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Electropalatographic therapy for children and young people with Down's syndrome

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Abstract
Articulation disorders in Down's syndrome (DS) are prevalent and often intractable. Individuals with DS generally prefer visual to auditory methods of learning and may therefore find it beneficial to be given a visual model during speech intervention, such as that provided by electropalatography (EPG). In this study, participants with Down's syndrome, aged 10:1 to 18:9, received 24 individualized therapy sessions using EPG. Simultaneous acoustic and EPG recordings were made pre- and post-intervention during 10 repetitions of a word list containing lingua-palatal consonants. Participants also completed the DEAP phonology sub-test at both time points. Post-treatment, all participants showed qualitative and quantifiable differences in EPG patterns and improvements in DEAP percentage consonants correct. EPG assessment and therapy appears a positive approach for identifying and improving articulatory patterns in children with DS.

Keywords: *Down's syndrome, electropalatography, intervention*

Introduction

Down's syndrome (DS) is the most common cause of intellectual impairment, affecting one in every 732 live births (Canfield, Honein, Yuskiv, Xing, Mai, Collins, Devine, Petrini, Ramadhani, Hobbs, and Kirby, 2006). Recent research suggests that in relation to their non-verbal mental age, people with DS present with deficits in expressive speech and language, and strengths in vocabulary comprehension (Chapman, 2006). Intelligibility of speech is a particular issue in DS (Rondal and Edwards, 1997). A survey of 937 families by Kumin (1994) found that over 58% of parents reported that their children frequently had difficulty being understood by people outside of their immediate circle, with a further 37% having difficulty being understood at least some of the time. People with DS present with a specific physiological and anatomical profile, including a smaller than average oral cavity (which gives the impression of a larger tongue), hypotonia of muscles around the mouth, fusion of lip muscles, and extra lip musculature (Spender, Dennis, Stein, Cave, Percy, and

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Reilly, 1995; Miller, Leddy, and Leavitt, 1999). All of these features may affect the ability to create the precise articulations required for clear speech.

In addition to the anatomical differences, people with DS perform poorly in most areas of motor functioning (Frith and Frith, 1974; Spender et al., 1995; Spano, Mercuri, Rando, Panto, Gagliano, Henderson, and Guzzetta, 1999) and specifically in speech motor control (Kumin, 1994). In a study by Barnes, Roberts, Mirrett, Sideris, and Misenheimer (2006), boys with DS showed significantly lower levels of lip, tongue, velopharynx, larynx, and coordinated speech function than typically-developing boys matched for non-verbal mental age, and lower levels of coordinated speech movements than boys with Fragile X (another common cause of intellectual disability), also matched for non-verbal mental age. This suggests that impaired motor function is not due to cognitive delay, but is a syndrome-specific impairment, which may lead to speech disorder. In their study of 15 children and young people with DS, Cleland, Wood, Hardcastle, Wishart, and Timmins (in press) show that the speech disorder in DS is not related to cognitive or language level.

There have been many studies which have suggested that speech difficulties in DS are a result of a phonological delay (e.g. Stoel-Gammon, 1980; Van Borsel, 1996). Others have suggested a phonological delay with some elements of disorder, following an idiosyncratic developmental pattern, different from typical speakers (Roberts, Long, Malkin, Barnes, Skinner, Hennon, and Anderson, 2005; Timmins et al., 2009). Alternatively, recent evidence from Kumin (2006) showed that the majority of children with DS showed signs of dyspraxia (childhood apraxia of speech), although this disorder is rarely diagnosed in DS. Clearly more research is needed to clarify the exact nature and origin of the speech disorder in DS in order to design appropriate interventions.

The speech disorder in DS is severe and specific, yet despite this there are limited studies investigating speech therapies to improve the speech of individuals with DS. In one intervention study, Dodd, McCormack, and Woodyatt (1994) focused on increasing consistency in the phonological systems of children with DS. Children were encouraged to produce key vocabulary consistently, with parents being instructed to reinforce productions irrespective of whether it was or was not adult-like, as long as the child said the target the same way each time. The aim of this approach was to stabilize incomplete phonological representations. Once inconsistency has been eliminated from the child's system it is then possible to use more traditional phonological therapy techniques, such as minimal pairs, to eliminate remaining delayed or disordered phonological processes. In this small study, four children with DS showed a significant improvement in both consistency and percentage consonants correct, demonstrating that speech difficulties in DS can be addressed.

Most types of speech intervention rely heavily on auditory skills, in that clients must listen to their own productions and modify them using auditory cues. Speech intervention which uses visual feedback may benefit people for whom visual skills are stronger than auditory skills, with visual feedback potentially most useful when the target articulation is hard to describe or see. It is well documented that the visual skills of individuals with DS are generally superior to auditory skills (Buckley and Bird, 1993). This is especially relevant for children with DS who are likely to have language impairments more severe than their level of cognitive impairment. By actually showing the child the required articulation, the need to describe it using complex language is negated. One visual feedback technique which is potentially useful for this client group is electropalatography (EPG). EPG is a relatively non-invasive technique which visually displays the timing and location of the tongue's contact with the hard palate during speech. Although the patterns produced will vary both between and within speakers, all lingua-palatal consonants have identifiably similar patterns, at least in typical adults.

McLeod and Roberts (2005) give templates for the 10 lingua-palatal consonants of English, based on recordings from eight typical Australian adults. Patterns such as these can be used as model articulations, enabling EPG to be used for visual feedback therapy. During therapy sessions, a target articulation pattern characteristic of a particular speech sound is displayed on the right hand side of a computer screen and the client attempts to copy this correct articulation by monitoring their own contact patterns in real time which are shown alongside the model, on the left hand side of the same screen.

EPG has been successfully used in the assessment and treatment of a range of speech disorders such as cleft palate, apraxia of speech, functional articulation disorders, cerebral palsy, and hearing impairment (Hardcastle and Gibbon, 1997). However, only one case study of its therapeutic use with DS has been reported. Gibbon, McNeill, Wood, and Watson (2003) used EPG to assess and treat the speech disorder of one 10-year old child with DS. This particular child presented with velar fronting, whereby velar stops /k, g, ŋ/ were produced at a more anterior place of articulation, [t, d, n]. EPG assessment showed that both alveolar and velar phonemes were produced with identical alveolar patterns. After 14 weeks of therapy, 87% of velar targets were produced with appropriate EPG patterns and were perceptually correct. This illustrates that EPG has the potential to be an effective tool for remediating speech disorders in children with DS, at least in the case of velar fronting.

This paper extends this earlier work to a larger group of children and young people with Down's syndrome. We aimed to determine whether measurable improvements were evident following intervention targeting a range of lingua-palatal consonants. Previous reports of EPG therapy in the literature have selected participants on the basis of expert opinion, that is, children were specifically chosen if their clinicians believed they were likely to benefit from this type of therapy. Moreover, EPG is usually only used with clients for whom more traditional types of therapy have failed (Hardcastle and Gibbon, 1997). The aim of this study was to determine whether EPG was likely to be of benefit to children with DS more generally. Almost all children with DS have some degree of speech delay/disorder (Kumin, 1994). Children were therefore recruited for this study on the basis that they had DS, difficulty with lingual consonants, and reduced intelligibility (as reported by their parents). From parent reports, none of the children had previously received intensive speech therapy.

Method

Participants

As part of a larger study, 27 participants were randomly allocated to three groups: EPG therapy, traditional speech therapy, or a control group which received no therapy. Some of the participants who took part in the study were members of a database of individuals with DS whose families were willing to take part in research projects. Other participants were recruited by advertising the study via a national charity. Since the participants were required to attend a large number of times (for the intervention phase of the project), the group may represent those children and young people for whom intelligibility is a particular issue and who were able to commit to an intervention programme. Most participants had undergone recent audiological testing which confirmed their hearing status. However, to confirm adequate speech perception ability, all participants also completed and passed (scores >83%) the Manchester Picture Test (Hickson, 1987).

Participants were excluded if any of the following criteria applied: (1) English was not the first language and/or not the main language of the home; (2) cognitive abilities were less than

3 years as assessed by the WPSSI (Wechsler, 2003); (3) there was evidence of severe hearing loss (aided threshold of 40 dB or better); (4) the participant was not able to use single words (i.e. no speech); or (5) there was a co-morbid diagnosis of autism.

This paper presents the progress made in therapy of the first six participants with DS randomly assigned to the EPG therapy group. All were living in the central belt of Scotland. The participants were five males and one female aged 10;1 to 18;9 (Mean 12.74, SD = 3.14).

All six participants had custom-made electropalatography palates (EPG palates) and they underwent a programme of acclimatization whereby they wore the palate for increasing periods of time up to 40 minutes, and for at least 2 hours in total, prior to the first recording (the actual EPG recording was no longer than 30 minutes). Palates were worn for no longer than 40 minutes during therapy sessions.

Pre-therapy assessments

Language, speech, and cognitive assessments. The participants completed a battery of standardized speech, language, and cognitive assessments prior to intervention. Speech and language tests were carried out by a speech and language therapist; cognitive assessments were carried out by a child psychologist. Most participants completed the battery in three, 1-hour sessions, with breaks as requested by either the participant or their carer. In order to accommodate the severe language and cognitive impairment typical of DS, in most cases the assessments used were standardized on much younger children. Age equivalent scores, raw scores, and percentages were therefore used in the analyses.

Cognitive ability. Cognitive ability was assessed using the full form of the Wechsler Preschool and Primary Scale of Intelligence (WPPSI-IIIUK, Wechsler, 2003) and age equivalents (mental ages) were calculated.

Receptive vocabulary. The British Picture Vocabulary Scales-II (BPVS-II, Dunn, Dunn, Whetton, and Burley, 1997) were used as a measure of receptive vocabulary. This assessment covers a wide age range. It is a multiple-choice test in which participants must select one of four pictures to match a single word spoken by the tester.

Receptive and expressive language. The Clinical Evaluation of Language Fundamentals-Preschool UK (CELF-P, Wiig, Secord, and Semel, 1992) was used to measure receptive and expressive language. This test allows calculation of receptive, expressive, and general language age equivalents.

Oromotor function. Oromotor function was assessed using the Robbins and Klee (1987) clinical assessment of oropharyngeal motor development in young children (RK). In this assessment, children are required to perform speech and non-speech oral movements, which are scored as either adult-like (2 points), approaching adult-like (1 point) or absent (0). Raw scores were converted to percentages.

Pre- and post-therapy measures

EPG measures. Each child was recorded reading a list of eight items, 10 times: 'a toe, a sun, a clock, a sheep, a chicken, a red car, a slipper, a helicopter'. Of the six participants, five had therapy primarily targeting sibilants and one had therapy primary targeting correct production of velars. In order to assess improvement in sibilants, attempts at the fricatives in 'a sun' and 'a sheep' were annotated. An EPG frame from the midpoint of each fricative was extracted and used for a qualitative visual analysis. In addition a variability index score (Farnetani and Provaglio, 1991) was calculated from the midpoint of the annotations. A pilot study showed no difference between measurements taken from midpoints and those taken from maximum frames of contact. Annotations were made from both the acoustic and EPG information. The Variability index is a measure of percentage frequency of activation of each EPG contact across repetitions. The index ranges from 0%, which is complete invariance, that is maximum stability, to 50%, which is maximum variance. Higher numbers therefore indicate less stable EPG patterns. It was hypothesized that EPG therapy would lead to increased stability and therefore reduced variability, in conjunction with an improvement in accuracy.

To assess improvement in velars, a further word list of 20 words containing /k/ in all word positions and 18 containing /g/ in all word positions was recorded pre- and post-therapy for the child who received therapy targeting velars. Closures were annotated and the midpoint found. In some cases a velar stop is audible but EPG shows incomplete closure due to closure being made posterior to the EPG palate. In these cases annotations were based on listener identifications and the presence of narrowing of contact at the back of the palate (Dagenais, Lorendo, and McCutcheon, 1994). Again an EPG frame from the midpoint of each fricative was extracted and used for a qualitative visual analysis. Centre of gravity (COG: Gibbon, Dent, and Hardcastle, 1993) values were calculated for each annotation. COG is a measure of whether the greatest concentration of activation is more anterior (usually more /t/-like) or posterior (usually more /k/-like). High values indicate anterior contact, low values indicate posterior contact.

Perceptual measures. Pre- and post-therapy the participants completed the phonology sub-test of the Diagnostic Evaluation of Articulation and Phonology (DEAP, Dodd, Hua, Crosbie, and Holm, 2002). Participants were wearing their EPG palates at the time of the recording. This test is a measure of consonant production in 50 single words, covering most consonants of English in word initial and final positions. The phonology sub-test allows calculation of percentage consonants correct (PCC), percentage vowels correct (PVC), percentage phonemes correct (PPC), and single words/connected speech phoneme agreement (SvC). Simultaneous audio and EPG recordings were made to allow for fine phonetic transcription. Table I shows the group results for the pre-therapy measures, with numbers expressed as age equivalents or percentages as appropriate. Most of the children failed to meet the basal age equivalent on the DEAP (3 years), with the result that mean age equivalents (AE) could not be calculated for this test; raw scores were therefore used in analyses.

In order to determine which consonants should be the focus of therapy, all errors produced in the phonology sub-test of the DEAP were subjected to a process analysis. Although all of the participants' errors were described in terms of process analyses, this does not necessarily suggest that the errors are a result of a phonological impairment. While some errors were thought to be phonological in nature, for example fronting of /k/ to [t], other processes were phonetic in nature, for example, lateralization of sibilants. To determine which errors were most likely to impact on speech, any error occurring less than three times in the DEAP was discounted (Dodd et al., 2002). Since EPG is only useful for remediating errors related to lingua-palatal consonants, any errors which affected non-lingua-palatal consonants were also discounted. This left a smaller set of errors from which therapy targets could be determined.

Table I. Pre-therapy assessment results.

			DEAP %						CELF			WPPSI AE	
Child	Sex	Age	PCC	PVC	PPC	SvC	CSIM %	BPVS AE	CELFE	CELFC	RK%	VAE	PAE
1	F	11;7	67	95	77	67	72	5;5	3;0	3;11	78.85	4;8	6;4
2	M	10;1	38	56	44	60	32	3;0	2;9	3;5	66.35	3;11	4;5
3	M	10;11	70	92	79	50	66	5;2	3;6	4;2	81.73	>5;1	>5;9
4	M	10;2	66	91	75	56	84	6;10	4;5	3;10	90.38	<4;0	>5;5
5	M	14;11	59	75	65	64	46	7;3	4;0	4;10	69.23	5;7	>7;2
6	M	18;9	81	96	86	67	81	4;3	3;5	4;0	81.73	5;3	<4;1
Mean		12.74	63.50	84.17	71.00	60.67	63.56	5.35	3.58	4.13	78.04		
SD		3.14	14.40	15.77	14.87	6.74	20.57	1.45	0.59	0.51	8.88		

DEAP = Diagnostic Evaluation of Articulation and Phonology; PCC = Percentage Consonants Correct; PVC = Percentage Vowels Correct; PPC = Percentage Phonemes Correct; SvC = Single Word/Connected speech agreement; CSIM = Children's Speech Intelligibility Measure, % correctly identified words; BPVS = British Picture Vocabulary Scale-II; CELF = Clinical Evaluation of Language Fundamentals-Preschool UK; CELFE = CELF Expressive Language; CELFC = CELF Receptive Language; RK = Robbins and Klee Clinical Assessment of Oropharyngeal Motor Development in Young Children; WPPSI = Wechsler Preschool and Primary Scale of Intelligence-3UK; VAE = Verbal Age Equivalent; PAE = Performance Age Equivalent.

Intelligibility. The Children's Speech Intelligibility Measure (CSIM, Wilcox and Morris, 1999) was chosen as a measure of intelligibility pre- and post-therapy. The test involves a listener who is unfamiliar with the participant listening to 50 imitated words and identifying which word was uttered from a possible 12 phonetically-similar words (for each of the 50 words). Percentage of correctly identified words was calculated. Since the wearing of an EPG palate may affect intelligibility slightly, the participants were not wearing their palates during the recording of the CSIM. As this test is not standardized on typical children, no age equivalents were available.

Therapy

Each participant received 24, 1-hour long, sessions of individualized therapy, using EPG as visual feedback. Participants attended the clinic twice a week over a period of ~ 12 weeks with a parent or carer. Each participant was given a portable training unit and individualized homework exercises and was instructed to practise for 10–15 minutes, 5 days a week. The focus of therapy was based on the error analysis outlined above.

Although the therapy was individualized, it followed a basic articulation hierarchy (Van Riper and Emerick, 1984), starting with the target phoneme in CV or VC (with a vowel likely to facilitate production, for example a back vowel for velars), progressing to CV and VC with differing vowels, through to words (building complexity) and then phrases and conversational speech. Initially participants were encouraged to copy the target pattern using the EPG for visual feedback. Target patterns were quasi-static patterns (Articulate Instruments Ltd, 2007), as shown in Figure 1.

When the participant achieved an acceptable pattern (for example, a grooved pattern for /s/) which was also perceptually acceptable, then the participant's own best attempt could be used as a target pattern. Generalization was built into the sessions, with progression to productions without visual feedback. Since individuals with Down's syndrome have difficulty with phonological awareness and speech perception, intervention also incorporated input activities (Stackhouse and Wells, 1997) designed to specifically address each participant's awareness

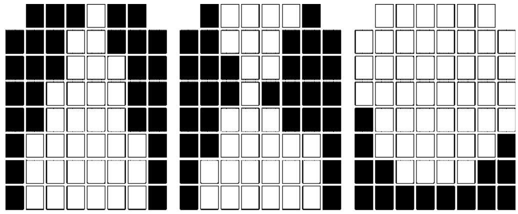

Figure 1. Template EPG patterns used in therapy.

and discrimination of the target phoneme(s). For example, several participants had post-alveolar fronting of /ʃ/ in which case the child's ability to discriminate between /s/ and /ʃ/ was tested and input activities were devised.

Results: Pre-therapy

Language and cognitive measures

The speech, language, and cognitive profile of the participants with DS was in line with that previously reported in the literature. The participants presented with severe cognitive deficits; despite the participants being chronologically aged 10;1 to 18;9 WPPSI verbal mental ages were in the range of 3;11 to 5;7, and performance age equivalents were in the range of 4;1 to >7;2. Language was more severely impaired, with receptive language age equivalents ranging form 3;5 to 4;10 and expressive language from 2;9 to 4;5.

Selecting therapy targets: Error analysis

Twenty-five different processes were identified in the single word productions of the DEAP phonology sub-test. Of these 25 different processes, 18 were evident at least three times in one or more child's speech (Table II). After eliminating the processes which did not primarily involve placement of lingua-palatal consonants, only six error types remained: gliding, velar fronting, post-alveolar fronting, affrication, backing, and lateralization. Four of the participants exhibited gliding, (participants 3, 4, 5, and 6), but this process was not treated as it is not normally targeted in EPG therapy (Gibbon and Paterson, 2006). The process with the highest number of errors, excluding gliding, was treated first in therapy. Table III shows a summary of the lingua-palatal errors and the targets chosen for therapy.

Results: Pre- and post-therapy

EPG patterns

Figures 2(*a–f*) show pre- and post-therapy EPG patterns for each participant. Each EPG pattern represents the midpoint of an attempt at the target consonant in a single word.

Participant 1 received therapy targeting production of /s/. Pre-therapy, she produced a range of productions including affricates and retracted sibilants, achieving one perceptually correct production out of 10 attempts. Post-therapy, all EPG patterns show central airflow and she produced five perceptually correct attempts.

Table II. Errors in the DEAP.

Process	Child 1	2	3	4	5	6	Total	% Total errors
Gliding	1	1	4	12	3	9	30	9.46
Velar fronting	3	4	1		6		14	4.42
Post alveolar fronting			3	7	1	6	17	5.36
Context sensitive voicing	3	4			2		9	2.84
Devoicing	3		2		3	2	10	3.15
Glottal replacement	1	8			1	1	11	3.47
Affrication	4				1		5	1.58
Backing		1			5		6	1.89
Debuccalization						3	3	0.95
Laterals	7	13	8	1	1		30	9.46
Weak Syllable Deletion	2	7			4		13	4.10
Consonant Harmony		3			4		7	2.21
Cluster Reduction	8	4	4	2	16	3	37	11.67
Final Consonant Deletion	8	4	1	6	3	5	27	8.52
Initial Consonant Deletion	7	26	7		5	4	49	15.46
Ingressive		20					20	6.31
Ejective	2	8					10	3.15
Other	4	8			7		19	5.99
Total	53	111	30	28	62	33	317	100
% Total errors	16.72	35.02	9.46	8.83	19.56	10.41	100	100

Table III. Lingua-palatal errors.

Child	Number of errors: Gliding	Velar Fronting	Post-alveolar fronting	Affrication	Backing	Laterals	Aims of therapy
1		3		4		**7**	To produce central s, ʃ, tʃ and dʒ
2		4				**13**	To produce central s, ʃ, tʃ and dʒ
3	4		3			**8**	To produce central s, ʃ, tʃ and dʒ
4	12		7				To produce central ʃ
5	3	**6**			5		To produce correct velars and alveolars
6	9		**6**				To produce central ʃ

Boldface in the body of the table denote the most prominent error, gliding excepted.

Patterns for participant 2 are similar pre- and post-therapy. Pre-therapy, all attempts at /s/ are ingressive lateral fricatives. Post-therapy, all attempts are egressive lateral fricatives. He therefore produces a more appropriate egressive airstream, but the contact pattern is still incorrect. This results in no increase in the number of perceptually correct attempts (zero each time), despite clear progress towards the correct form.

Participant 3 also received therapy targeting correct production of /s/. Pre-therapy, there were four correct attempts out of a possible 10. Errors included affrication, velopharyngeal

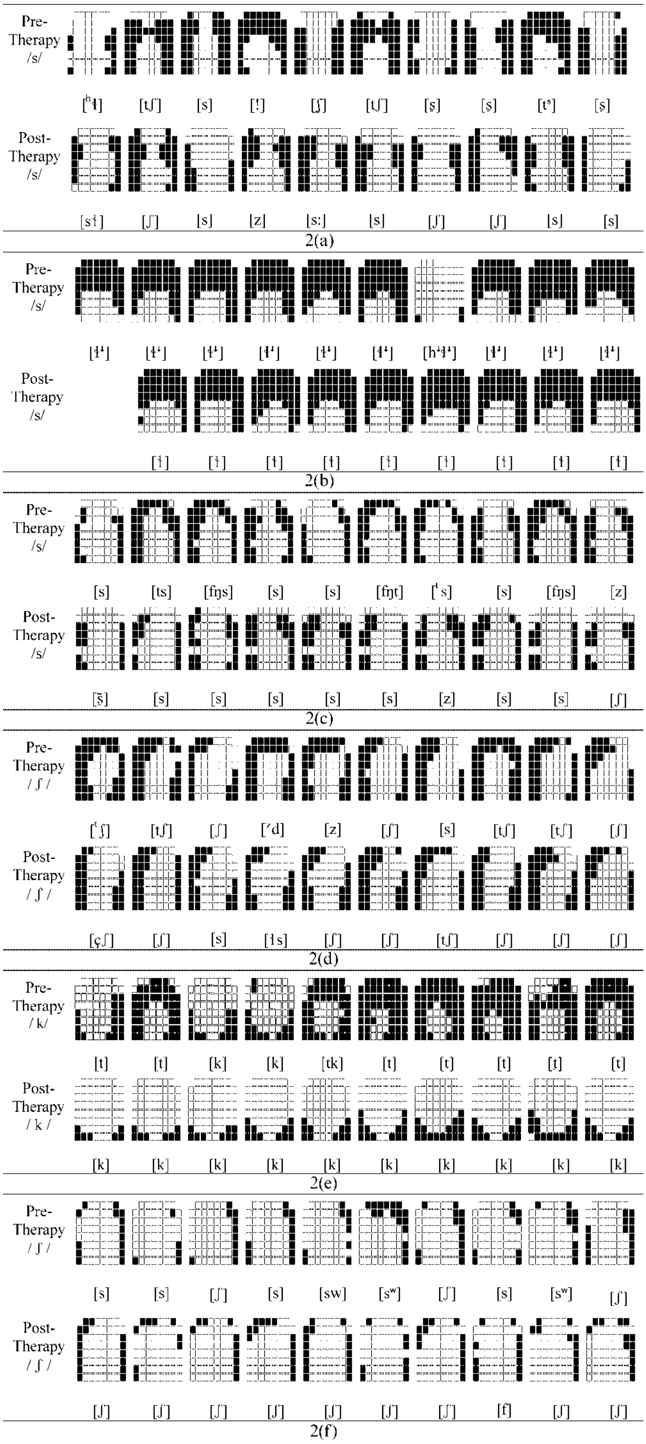

Figure 2. (*a*) Participant 1, pre- and post-therapy, /s/ midpoints from 'sun'; (*b*) Participant 2, pre- and post-therapy, /s/ midpoints from 'sun'; (*c*) Participant 3, pre- and post-therapy /s/, midpoints from 'sun'; (*d*) Participant 4, pre- and post-therapy, /ʃ/ midpoints from 'sheep'; (*e*) Participant 5, pre- and post-therapy, /k/ midpoints from word initial /k/; (*f*) Participant 6, pre- and post-therapy, /ʃ/ midpoints from 'sheep'.

friction, and voicing, with four EPG patterns showing complete closure. Post-therapy, all productions were central and seven were perceptually correct. The remaining three attempts were retracted, nasalized, or voiced.

Participant 4 received therapy targeting production of /ʃ/. Pre-therapy, three productions were correct, one was fronted, four were affricated, one was voiced (and fronted), and one was stopped. Post-therapy, six productions were correct and none of the patterns show complete closure.

Participant 5 received therapy targeting inconsistent velar fronting. Pre-therapy, only two productions were correct, one was a double articulation and the remainder were fronted. Post-therapy, all productions were correct.

Lastly, participant 6 received therapy targeting correct production of /ʃ/. Pre-therapy, reduced contact is evident, particularly on the left side, and only three productions were perceptually correct, with the remainder fronted (some with appropriate lip rounding). Post-therapy, reduced contact is still evident, though perhaps less so, but all productions were perceptually correct.

As a group, positive changes are evident in five out of these six participants, with participant 2 showing no change in EPG patterns but a change to a more appropriate airstream. Perceptually, all of the children, except participant 2, show an increase in the number of perceptually correct productions. As a group this increase is significant ($t(5) = -3.286$; $p = .022$).

EPG measures

There was a significant decrease in variability of /s/ post-therapy for all participants ($t(5) = 4.037$, $p = .01$) but no significant difference for /ʃ/ ($t(4) = 1.481$, $p = .213$). This suggests more stable productions post-therapy for /s/ only.

Centre of gravity during productions of /k/ and /g/ was calculated pre- and post-therapy for participant 5 because therapy for this participant specifically targeted production of velars. There was a significant decrease in COG for /k/ post-therapy ($t(20) = 3.736$, $p = .001$) and similarly for /g/ ($t(15) = 6.515$, $p < .0005$), indicating more posterior articulations post-therapy.

Perceptual measures

Table IV shows pre- and post-therapy percentage consonants correct from the DEAP and percentage correctly identified words from the CSIM.

Table IV. Perceptual measures, pre- and post-therapy.

Child	PCC Pre	PCC Post	CSIM % Pre	CSIM % Post
1	67	75	72	58
2	38	41	32	26
3	70	86	66	78
4	66	87	84	94
5	59	65	46	54
6	81	88	81	86
Mean	63.50	73.67	63.56	66.04
SD	14.40	18.33	20.57	25.00

There was a significant increase in PCC from 63.50% to 73.67% ($t(5) = -3.634$, $p = .015$) with a mean increase per child of 10.17%. There was a slight but not significant increase from 63.5% to 66.06% in the number of words correctly identified by listeners post-intervention ($t(5) = -.616$, $p = 0.565$) in the CSIM.

Discussion

Cognition and language

The participants presented with severe cognitive deficits and even more severely impaired language. Hardcastle and Gibbon (1997) suggest that EPG may not be a suitable therapy tool for children with cognitive deficits, however none of participants in this study had any difficulty using EPG for visual feedback. Although EPG is not often used with children under the age of 7 years, this is often to avoid issues with dentition (loss of primary dentition in younger children) rather than necessarily a suggestion that participants require cognitive ages of 7 and above to understand EPG. Moreover, while people with DS may measure as having low cognitive ages, they have world experiences that make them more mature than typical children at the same cognitive age equivalents. This suggests that the ability to understand and use EPG needs to be assessment on a case-by-case basis and offers promising evidence that EPG is in fact suitable for children and adults with a wide range of cognitive impairments, especially when visual skills are a strength, as they are in DS.

EPG analyses

Because therapy was individualized, it was not appropriate to use the same EPG measures for each child. However, errors involving sibilants were frequent and five of the participants had therapy targeting either post-alveolar fronting and/or distorted (lateralized) sibilants. We hypothesized that poor motor control leads to increased variability, and therefore decreased intelligibility, in this population. Post-therapy, there was a significant decrease in variability of /s/, suggesting more stable productions.

No reduction in variability of /ʃ/ was evident. However, a study by Timmins, Hardcastle, Wood, McCann, and Wishart (2007) demonstrated that while /s/ is more variable in speakers with DS than typical speakers, /ʃ/ is not. It is therefore possible that variability for /ʃ/ did not decrease post-therapy because it was already in line with typical speakers. However, post-therapy differences were observable in the EPG patterns with participants 4 and 6 both showing improved patterns and more perceptually correct attempts for /ʃ/. It is, of course, possible for individuals to produce consistent but incorrect articulations, in which case a reduction in variability would not necessarily indicate an improvement in accuracy, but could still indicate an improvement in motor control. This highlights the need for EPG measures that take similarities between patterns into account. Moreover, immediately post-therapy we may expect increased variability as participants learn new articulations and reorganize their phonetic systems.

Child 2 showed no difference in pre- and post-therapy EPG patterns. He did, however, show an increase in percentage consonants correct. This particular child presented with very unusual errors, namely deletion of all word final fricatives and substitution of all word initial fricatives for an ingressive lateral fricative. Post-therapy, fricatives were egressive but still lateral and he was marking word final fricatives with an egressive lateral fricative. Clearly a change in airstream shows progress in this child's phonology which was not measurable by

EPG, highlighting the need for one to use perceptual measures alongside EPG patterns and measures.

Child 5 presented with an atypical case of velar fronting. Post-therapy, there was a significant decrease in centre of gravity measurements for both /k/ and /g/, confirming the findings of Gibbon et al. (2003) that velar fronting in DS is amenable to remediation using EPG.

In sum, five out of six of the children showed observable differences in EPG patterns post-therapy. EPG patterns represents only tongue-palate contact, and do not specify which part of the tongue is making this contact, or what the involvement of other articulators is. For example, it is possible to achieve a velar-like pattern by reteroflexing the tongue and production of /ʃ/ involves tongue retraction and often lip rounding. For this reason, it is important to combine EPG analyses with perceptual analyses.

Perceptual measures

Pre-therapy, the participants with DS presented with mild-to-severe speech disorders, with percentage consonants correct ranging from 31–82%. Moreover, average intelligibility ratings, as measured by the CSIM, were only 64%, suggesting that around a third of the words spoken by the participants with DS were unintelligible. A range of different phonetic and phonological errors were evident in the participants' speech, but only six error types were appropriate for EPG therapy: gliding, velar fronting, post-alveolar fronting, affrication, backing, and lateralization. This in itself demonstrates a limitation of EPG therapy, illustrating how speech in DS may be characterized by errors affecting both lingual and non-lingua-palatal consonants. However, errors affecting linguapalatal sibilants were very common. Many of these errors were distortions such as laterals; fewer were developmental processes such as post-alveolar fronting (/ʃ/ was produced as [s]). Hamilton (1993) used EPG to investigate articulatory patterns in adults with DS. She also found that /ʃ/ and /s/ were not differentiated but, rather than attributing this to a developmental delay, she suggests that it may be due to dysarthria in DS, which is consistent with the hypotonia found in the syndrome.

All of the participants received 24 sessions of individualized therapy, aiming to remediate lingua-palatal errors. Post-therapy, there was a significant increase in percentage consonants correct, with some participants making more progress than others, with PCC in participant 1 for example, increasing from 66% to 87%. Therefore, for this participant, although only /s/ was targeted in therapy, post-therapy productions of other sibilants had also improved. This suggests promising evidence of the ability of people with DS to generalize. However, this improvement was not detectable in the CSIM. This test is an imitation test where participants are required to repeat single words spoken by the examiner. Most of the words are low frequency (because the test is designed to be phonetically balanced) and would be unfamiliar to the participants. Since the participants may not have lexical representations for these words, the task essentially becomes a nonword repetition task. People with DS are known to have difficulty with phonological memory and specifically with non-word repetition tasks (Laws, 1998), suggesting that this test may not give an accurate representation of intelligibility in this population.

Conclusions

The participants in this study presented with mild-to-severe speech disorders. Atypical sibilants were common, with four out of five of the participants receiving therapy targeting these phonemes. The quantitative EPG analysis showed atypical patterns, unlike that of typical speakers, suggesting that speech is disordered in DS. One reason for this may be the atypical anatomy in DS. All of the participants showed improvements in percentage consonants correct and most of the participants produced observably different EPG patterns following 24 sessions of EPG visual feedback therapy. This is an encouraging finding, confirming observations that visual processing skills are a relative strength in DS. In this study participants received therapy twice a week for 12 weeks. What is not clear is whether the same gains could be achieved with less input or whether more improvements are possible with more input. Our ongoing research seeks to establish whether gains were maintained (e.g. Wood, Wishart, Hardcastle, Cleland, and Timmins, 2009) after the intervention period and also to compare progress made with EPG therapy to that in a control group of participants not receiving intervention.

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