundamental ways. In usage-based phonology theory, phonological units and speech learning emerges in a bottom-up way, from raw speech and hearing events (Bybee, 2001; Menn et al., 2013). In contrast, schema theory is a top-down model (Schmidt, 1975): Abstract, generalised motor programs (GMP) are converted to motor movements through the application of schemas. Schemas, which can be conceived as "rules", provide specific instructions to the musculature. According to this theory, schemas are refined progressively through practice. Such theoretical differences

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produce variances in the enactment of therapy. For example, schema theory suggests variable practice and errors in production are needed to refine schemas (and thus speech). In contrast, usage-based theory does not have such practice requirements. Rather block practice is indicated and no particular requirement for errors is needed.

Limitations and directions for further research

This was a single centre study, with all treatment carried out by a single, experienced, speech-language pathologist. Future studies need to involve other centres and other speech-language pathologists to establish if findings can be replicated. Since this was a within-participant study, findings cannot be directly generalised to wider populations. However, use of the effect size (standard mean difference) index (Gierut et al., 2015) permits across study comparisons with future studies, and use of this index is recommended.

The study's small sample size and participants' wide age-range (7- 27 years) should be noted when interpreting findings. Although participants' lexical generalisation and high levels of functional generalisation following intervention are encouraging, such results may not have occurred with larger numbers of participants.

In this study the same untreated word list was used at each assessment time-point. Although assessment occurred at least 5-weeks apart and many untreated words were included, production of untreated words may have been subject to a practice effect. Further research should consider using different untreated word lists at each assessment time-point.

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The treating speech-language pathologist and first author carried out a proportion of the assessment completed in this study, such as all phonetic transcription of initial assessments prior to baseline assessment. The treating speech-language pathologist achieved high levels of inter-rater agreement with the two independent speech-language pathologists with phonetic transcription. However, the potential for rater bias by the treating clinician should be noted. Further, lower levels of intra-rater agreement for the speech understandability and speech acceptability scales (60%) mean caution is needed when interpreting findings from these outcome measures.

At present whether the usage-based EPG technique is more efficacious than other EPG therapy is unknown. Further research could directly compare the usage-based EPG technique with conventional EPG therapy which utilises traditional articulation therapy (Lohmander et al., 2001; Gibbon et al., 2001) or with EPG therapy which utilises a schema motor learning theory approach (Preston & Leece, 2021).

As well as high volume practice, word frequency was posited as important for acquisition and generalisation. However, given the design of the current study, the importance of this variable could not be definitively established. Further research could manipulate word frequency by comparing use of high frequency word targets with use of low frequency word targets in the generalisation phases of the usage-based phonology treatment approach.

Conclusions

This paper reports on the first application of usage-based phonology to the treatment of cleft palate speech. Six consecutively treated school-aged children and adults with persistent SSD secondary to cleft palate responded to a novel usage-based EPG therapeutic

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technique, with functional generalisation occurring for all participants. This response to the therapeutic technique is encouraging and further research is indicated.

Declaration of interest

The authors report there are no competing interests to declare.

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Figure 1

Flowchart for patients assessed, excluded, treated and followed-up

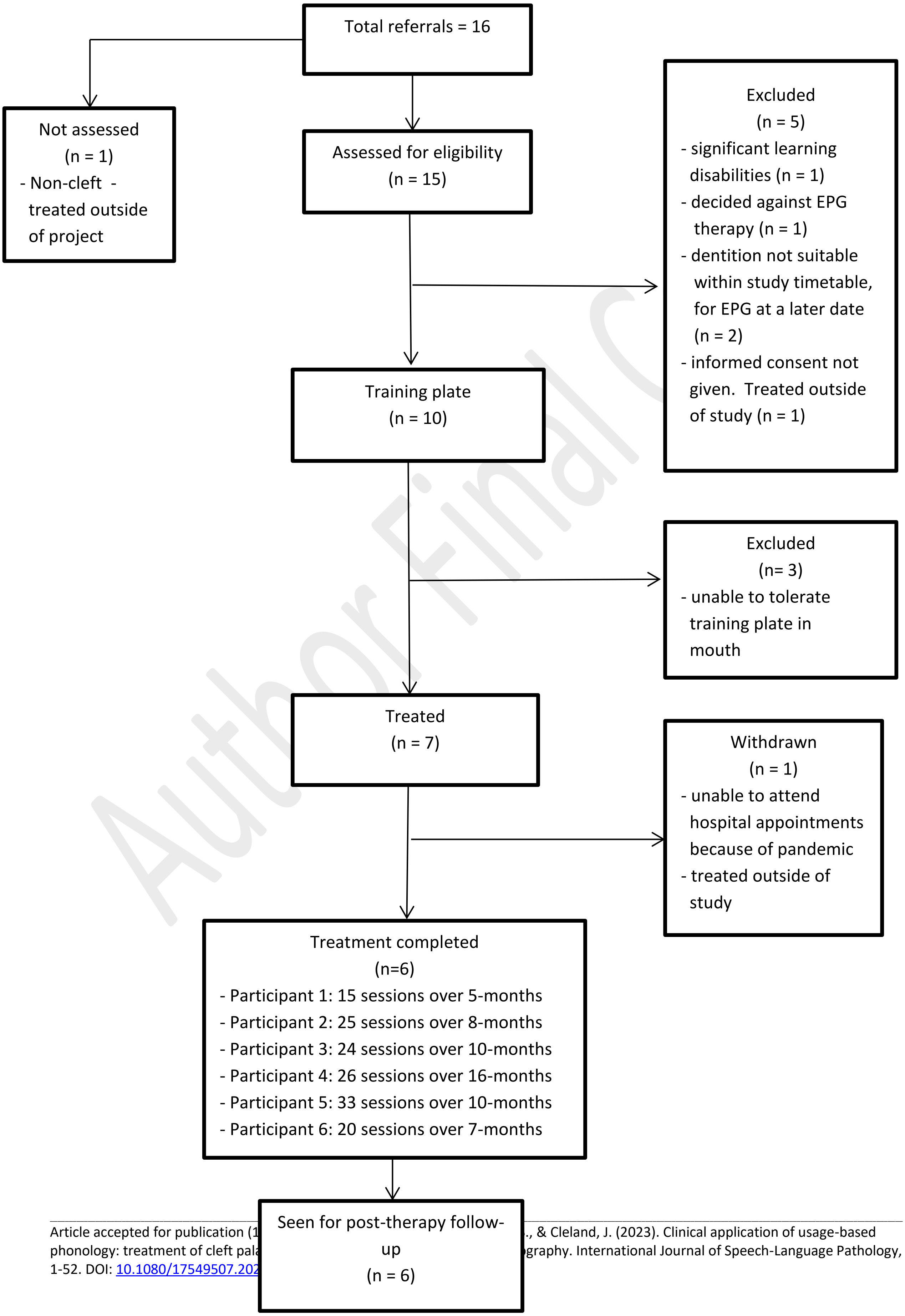

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Figure 2

Illustration of the visual feedback provided by EPG for lateral production of /s/ and typical production of /s/

Note: Black squares represent tongue-palate contact, white squares no contact. Lateral /s/ shows complete anterior contact, with no central flow of air.

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Figure 3

Percentage of targets correct in untreated words at B1, B2, B3, P, M assessments – from independent listeners' scoring (average score)

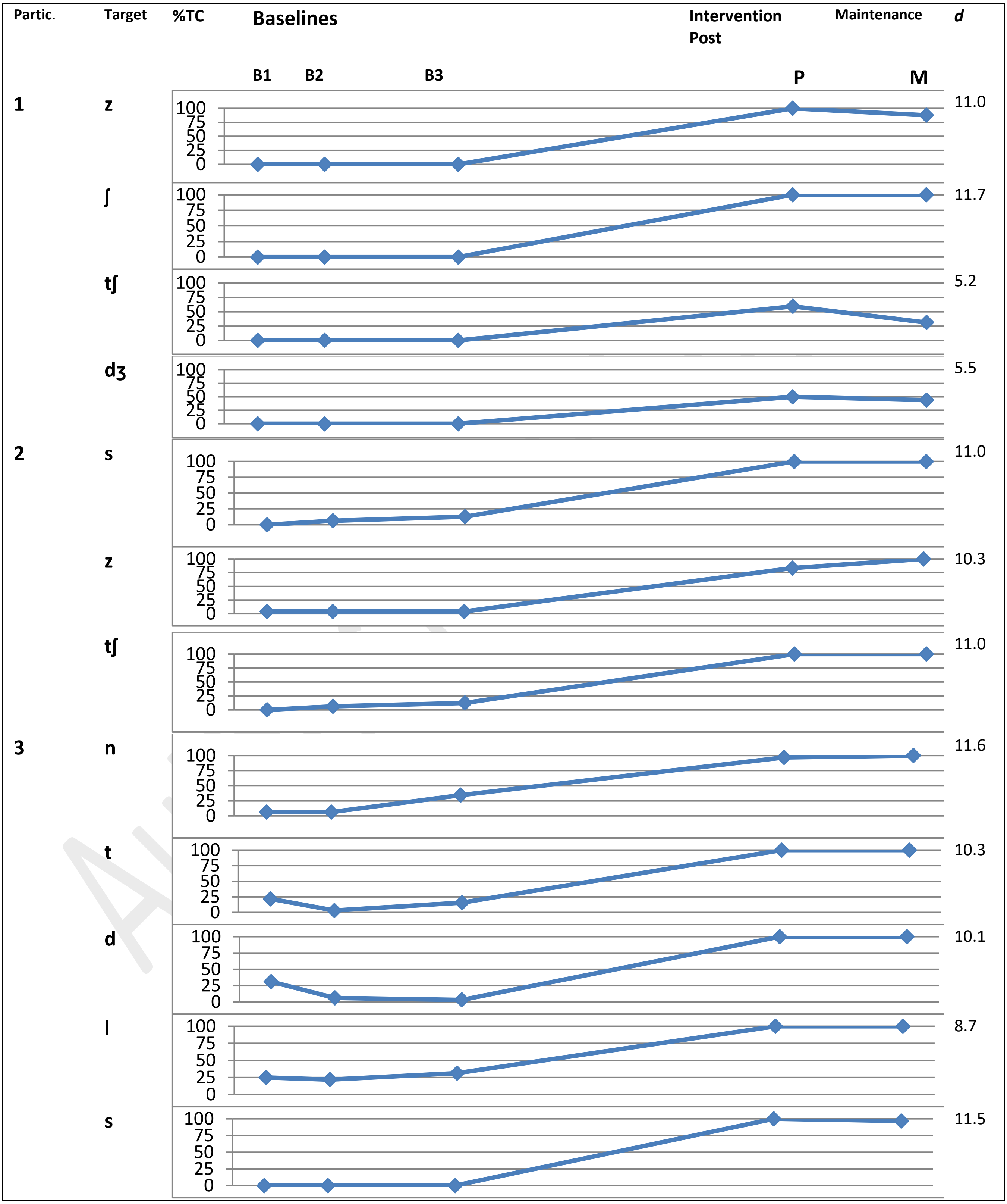

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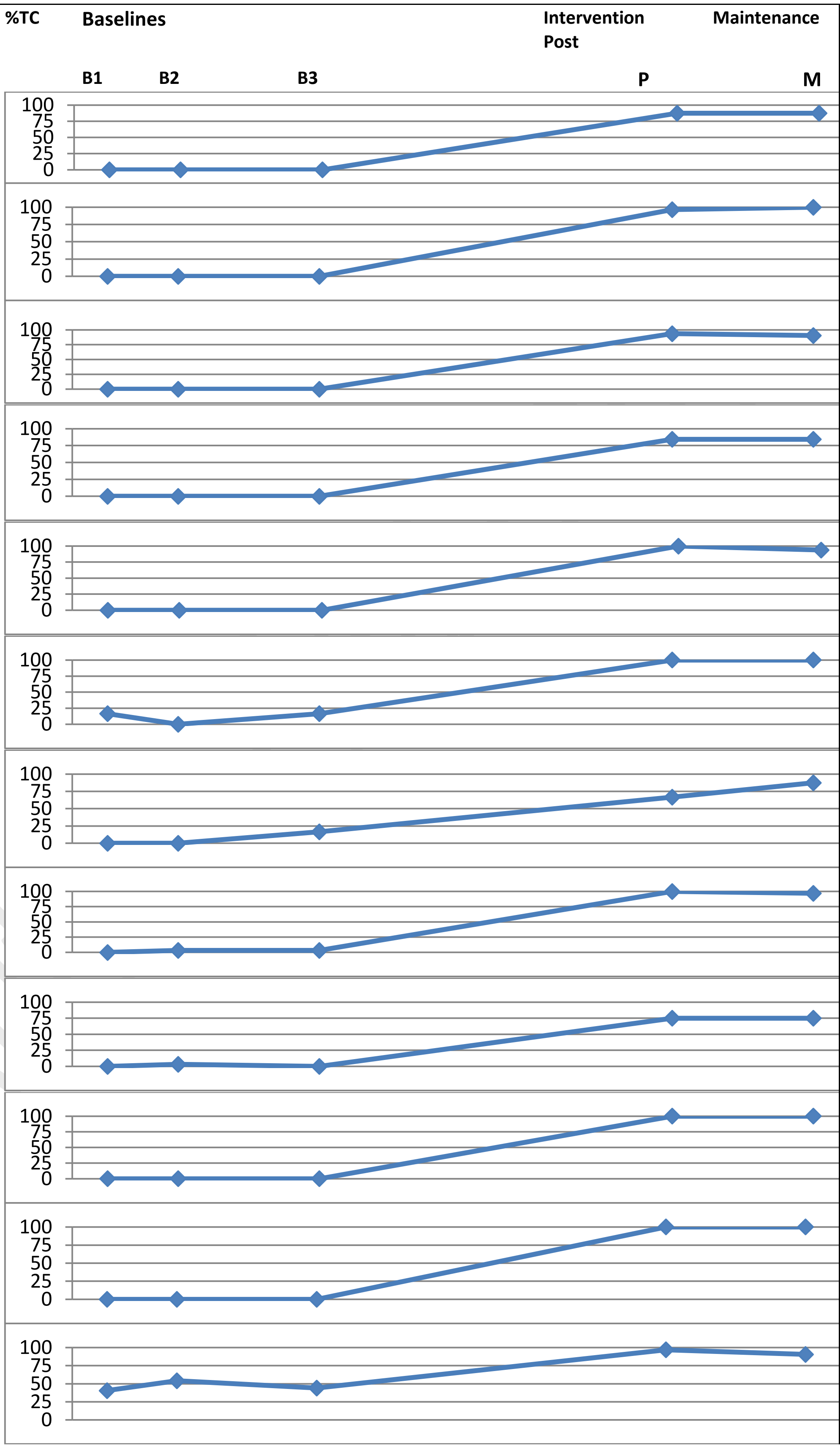
Figure 3 continued

Partic.	Target	d
3	z	10.3
	ʃ	11.5
	tʃ	10.8
	dʒ	9.9
4	s	11.1
	ʃ	10.4
	z	8.3
	tʃ	11.3
	dʒ	8.6
5	s	11.7
	z	11.7
6	n	5.6



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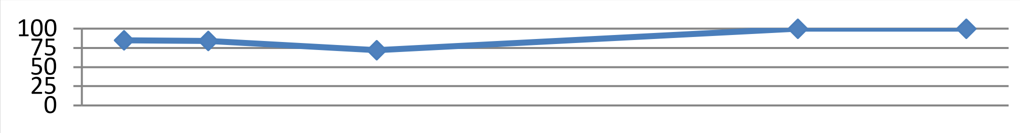
I		2.3

Note: Partic. = Particiants*;* %TC = Percentage of targets correct B1 = Baseline 1; B2 = Baseline 2; B3 = Baseline 3 immediately pre-therapy; P = Assessment immediately post intervention; M = Maintenance assessment 3-months post-intervention; *d* = Effect size.

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Table 1

Therapeutic premises and associated rationales derived from usage-based phonology theory (Bybee, 2001; 2010; Menn et al., 2013)

Premise	**Rationale**
Premise 1: Speech production practice is needed to achieve speech production change.	The usage-based model is a two-lexicon model with separate production and auditory memory traces.
Premise 2: The focus of therapy is with articulatory gestures and how to produce these in the vocal tract.	Speech output is the realisation of neuromotor memories for speech.
Premise 3: Meaningful word production is important.	Neuromotor and auditory memories are intrinsically linked to words/meaningful units.
Premise 4: A high dosage of production trials is needed for speech production change.	Neuromotor memories become increasingly entrenched with usage. Speech output will typically consist of the most frequently occurring neuromotor memory for a particular word or meaningful unit.
Premise 5: Generalisation of speech learning to untreated words and everyday speech can occur through production of treated words.	Change to articulatory gestures with treated words will activate sub-neural networks, leading to the updating of articulatory gestures in untreated words in a range of communicative contexts.
Premise 6: Manipulation of word frequency is facilitative.	Words occurring with low frequency have less entrenched neuromotor memories, while words occurring with high frequency will have highly entrenched neuromotor memories. Low frequency words may be easier to remediate in the early stages of therapy, while high frequency words may expedite generalisation in the later stages of therapy since high frequency words have stronger sub-neural links to other words.

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Table 2

Participants' demographic information, main cleft speech characteristics and therapy speech targets

Participant no.	Sex	Age	Diagnosis	Co-occurring diagnosis	Dental Occlusion	Main cleft speech characteristics at word level	Speech targets
1	M	10	Cleft palate		Class I (normal)	Lateral production of lingual sibilants	z, ʃ, tʃ, dʒ
2	F	20	Submucous cleft palate		Class II div I (mild)	Palatal production of /s/ and /z/	tʃ, s, z
3	F	11	Submucous cleft palate	22q1.1 deletion syndrome	Class I	Backing and lateral production of lingual speech sounds	n, l, t, d, s, z, ʃ, tʃ, dʒ
4	F	27	Unilateral cleft lip and palate		Class I	Non-oral production of lingual sibilants (pharyngeal fricatives)	s, z, ʃ, tʃ, dʒ
5	F	7	Cleft palate		Left-sided crossbite primary molars	Palatal production of /s/ and/z/	s, z
6	F	17	Unilateral cleft lip and palate		Class I	Backing of /n/ and /l/	n, l

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Table 3

Assessments used to measure response to therapy reported in this article

Assessment
Reading untreated word list (generating percentage of targets correct in untreated words)
2-minute spontaneous speech sample (generating percentage of targets correct in connected speech)
Intelligibility in Context Scale, ICS, (McCleod et al., 2012)
Speech Understandability and Speech Acceptability Scales (Henningsson et al., 2008)
Speech Participation and Activities of Children, SPAA-C (McCleod, 2004) – QoL measure for child participants
Quality of Life Instrument, QoL-dys (Piacentini et al., 2011) – QoL measure for young people and adult participants

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Table 4

Percentage of targets correct in continuous speech (2-minute connected speech sample) at baseline and post-therapy assessments

Participant	% Targets correct, baseline assessments (average of three baselines)	% targets correct, end of treatment assessment	% of targets correct, maintenance assessment
1	0	100	80
2	0	93.33	100
3	3.62	98.52	98.07
4	0	80	78.95
5	2.86	98.18	95
6	0	92	92

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Table 5

Intelligibility in context scale scores at assessment points (average score across seven different speaking conditions)

Participant	ICS score			
	Initial Assessment	Baseline 3	End of therapy	Maintenance
1	3.85	3.71	4.00	3.85
2	3.42	3.50	4.00	4.33
3	3.50	3.14	4.28	5.00
4	3.80	3.80	4.80	4.40
5	4.57	4.57	4.71	4.71
6	4.28	3.80	5.00	5.00

Note: ICS = Intelligibility in context; score of 3 = sometimes understood; score of 4 = usually understood; score of 5 = always understood.

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Table 6

Independent SLPs' ratings of participants' speech understandability (ratings from 2-minute connected speech sample) at B1, B2, B3, P and M

Participant	Independent SLP rating	Assessment				
		B1	B2	B3	P	M
1	SLP no. 1	Orange	Light green	Light green	Light green	Orange
	SLP no. 2	Orange	Light green	Light green	Light green	Orange
2	SLP no. 1	Orange	Orange	Orange	Green	Green
	SLP no. 2	Orange	Light green	Light green	Green	Green
3	SLP no. 1	Orange	Orange	Orange	Light green	Light green
	SLP no. 2	Light green	Orange	Orange	Light green	Green
4	SLP no. 1	Red	Red	Red	Light green	Light green
	SLP no. 2	Light green	Orange	Light green	Light green	Light green
5	SLP no. 1	Green	Green	Light green	Light green	Light green
	SLP no. 2	Green	Green	Light green	Green	Green
6	SLP no. 1	Green	Light green	Light green	Green	Green
	SLP no. 2	Green	Light green	Green	Green	Green

Note: SLP = Speech-language pathologist; B1 = Baseline 1; B2 = Baseline 2; B3 = Baseline 3 Immediately pre-therapy; P = Assessment immediately post-intervention; M = Maintenance assessment 3-months post-intervention; Green shading = Always easy to understand; Light green shading = Occasionally hard to understand; Orange shading = Often hard to understand; Red shading = Hard to understand most of the time.

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Table 7

Independent SLPs' ratings of participants' speech acceptability (ratings from 2-minute connected speech sample and single word production) at B1, B2, B3, P and M

Participant	Independent SLT	Assessment				
		B1	B2	B3	P	M
1	SLP no. 1					
	SLP no. 2					
2	SLP no. 1					
	SLP no. 2					
3	SLP no. 1					
	SLP no. 2					
4	SLP no. 1					
	SLP no. 2					
5	SLP no. 1					
	SLP no. 2					
6	SLP no. 1					
	SLP no. 2					

Note: SLP = Speech-language pathologist; B1 = Baseline 1; B2 = Baseline 2; B3 = Baseline 3 immediately pre-therapy; P = Assessment immediately post-intervention; M = Maintenance assessment 3-months post-intervention; Green shading = Normal acceptability; Light green shading = Mild deviation; Orange shading = Moderate deviation; Red shading = Severe deviation.

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Supplementary Material

Table 1

Adult participants' scores on the QoL-dys measure

Participant	**Scores on QoL- dys**		
	Initial assessment	Assessment immediately following therapy	Maintenance assessment
2	62	41	39
4	66	22	35
6	18	26	21

Note: QoL-dys = Quality of Life, Dysarthria instrument*;* 0 = Speech never impacts on everyday life; 160 = Maximum score where speech always impacting on life

Table 2

Differences in percentage targets correct for low frequency and high frequency words in treated and untreated words at A5 and A10 (Wilcoxon signed-rank test) for all participants (combined)

	Percentage of Targets Correct Mean			
Assessment	Low frequency words	High frequency words	Z score	p value
A5	57.64	58.77	-.53	.593
A10	88.00	88.63	.00	1.000

Note: A5 = Assessment end of five sessions; A10 = Assessment end of 10 sessions; Percentage of targets correct from all treatment targets for all six participants (research SLT transcription)

Table 3

Differences in percentage targets correct for low frequency and high frequency words in continuous connected speech sample (Wilcoxon signed-rank test) towards end of acquisition phase for all participants (combined)

Percentage of Targets Correct Mean			
Low frequency words (n = 85)	High frequency words (n = 93)	Z score	p value
84.48	39.53	-2.20	.028

Note: The 2-minute speech sample was elicited by asking the participants to recount what they had done the previous day, from getting up, to going to bed. The first 2-minutes of this sample was phonetically transcribed from video recordings. Words containing target sounds for each participant were identified and these were further categorised into low and high frequency words using the spoken and written frequency corpus published by Leech et al. (2001). Words with a frequency of less than 100 (rounded frequency per million word tokens) were classified as low frequency words, while words with a frequency of more than 100 were classed as high frequency words.

Table 4

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Treated and untreated word lists for all speech targets

Untreated	**Treated**
/s/ word initial high frequency Set (CVC) Save (CVC) Say (CV) So (CV)	/s/ word initial high frequency Sit (CVC) Same (CVC) See (CV) Soon (CVC)
/s/ word initial low frequency Sing (CVC) Suck (CVC) Soup (CVC) Sword (CVC)	/s/ word initial low frequency Sail (CVC) Sad (CVC) Soap (CVC) Sock (CVC)
/s/ word final high frequency Horse (CVC) This (CVC) Less (CVC) Force (CVC)	/s/ word final high frequency House (CVC) Face (CVC) Yes (CVC) Pass (CVC)
/s/ word final low frequency Mess (CVC) Boss (CVC) Dose (CVC) Lease (CVC)	/s/ word final low frequency Bus (CVC) Mouse (CVC) Nurse (CVC) Lace (CVC)

Untreated	**Treated**
/z/ word initial high frequency	/z/ word initial high frequency

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No high frequency targets available	No high frequency targets available
/z/ word initial low frequency Zone (CVC) Zack (CVC) Zipper (CVCV) Zebra (CVCCV)	/z/word initial low frequency Zoom (CVC) Zap (CVC) Zoe (CVCV) Zero (CVCV)
/z/ word final high frequency Does (CVC) Was (CVC) His (CVC) As (VC)	/z/ word final high frequency Days (CVC) Those (CVC) Is (VC) Has (VCV)
/z/ word final low frequency Toes (CVC) Cheese (CVC) Keys (CVC) Shoes (CVC)	/z/ word final low frequency Nose (CVC) Knees (CVC) Bees (CVC) Rose (CVC)

Untreated	**Treated**
/tʃ/ word initial high frequency	/tʃ/ word initial high frequency

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Choose (CVC) Chance (CVCC) Charge (CVC) Check (CVC)	Choice (CVC) Child (CVCC) Church (CVC) Change CVCC)
/tʃ/ word initial low frequency Chip (CVC) Chew (CV) Chase (CVC) Cheek (CVC)	/tʃ/ word initial low frequency Chin (CVC) Chair (CV) Cheese (CVC) Chain (CVC)
/tʃ/ word final high frequency Reach (CVC) Such (CVC) March (CVC) Each (CV)	/tʃ/ word final high frequency Teach (CVC) Much (CVC) Watch (CVC) Which (CVC)
/tʃ/ word final low frequency Punch (CVCC) Rich (CVC) Touch (CVC) Fitch (CVCC)	/tʃ/ word final low frequency Lunch (CVCC) Beach (CVC) Search (CVC) Pitch (CVCC)

Untreated	**Treated**
/ʃ/ word initial high frequency	/ʃ/ word initial high frequency

Short (CVC) Share (CV) Show (CV) Shall (CVC)	Shop (CVC) She (CV) Shown (CVC) Should (CVC)
/ʃ/ word initial low frequency Ship (CVC) Shape (CVC) Shut (CVC) Shock (CVC)	/ʃ/ word initial low frequency Sheep (CVC) Shine (CVC) Shed (CVC) Shirt (CVC)
/ʃ/ word final high frequency Wish (CVC) Publish (CVCCVC) British (CCVCVC)	/ʃ/ word final high frequency Fish (CVC) English (VCCVC) Finish (CVCVC) (no other high frequency words available)
/ʃ/ word final low frequency Harsh (CVC) Rush (CVC) Punish (CVCV) Ash (VC)	/ʃ/ word final low frequency Wash (CVC) Bush (CVC) Polish (CVCV) Cash (CVC)

Untreated	**Treated**
/dʒ/ word initial high frequency James (CVCC)	/dʒ/ word initial high frequency Just (CVCC)

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John (CVC) June (CVC) January (CVCCVCVCV)	Job (CVC) Join (CVC) July (CVCV)
/dʒ/ word initial low frequency Jet (CVC) Jaw (CV) Joke (CVC) Jam (CVC)	/dʒ/ word initial low frequency Jane (CVC) Jar (CV) Juice (CVC) Jump (CVCC)
/dʒ/ word final high frequency Charge (CVC) Stage (CCVC) Range (CVCC) Manage (CVCVC)	/dʒ/ word final high frequency Large (CVC) Page (CVC) Change (CCVC) Village (CVCVC)
/dʒ/ word final low frequency Judge (CVC) Merge (CVC) Rage (CVC) Age (VC)	/dʒ/ word final low frequency Hedge (CVC) Lodge (CVC) Ridge (CVC) Cage (CVC)

Untreated	**Treated**
/s/ consonant cluster word initial high frequency Smile (CCVC)	/s/ consonant cluster word initial high frequency Small (CCVC)

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Star (CCV) Step (CCVC) Space (CCVC)	Stay (CV) Start (CCVC) Speak (CCVC)
/s/ consonant cluster word initial low frequency Sleeve (CCVC) Score (CCV) Spin (CCVC) Smoke (CCVC)	/s/ consonant cluster word initial low frequency Sleep (CCVC) Sky (CCV) Spell (CCVC) Snake (CCVC)
/s/ consonant cluster word final high frequency Must (CVCC) Task (CVCC) Rest (CVCC) Used (CVCC)	/s/ consonant cluster word final high frequency Best (CVCC) Last (CVCC) Most (CVCC) It's (VCC)
/s/ consonant cluster word final low frequency Least (CVCC) Mix (CVCC) Dust (CVCC) Knives (CVCC)	/s/ consonant cluster word final low frequency Missed (CVCC) Pigs (CVCC) Lost (CVCC) Laughs (CVCC)

Untreated	**Treated**
/t/ word initial high frequency Tell (CVC) Town (CVC)	/t/ word initial high frequency Ten (CVC) Top (CVC)

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Take (CVC) Time (CVC)	Talk (CVC) Two (CV)
/t/ word initial low frequency Tin (CVC) Ton (CVC) Toe (CV) Tea (CV)	/t/ word initial low frequency Tail (CVC) Tap (CVC) Tall (CVC) Tie (CV)
/t/ word final high frequency Light (CVC) But (CVC) Meet (CVC) Put (CVC)	/t/ word final high frequency Let (CVC) That (CVC) It (CV) Might (CVC)
/t/ word final low frequency Nut (CVC) Bite (CVC) Boat (CVC) Hurt (CVC)	/t/ word final low frequency Hut (CVC) Bat (CVC) Boot (CVC) Dot (CVC)

Untreated	**Treated**
/d/ word initial high frequency Done (CVC) Door (CV) Do (CV)	/d/word initial high frequency Date (CVC) Day (CV) Did (CVC)

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Dog (CVC)	Dark (CVC)
/d/ word initial low frequency Deep (CVC) Doll (CVC) Dig (CVC) Dock (CVC)	/ d/ word initial low frequency Dip (CVC) Dot (CVC) Dish (CVC) Duck (CVC)
/ d/ word final high frequency Need (CVC) Good (CVC) Would (CVC) Bad (CVC)	/d/ word final high frequency Did (CVC) Could (CVC) Made (CVC) Bed (CVC)
/d/ word final low frequency Mad (CVC) Bid (CVC) Card (CVC) Fade (CVC)	/d/ word final low frequency Mud (CVC) Bird (CVC) Code (CVC) Feed (CVC)

Untreated	**Treated**
/l/ word initial high frequency Lie (CV) Late (CVC) Learn (CVC)	/l/ word initial high frequency Lay (CV) Lead (CVC) Lot (CVC)

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Live (CVC)	Leave (CVC)
/l/ word initial low frequency Lap (CVC) Lid (CVC) Lock (CVC) Loud (CVC)	/l/ word initial low frequency Lamb (CVC) Lane (CVC) Log (CVC) Lawn (CVC)
/l/ word final high frequency Feel (CVC) Well (CVC) Goal (CVC) Feel (CVC)	/l/ word final high frequency Fill (CVC) Tell (CVC) Call (CVC) Fill (CVC)
/l/ word final low frequency Tall (CVC) Ball (CVC) Bull (CVC) Tail (CVCVC)	/l/ word final low frequency Doll (CVC) Bowl (CVC) Dull (CVC) Said (CVCVC)

Untreated	Treated
/n/ word initial high frequency New (CV) Name (CVC) Nice (CVC)	/n/ word initial high frequency No (CV) Night (CVC) Nine (CVC)

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Note (CVC)	Not (CVC)
/n/ word initial low frequency Nurse (CVC) Noise (CVC) Nut (CVC) Neat (CVC)	/n/ word initial low frequency Nose (CVC) Nerve (CVC) Net (CVC) Near (CV)
/n/ word final high frequency An (CV) Fine (CVC) Than (CVC) When (CVC)	/n/ word final high frequency On (CV) One (CVC) Then (CVC) Man (CVC)
/n/ word final low frequency Born (CVC) Bean (CVC) Fun (CVC) Burn (CVC)	/n/ word final low frequency Bone (CVC) Bin (CVC) Fan (CVC) Pan (CVC)

C = consonant; V = vowel

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