Personalised Speech and Language Therapy for Children with Cerebral Palsy and Dysarthria

A thesis submitted to the Population Health Sciences Institute at Newcastle University for the degree of Doctor of Philosophy

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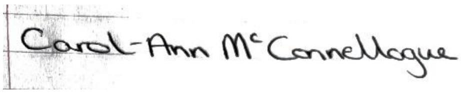
Author Declaration

I declare that all work presented was completed by myself, unless otherwise stated, and has not been submitted for any other qualification.

Signed:



Abstract

Background: Cerebral Palsy (CP) is the most common childhood motor disorder, with a prevalence of around 1.5-2 per 1000 live births. Approximately half of individuals with CP have speech difficulties, most of whom have dysarthria. Dysarthria disrupts the subsystems underpinning speech and reduces intelligibility.

Aim: To examine the effect of personalised dysarthria therapy on the intelligibility of children with CP and dysarthria using perceptual and acoustic speech outcomes.

Method: Fifteen children with CP and dysarthria received individualised online therapy. Intelligibility was measured at 6- and 1-week pre-therapy and 1- and 12-weeks post-therapy. Generalised linear mixed models determined whether children made statistically significant gains in the intelligibility of single words (SWs) and connected speech (CS). Acoustic profiling was used to explore acoustic speech changes.

Results: Group results showed that SW and CS intelligibility significantly improved from 1-week pre- to 12-weeks post-therapy. Clinically significant gains of greater than 10% words understood were mainly observed in those with a higher intelligibility at baseline. More children made clinically significant gains in SWs than in CS. No single factor explained the change in intelligibility, but better perception of polysyllabic words and word-initial and word-final consonants was observed post-therapy. Acoustic profiling showed no obvious relationship between changes in articulatory precision and vocal cues. Acoustic changes specific to individual children occurred post-therapy, but were not necessarily perceived by ear, e.g., evidence of word-final consonants being produced.

Interpretation: Personalised intervention seems to be effective at improving the intelligibility of children with CP and moderate-to-severe dysarthria. Those with profound dysarthria made little change, suggesting that support for their communication should focus on augmentative and alternative communication. Future research should further evaluate personalisation of the intervention to establish the best cues for individual speech characteristics.

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Glossary

Affricate: An affricate in English is a phoneme in which a plosive is immediately followed by a fricative, e.g., /tʃ/ or /dʒ/.

Articulation Rate: A measure of speech rate which excludes dysfluencies, pauses and boundary markers. It measures the speed at which articulators move and is typically measured in syllables per second (Walker and Archibald, 2006; Haselager, Slis and Rietveld, 1991).

Coronal: Consonants produced using the tip or blade of the tongue.

Devoicing: The vocal folds do not vibrate when producing a voiced sound (e.g., /d/ or /v/), so it becomes voiceless.

Dorsal: Consonants produced using the back of the tongue.

Dysfluency: Disruption to the fluency, rhythm, and rate of speech. It includes repetition, the use of fillers (e.g., “uh”), prolongations, and hesitations.

Fricative: A phoneme involving a narrowing of the oral cavity so air can still escape causing audible friction, e.g., /f/ or /v/.

Fronting: A phonological process where a child substitutes a sound produced at the back of the mouth with a sound produced at the front of the mouth (e.g., /k/ to [t]).

Fundamental Frequency (F_0): The lowest frequency of a periodic waveform. It is perceived as pitch. Measured in Hz.

Gloss: Comparing a speaker’s perceived production to the actual target production.

Intensity: Intensity is the amount of energy a sound wave carries through an area. It is perceived as the loudness of sound and typically measured in decibels (dB). The greater the intensity, the louder a sound is perceived.

Labial: Consonants made using the lip(s).

Manner of Articulation (MoA): The degree of constriction caused by the position of the articulators in the vocal tract. Different degrees of constriction affect the airstream differently as it flows from the lungs out through the oral and nasal cavity, e.g., affricates, fricatives, and plosives have different manners of articulation.

Obstruent: Phonemes made by fully constricting the air flow.

Phoneme: A phoneme is the smallest unit of sound within a word. For example, the word ‘dog’ consists of three phonemes: /d/, /ɒ/, /g/.

Phonological Process: A systematic pattern of sound changes in a child’s speech that emerges as they learn to articulate sounds and develop their language skills. These processes may include substitutions, deletions, or modifications of phonemes within words to simplify the production.

Place of Articulation (PoA): This describes where an obstruction is made by the articulators to restrict the passage of air so to produce different consonants. For example, bilabial sounds (/p/, /b/ and /m/) are produced by bringing the upper and lower lip together.

Plosive: A phoneme involving complete closure of the oral tract which blocks the airflow followed by a release of the consonant, e.g., /p/ or /b/.

Sonorant: Voiced phonemes in English produced by continuous non-turbulent airflow through the vocal tract that resonate freely.

Speech Rate: The rate of speech over an entire speaking turn. It captures linguistic and non-linguistic speech material including dysfluencies, pauses, sounds, and gestures and is typically measured in syllables per second (Gold, 2018).

Stopping: The phonological process whereby an affricate or a fricative is replaced with a plosive (e.g., /f/ to [p]).

Voiced: Voiced sounds are produced by the vibration of the vocal cords. All vowels are voiced but consonants may be voiced or voiceless. For example, in English /b/ is a voiced bilabial plosive and /p/ is a voiceless bilabial plosive.

Voiceless: Voiceless sounds do not require vocal cord vibration. They are produced by air flowing freely from the lungs to the mouth, with the sound being modulated by the position of the articulators, e.g., lips, teeth, and tongue.

Abbreviations

95% CI – 95% Confidence Intervals

AAC – Augmentative and Alternative Communication

ABI – Acquired Brain Injury

ADHD – Attention Deficit Hyperactivity Disorder

AMR – Alternating Motion Rate

ASD – Autism Spectrum Disorder

C&C – Capacity and Capability

CAS – Childhood Apraxia of Speech

CFCS – Communication Function Classification System

CI – Chief Investigator

CP – Cerebral Palsy

CS – Connected Speech

CYP – Children and Young People

dB – decibel

DEAP – Diagnostic Evaluation of Articulation and Phonology

DDK – Diadochokinesis

EBP – Evidence Based Practice

EPG – Electropalatography

F_0 – Fundamental Frequency

F1 – First Formant

F2 – Second Formant

FCCS – Functional Communication Classification System

F.O.T.T. – Facial Oral Tract Therapy

GDD – Global Developmental Delay

GLMM – Generalized Linear Mixed Model

GMFCS – Gross Motor Function Classification System

ICC – Intraclass Correlation Coefficient

ICF – International Classification of Functioning, Disability and Health

ICS – Intelligibility in Context Scale

ITS – Interrupted Time Series

K-S – Kolmogorov-Smirnov Test

LD – Learning Disability

LSVT – Lee Silberman Voice Therapy

MACS – Manual Ability Classification System

MoA – Manner of Articulation

MS – Multiple Sclerosis

NICE – National Institute for Health and Care Excellence

NSOMEs – Non-Speech Oral Motor Exercises

NU – Newcastle University

OMT – Orofacial Myofunctional Therapy

PD – Parkinson’s Disease

PI – Principal Investigator

PIC – Participant Identification Centre

PoA – Place of Articulation

PPT – Phonetic Placement Therapy

PVC – Percent Vowels Correct

QoL – Quality of Life

R&D – Research and Development

RCSLT – Royal College of Speech and Language Therapists

RCT – Randomised Control Trial

REC – Research Ethics Committee

ReST – Rapid Syllable Transition Treatment

SE – Standard Error

sEMG – Surface Electromyography

SD – Standard Deviation

SE – Standard Error

SENCO – Special Educational Needs Coordinator

SLCN – Speech, Language and Communication Needs

SLT(s) – Speech and Language Therapy/Speech and Language Therapist(s)

SMA – Spinal Muscular Atrophy

SSA – Speech Systems Approach

SW – Single Word

TA – Teaching Assistant

TBI – Traumatic Brain Injury

TROG – Test for Reception of Grammar

VMPAC – Verbal Motor Production Assessment for Children

VPM – Voice Place Manner

VSS – Viking Speech Scale

WDS – Worster-Drought Syndrome

WF – Word Final

WHO – World Health Organisation

WI – Word Initial

WM – Word Medial

YP – Young People

			Place							
			Labial		*Coronal*			*Dorsal*		
Manner Group	**Manner**	**Voicing**	Bilabial	Labio-dental	Interdental	Alveolar	Post-alveolar	Palatal	Velar	Glottal
Obstruent	Plosive	Voiced	b			t			g	
		Voiceless	p			d			k	
	Fricative	Voiced		v	ð	z	ʒ			h
		Voiceless		f	θ	s	ʃ			
	Affricate	Voiced					d͡ʒ			
		Voiceless					t͡ʃ			
Sonorant	Nasal	Voiced	m			n			ŋ	
		Voiceless								
	Approximant	Voiced	w			ɹ		j		
		Voiceless								
	Lateral	Voiced				l				
		Voiceless								

Table 1 Table Summarising the Voice, Place and Manner of English Consonants

Key:

ð = ‘th’ as in ‘that’	ʃ = ‘sh’ as in ‘shower’	ɹ = ‘r’ as in ‘run’
θ = ‘th’ as in ‘think’	d͡ʒ = ‘j’ as in ‘jump’	j = ‘y’ as in ‘yes’
ʒ = ‘zh’ as in ‘measure’	t͡ʃ = ‘ch’ as in ‘chin’	ŋ = ‘ing’ as in ‘going’

Chapter 1. Introduction

1.1. Introduction to the Chapter

This thesis examines the effect of personalised speech and language therapy on the intelligibility of children with cerebral palsy and dysarthria using perceptual and acoustic data. This chapter provides a detailed overview of cerebral palsy, dysarthria, and the difficulties children with cerebral palsy and dysarthria face in terms of how their motor speech disorder affects their intelligibility. It also briefly discusses the impact of these disorders on their participation and quality of life.

1.2. Cerebral Palsy

1.2.1. *What is Cerebral Palsy?*

Cerebral palsy (CP) describes “a group of permanent disorders of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing foetal or infant brain” (Rosenbaum *et al.*, 2007, p. 9). Signs of CP include abnormal posture, variations in muscle tone, muscle weakness, tremors, or involuntary movements, and writhing movements (Rosenbaum *et al.*, 2007, p. 9). CP is the most common childhood motor disorder (Sellier *et al.*, 2016) with a prevalence of around 1.5-2 per 1000 live births (Sellier *et al.*, 2016; McIntyre *et al.*, 2022). Preterm birth is the main risk factor for CP, with babies born under 28 weeks of gestation 60 times more at risk compared to those born at term (Jacobsson *et al.*, 2002).

1.2.2. *Subtypes of Cerebral Palsy*

There are different subtypes of CP: spastic, dyskinetic, ataxic and mixed, and symptoms and signs vary depending on the type. Spastic CP is the most common type, accounting for over 80% of total cases (Kinsner-Ovaskainen *et al.*, 2017). It is the most prevalent CP subtype in babies born prematurely and babies of very low birth weight (<1500 g) (Dammann, Allred and Veelken, 1998). Spastic CP is associated with stiff muscles, jerky movements, and a reduced range of movement. It is caused by damage to the motor cortex (which regulates voluntary movement) and pyramidal tracts (which conduct signals from the motor cortex to the spinal cord).

Around 7% of people with CP have dyskinesia which is associated with involuntary movements due to the presence of choreoathetosis and dystonia which often present simultaneously (Monbaliu *et al.*, 2017). Choreoathetosis combines the features of both chorea and athetosis, including involuntary irregular twitching and continuous writhing movements, respectively. Dystonia refers to abnormal tone and is associated with unusual posturing and slow, writhing, and repetitive movements. Both choreoathetosis and dystonia are more prominent during intentional actions, than when at rest (Monbaliu *et al.*, 2016). Dyskinesia arises from damage/maldevelopment of the basal ganglia, which is a key contributor to movement control.

Ataxic CP accounts for about 4% of CP cases. Poor balance, poor co-ordination and depth perception problems are symptoms of ataxic CP. It is caused by maldevelopment of/injury to the cerebellum which is responsible for controlling motor function.

Mixed CP occurs when symptoms of more than one type of CP are evident, and it is caused by damage to several areas of the brain. Many children labelled as having spastic CP will have significant elements of dystonia, so mixed CP is in a sense an underestimated category (Carr, 2018). The location and severity of the brain lesion determines the type of CP, the number of limbs affected (e.g., monoplegia affects one limb's movement) and the side of the body impacted (e.g., hemiplegia impacts one side of the body).

As CP is non-progressive symptoms do not worsen throughout a person's life, but the clinical picture evolves over time due to child development (Rosenbaum *et al.*, 2007). From childhood into adolescence symptoms may be heightened causing a relapse of functional skills until new skills and a new neuromotor equilibrium are obtained (Ansel and Kent, 1992).

A rare form of CP is Worster Drought Syndrome (WDS) (Clark, Carr, Reilly and Neville, 2000; Gowda, 2020), previously known as congenital suprabulbar paresis (Worster-Drought, 1956). The main site of motor impairment of WDS is the bulbar muscles Clark *et al.* (2010). Diagnosis of WDS in children is rare and is usually quite late, with the average age of diagnosis being 5-6 years (Clark, Carr, Reilly and Neville, 2000; Clark *et al.*, 2010). The prevalence is thought to be around 2 to 3 per

100,000 live births (Clark *et al.*, 2010; Shevell, Majnemer and Morin, 2003). Children with WDS have varying degrees of weakness and movement of their lips, tongue, soft palate, pharynx and laryngeal muscles, and difficulty with speech and swallowing (Worster-Drought, 1956). They may also have additional impairments such as increased tone, brisk reflexes, clonus, gastro-oesophageal reflux, aspiration and learning difficulties. It usually takes time for these additional impairments to become apparent explaining why it is a more poorly recognised CP type (Clark, Carr, Reilly and Neville, 2000).

1.2.3. *Comorbidities*

Conditions associated with CP include epilepsy, cognitive deficits, sensory impairments, pain, communication difficulties associated with speech and language disorders, and multiple neurodevelopmental conditions (Aisen *et al.*, 2011; Berry *et al.*, 2018; Rosenbaum *et al.*, 2007).

1.2.3.1. Cognitive Difficulties

Cognitive difficulties occur in approximately 50% of people with CP (Novak, Hines, Goldsmith and Barclay, 2012; Vitrikas, Dalton and Breish, 2020). However, estimates of their prevalence varies amongst studies due to the limitations that arise with using standard measures of intelligence to assess children with CP. Children with CP are often unable to complete all tasks within intelligence assessments due to their reduced motor and verbal abilities (Reid, Meehan, Arnup and Reddihough, 2018); thus scores are often misrepresentative of their functioning, particularly if tasks assess speed of response or require fine motor skills (Sherwell *et al.*, 2014). Learning disability appears to be associated with the type of CP. A learning disability can affect an individual's ability to understand or use language, do mathematics, or direct attention (Lyon, 1996). Children with dyskinesia are more likely to have a severe intellectual disability than children with spastic CP (Novak, Hines, Goldsmith and Barclay, 2012); in particular, children with spastic hemiplegia and diplegia appear to have better cognitive outcomes than children with spastic quadriplegia and dyskinesia (Sigurdardottir *et al.*, 2008).

1.2.3.2. Epilepsy

Around 25% of those with CP have epilepsy (Vitrikas, Dalton and Breish, 2020; Novak, Hines, Goldsmith and Barclay, 2012). Epilepsy is associated with a lower IQ (Stadskleiv, 2020; Sigurdardottir *et al.*, 2008).

1.2.3.3. Sensory Deficits

Sensory impairments involve visual, hearing, and sensory processing difficulties. Approximately 50% of children with CP have some degree of visual impairment, with between 5% and 9% having severe visual impairment (Dufresne, Dagenais, Shevell and Consortium, 2014). The prevalence of hearing loss in children with CP is thought to be between 4% and 57% of children with CP (Khaydarova, Madrimova and ES, 2021; Pellegrino, 2007; Reid, Modak, Berkowitz and Reddihough, 2011; Kumar *et al.*, 2023). Hearing loss in children with CP can be caused by hypoxic-ischaemic encephalopathy (brain injury caused by lack of oxygen and blood flow to the brain before, during, or just after birth), and is more common in children of very low birth weight, and pre-term birth (Reid, Modak, Berkowitz and Reddihough, 2011). It is vital that children with CP receive early diagnosis and intervention for hearing loss as it can greatly impact speech and language development (Richard *et al.*, 2021). Children with CP experience somatosensory impairment, which involves tactile deficits and impairments in sensory processing such as vibration and stereognosis and two-point discrimination (Knijnenburg *et al.*, 2023). Stereognosis is the ability to identify objects through touch, without seeing or hearing them. Over 75% of children with unilateral CP have tactile impairments, with deficits worse in their impaired hand (Auld *et al.*, 2012). However, 54% of the children in Auld et al.'s (2012) study still experienced tactile deficits in their unimpaired hand. Sensory function has been found to be worse in those with cortical lesions (damage in the cortical grey matter of the brain) as opposed to white matter tract lesions (Knijnenburg *et al.*, 2023).

1.2.3.4. Pain

The number of children with CP reported to experience pain varies across the literature, with prevalence ranging from 14% to 77% (Vinkel, Rackauskaite and Finnerup, 2022; Mckinnon *et al.*, 2019). Penner and colleagues (2013) found 25% of children with CP experienced moderate to severe pain which limited participation in activities. The most common pain amongst children with CP is musculoskeletal, with around two-thirds experiencing recurrent musculoskeletal pain (Ramstad, Jahnsen, Skjeldal and Diseth, 2011). The pain is often caused by increased muscle tone, muscle spasms, muscle weakness or fatigue, a misalignment of joints, and osteoporosis (Vinkel, Rackauskaite and Finnerup, 2022; Penner *et al.*, 2013).

1.2.3.5. Speech, Language and Communication Difficulties

Motor disorders such as CP can reduce coordination and control of one or more subsystems essential for speech, including respiration, phonation, resonance, prosody, and articulation, ultimately impacting speech production. The most common speech disorder associated with CP is dysarthria, which will be discussed in detail sections 1.4 and 1.5.

Children with CP experience limitations in their ability to produce facial expressions, use gestures, and employ body movements effectively, which further impacts their role as effective communicators. Their motor impairments hinder the initiation of movements, potentially delaying responses in conversation, and reducing movement precision, often resulting in unclear speech or uncoordinated gestures. Such limitations can impede their ability to make requests or convey needs and wants, which may lead children with CP to adopt a passive communication style and prevent the full development of a range of communication skills (Pennington, 2008).

The prevalence of language disorders in children with CP is approximately 36% to 74% of cases (Mei *et al.*, 2016; Pirila *et al.*, 2007). There is a correlation between language disorders and non-verbal cognitive abilities (Pennington *et al.*, 2020; Mei *et al.*, 2016). For those children with CP who are non-verbal at age 2, the likelihood of developing speech is low (Pennington *et al.*, 2020). These children often exhibit delayed receptive language development trajectories and substantial comprehension challenges, and make limited language gains over time (Hustad, Sakash, Broman and Rathouz, 2018; Hustad *et al.*, 2017). They are at greatest risk of having severe speech, language, and communication difficulties and will likely require augmentative and alternative communication (AAC) to support or replace speech and facilitate communication (Pennington *et al.*, 2020).

1.2.3.6. Neurodevelopmental Disorders

Neurodevelopmental disorders such as autism (ASD) and attention deficit/hyperactivity disorder (ADHD) are more common in children with CP compared to typically developing children (Kilincaslan and Mukaddes, 2009;

Bjorgaas, Hysing and Elgen, 2012; Christensen *et al.*, 2014; Påhlman, Gillberg and Himmelmann, 2021). ASD is estimated to occur in 3% to 16% of children with CP, while the prevalence of ADHD is around 7% in this population (Craig, Savino and Trabacca, 2019). ASD and ADHD can further impact the communication skills of children with CP. Children with CP and ASD struggle with social communication and interaction and may exhibit restricted interests and repetitive behaviours (Påhlman, 2020), which may contribute to passive communication. Children with CP and ADHD may face difficulties listening, concentrating, turn taking, and may talk excessively (Påhlman, 2020). Their hyperactivity, poor attention and limited speech and language skills can further hinder effective communication, making it challenging for listeners to understand them.

1.2.4. *Participation and Quality of Life*

The difficulties associated with CP can often impact quality of life (QoL) and self-esteem (Russo *et al.*, 2008) as well as participation. QoL is a subjective term which relates to an "individual's perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns" (WHO, 1995). Self-esteem refers to how an individual perceives their own worth and demonstrates self-acceptance and self-respect (Orth and Robins, 2014). Self-esteem can be classified on a spectrum from high to low. Adolescents with CP who experience severe pain have been found to have lower QoL in areas such as physical and psychological wellbeing, moods and emotions and relationships with parents (Colver *et al.*, 2015; Vinkel, Rackauskaite and Finnerup, 2022).

The World Health Organization's (WHO) International Classification of Functioning, Disability and Health (ICF) is a classification of health domains describing peoples' body functions and structures, their activity, participation, level of capacity and level of performance, and the environmental components that interact with these. Activity is described as "the execution of a task or action by an individual" and participation refers to a person's involvement in life situations (WHO, 2001). Level of capacity relates to an individual's ability to carry out a specific task, whereas level of performance is their actual execution of the task in their typical environment (Westby, 2007).

Unlike QoL, participation can be measured objectively, counting what a person does (Fauconnier *et al.*, 2009). The European study SPARCLE (Colver *et al.*, 2015; Dickinson *et al.*, 2007; Dickinson *et al.*, 2012) investigated the QoL of a group of 818 children with CP at 8-12 years of age and then again at 13-17 years of age. Only 355 adolescents remained in the follow-up study. The European regions involved in SPARCLE included East Denmark, France, Southwest Ireland, Central Italy, West Sweden, UK, and Northwest Germany. This study revealed that on average both children and adolescents with CP self-reported similar QoL overall to their typically developing peers. However, adolescents with CP reported poorer 'social support and relationships with peers' compared to typically developing adolescents.

Fauconnier et al., (2009) evaluated the participation of children with CP and how it varies depending on their CP type and severity in the SPARCLE study. Those with CP were found to participate in fewer activities than their typically developing peers, and engage less in the activities they did attend, both as children and adolescents. Low participation is particularly observed in children with CP who experience severe pain or have additional impairments such as communication or learning difficulties (Fauconnier *et al.*, 2009; Penner *et al.*, 2013).

Children with mild speech impairment have been found to participate similarly to children with no motor speech disorder at home, in school, and within the community (Mei *et al.*, 2014); whereas non-verbal children experience significant challenges to activity and participation (Mei *et al.*, 2015; Mei *et al.*, 2020a). Parent perspectives of minimally/non-verbal children expressed the importance of communication for participation (Mei *et al.*, 2015). Parents reported that successful communication is necessary to make basic needs known, develop independence, and form friendships, and that communication to some degree is needed in almost every activity. The prevalence of nonverbal children with CP ranges from between 16% to 32% (Nordberg, Miniscalco, Lohmander and Himmelmann, 2013; Sigurdardottir and Vik, 2011). Children with CP may be non-verbal due to profound learning disabilities or anarthria caused by their severe motor impairment. For children with CP and anarthria, their inability to express themselves verbally can result in frustration, especially if their receptive language skills are still intact. This difficulty in communication may lead to feelings of isolation and reduced emotional well-being. Augmentative and alternative communication (AAC) refers to all the techniques of communication intended to support or substitute speech when it is impaired or inaccessible (Simion, 2014). The use of AAC alongside support from caregivers and trained communication partners can improve children's ability to interact and express themselves (Raghavendra *et al.*, 2011). Children with CP who are non-verbal due to profound learning difficulties often struggle understanding social norms, which affects their ability to participate in social interactions and activities (Tabacaru, 2016). Impaired receptive language skills can further hinder their ability to engage in conversations, limiting opportunities for meaningful social participation and increasing their dependence on caregivers (Mutlu, Akmese and Kayhan, 2012).

1.3. Typical Speech Production

Accurate speech production requires co-ordinated muscular activity (Clement and Twitchell, 1959) including the muscles of the chest wall, the larynx and the articulators (Smith, 2006). The mechanism of speech production can be described using the Source Filter Model which is based on the theory that a sound source is generated and then filtered and shaped by the vocal tract (Tokuda, 2021; Fant, 1960) (See Figure 1 (Sukor and Syafiq, 2012)).

The chest wall muscles are used for breath support and the production of airflow required for speech production. The primary muscle for these functions is the diaphragm. The laryngeal muscles, which can be divided into extrinsic and intrinsic, modify the airflow travelling from the lungs to the vocal tract. The extrinsic muscles enable the larynx to move superiorly and inferiorly whilst the intrinsic muscles alter the length and tension of the vocal cords and the shape of the rima glottidis (the opening between the vocal folds in the larynx). The intrinsic muscles play a crucial part in respiration and voice. Air travels from the larynx through the vocal folds to generate phonation (voice source). The vocal folds can be closed, so that no air passes through them, or have a narrow constriction so that the air causes them to vibrate or be open so that the air can pass freely. The different manipulations of the vocal folds vary the speech sound being produced; for example, a narrow constriction generates obstruent sounds, while more open vocal folds produce sonorant sounds. Once the air has passed through the vocal folds, it moves into the nasal cavity or oral cavity depending on the phoneme being produced. Manipulation of the velum (soft palate) determines where the air goes. A raised velum prevents air from going into the nasal cavity whereas a lower velum allows air to enter the nasal cavity. If the oral cavity is blocked whilst the velum is lowered then a nasal sound will be produced, e.g., /m/ and /n/. Finally, the articulators shape and filter the airflow. The muscles involved in articulation include some of the facial muscles, especially the lips, and the tongue muscles. Movement of the articulators change the shape of the oral cavity- i.e., open it, narrow it, or close it. This helps to differentiate the different phonemes (sounds) in a language.

The ability to generate enough energy from the air supplied at the lungs so that it can travel through the larynx enables speakers to produce a clear and strong speech signal. Speakers need to be able to open and close their vocal folds for phonation to occur. Voiced phonemes (e.g., /z/) require the vocal folds to come together and vibrate, whereas voiceless phonemes (e.g., /s/) are produced with the vocal folds held open. Accurate speech production then requires speakers to be able to coordinate the movements of their articulators, placing them precisely and moving smoothly between different places of articulation. This ensures target phonemes are hit correctly and prevents speech sounding slurred or dysfluent.

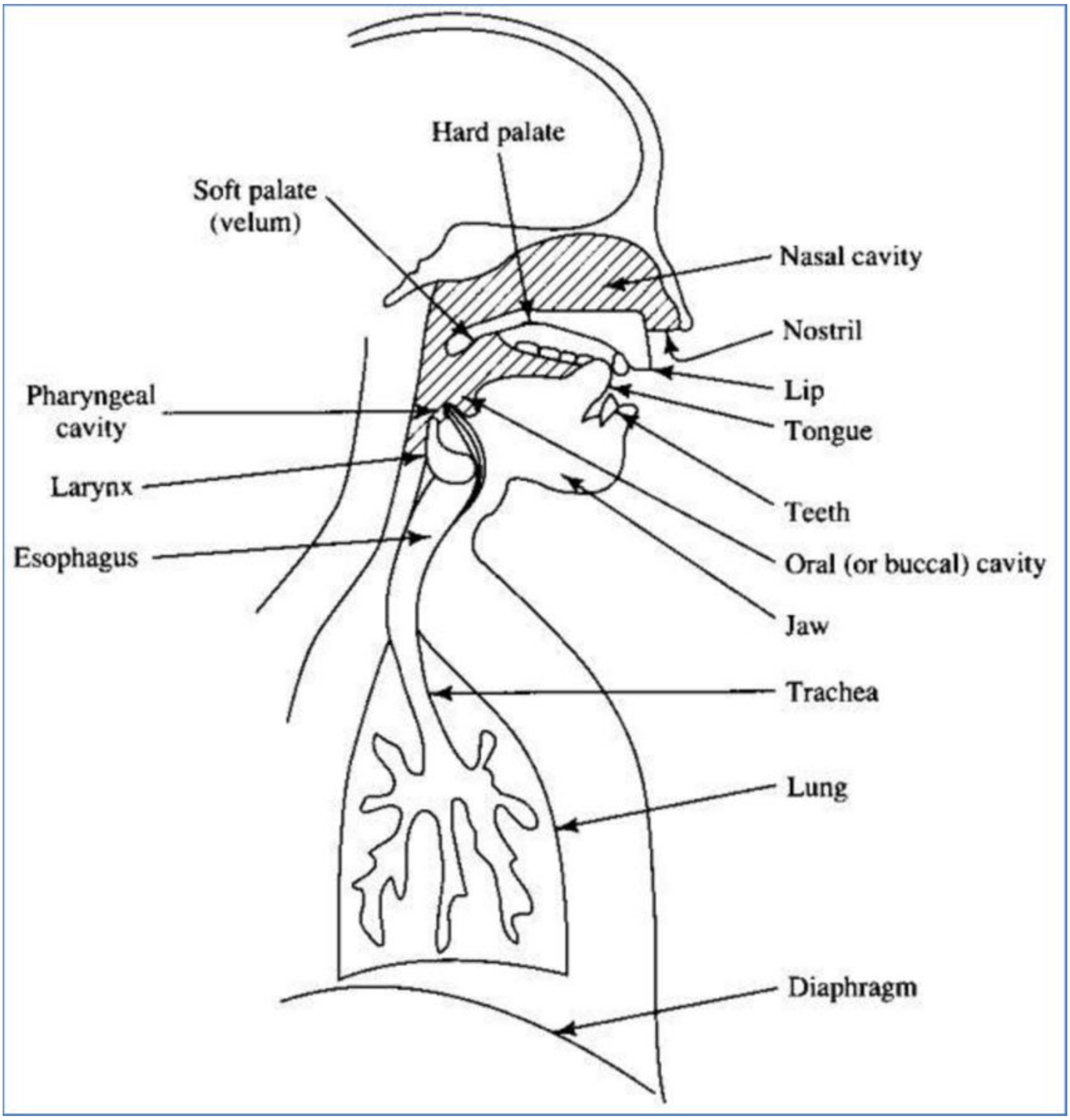

Figure 1 Vocal Tract of Speech Production System

1.3.1. *Speech Production in Typically Developing Children*

Speech is a developmental process which begins within the first few months of life and continues throughout childhood. Development of oral, laryngeal, and respiratory control begins in infancy (Sharp and Hillenbrand, 2008). In the early pre-linguistic stage of speech sound development, occurring between 2 to 3 months of age, infants produce cooing sounds that mainly encompass vowels. By approximately 6 to 8 months, infants begin to engage in babbling, generating repetitive consonant-vowel combinations, such as “ba-ba” (Elom, 2019). During this phase, both voiced and voiceless consonants begin to emerge, with an emphasis on sounds articulated at the front of the mouth. Intonation patterns similar to those found in adult speech may also start to be observed (Crystal, 1986; Dore, 1975).

From 12 to 18 months, children start to articulate their first words, which typically follow a consonant-vowel structure (e.g., “ma”). During this period, children frequently produce consonants such as /m/, /p/, /b/, /t/, and /n/, as these sounds are easier to articulate and are common across many languages. Between 18 and 24 months, children enter the two-word stage, during which they may begin to produce early consonant clusters (e.g., /sp/). They may also exhibit phonological processes, such as consonant deletion (e.g., ‘top’ becoming ‘op’) or final consonant deletion (e.g., ‘cat’ becoming ‘ca’).

From ages 2 to 3, children begin to use a broader range of consonants, and their speech sound accuracy gradually improves. However, reduced motor control is still expected in the first three years of life; therefore, phonological processes like stopping and fronting may still be present (Hustad, Mahr, Natzke and Rathouz, 2020; Dodd, Holm, Hua and Crosbie, 2003). In the later multi-word stage, occurring from ages 3 to 5 years, children become more proficient in producing complex consonants like /s/, /z/, /ʃ/, and /ʧ/. By 4 to 5 years, most children have mastered the majority of speech sounds and there are fewer instances of phonological processes. However, some later-acquired consonants such as /ɹ/, /θ/, and /ð/ may still be challenging, and often are not fully developed until around 6 to 7 years (Dodd, Holm, Hua and Crosbie, 2003).

Research has indicated that the respiratory and articulation rates in typically developing 9-year-olds still differ somewhat from those of adults. For instance, they tend to inhale more frequently and speak at a slower pace, highlighting that certain aspects of speech motor control are still developing at this age (Schölderle, Haas, Baumeister and Ziegler, 2021).

1.4. Dysarthria

1.4.1. *What is Dysarthria?*

Dysarthria is a motor speech disorder caused by brain damage due to neurological diseases or brain injury. Dysarthria is characterised by “abnormalities in the strength, speed, range, steadiness, tone, or accuracy of movements required for breathing, phonatory, resonatory, articulatory, or prosodic aspects of speech production”. muscle weakness, paralysis, and/or incoordination of the muscles required for accurate speech production” (Duffy, 2020, p. 3). This results in impaired speech and consequently reduced intelligibility. Speech intelligibility is defined as “the degree to which a listener understands the acoustic signal produced by a speaker” (Duffy, 2005, p. 96) and it refers to the acoustic-phonetic decoding of speech (Pommée *et al.*, 2020; Kent, Weismer, Kent and Rosenbek, 1989). Intelligibility is dyadic in nature, involving a complex interaction between a speaker who produces a speech signal and a listener who receives the signal (Hustad, Oakes and Allison, 2015).

1.4.2. *Classification of Dysarthria*

Darley et al. (1969) categorised acquired dysarthria into five types – spastic, flaccid, ataxic, hyperkinetic and hypokinetic in the Mayo Clinic classification system. Each type of dysarthria is associated with different motor functioning due to different neurological pathologies and is characterised by a set of perceptual speech characteristics, which include the range, speed and precision of movements as well as muscle tone and strength (Schröter-Morasch and Ziegler, 2005).

Table 2 describes the sites of lesions which cause the various dysarthria types, what neurological conditions are associated with each type or dysarthria and the speech characteristics associated with the different types of dysarthria.

Dysarthria Type	Site of Lesion	Neurological Condition	Perceptual Characteristics
Flaccid Dysarthria	Lower motor neuron system	• Bulbar Palsy	• Weak voice • Breathiness • Hypernasality • Slow rate of speech • Imprecise consonants (due to reduced muscle tone)
Spastic Dysarthria	Upper motor neuron system	• Pseudobulbar Palsy (impacts face and mouth muscle control, and throat) – common in amyotrophic lateral sclerosis (ALS)/motor neurone disease (MND), multiple sclerosis (MS), and stroke	• Harsh and strained vocal quality • Slow rate of speech • Monotonous • Imprecise consonant production • Hypernasality
Ataxic Dysarthria	Cerebellum and key connections including red nucleus and the inferior olive	• Cerebellar degeneration • MS • Brainstem or midbrain stroke (caused by lesions to the connections to the cerebellum) • Friedreich's ataxia (an inherited progressive disease where the nerve fibres in the spinal cord and peripheral nerves degenerate and thin) • Toxic or metabolic disorders • Traumatic head injury • Cancer (paraneoplastic conditions)	• Hoarse and strained vocal quality • Unstable pitch/pitch breaks • Unstable loudness • Devoicing (vocal cords do not vibrate when producing a voiced phoneme; e.g. /b/ becomes /p/) • Syllabic speech • Irregular articulatory breakdowns • Distorted vowels

Dysarthria Type	Site of Lesion	Neurological Condition	Perceptual Characteristics
Hyperkinetic Dysarthria	Basal ganglia/ Extrapyramidal system	• Chorea	• Increased speech rate • Intermittent breathiness • Distorted vowels • Occasional vocal strain • Vocal tremor • Excessive variations in intensity • Inappropriate vocal noises
Hypokinetic Dysarthria	Basal ganglia/Extrapyramidal system	• Parkinson's Disease	• Imprecise articulation • Repetition of sounds and syllables • Occasional vocal tremor • Weak voice • Breathiness • Increased speech rate • Mono-pitch • Mono-loudness
Mixed Dysarthria	Upper and lower motor neurons	• Motor Neurone Disease	• Speech characteristics related to both flaccid and spastic dysarthria

Table 2 Table Describing the Phenotypes of the Various Types of Dysarthria
(Darley, Aronson and Brown, 1969; Kent et al., 2000; Schröter-Morasch and Ziegler, 2005; Duffy, 2013b)

It is important to note that the Mayo Clinic classification has not been well replicated in other studies. For example, Simmons and Mayo (1997) explained that it can be difficult to use the classification for people with mixed diagnoses, complex needs and co-occurring language impairments. Furthermore, research on the characterisation of dysarthria focuses on acquired dysarthria in adults where the typically developed brain is disrupted through disease or injury. The classification cannot be used for paediatric dysarthria as the child's brain and speech systems have not yet fully developed when injury to the brain occurs and the developmental effects on speech characteristics are not accounted for (Morgan and Liegeois, 2010). Similarities exist between the characteristics of dysarthria and the error patterns of typical development in young children (Hustad, Oakes and Allison, 2015). For example, both dysarthric speech and the speech of young typically developing children may sound breathy (van Mourik *et al.*, 1997) or involve sound/syllable omission (e.g. final consonant deletion), additional sounds, substitutions of one sound for another (e.g. /w/ instead or /ɹ/), stopping, and/or voicing errors (Kim, Martin, Hasegawa-Johnson and Perlman, 2010; Dodd, Holm, Hua and Crosbie, 2003). All these characteristics are normal in developing speech but are classified as disordered in adult speech. As typically developing children develop, their speech matures, and speech errors resolve without any intervention. However, for children with dysarthria, the speech errors persist into adolescence/adulthood, and they require speech and language therapy (SLT) to reduce the speech disorder. It has been suggested that paediatric dysarthria is characterised by universal features, including harsh or strained voice quality, breathiness, monopitch, mono-loudness, imprecise consonants, and distorted vowels (Workinger *et al.*, 1991; van Mourik *et al.*, 1997).

1.5. Dysarthria in Cerebral Palsy

Approximately half of individuals with CP have speech difficulties (Nordberg, Miniscalco, Lohmander and Himmelmann, 2013), most of whom have dysarthria.

1.5.1. *The Impact of Dysarthria on the Speech Subsystems and the Corresponding Perceptual and Acoustic Speech Characteristics*

The dysarthria symptoms experienced by children with CP depend on which speech subsystems are affected.

Perceptual speech characteristics are the qualities of speech which can be perceived by ear, e.g., articulation, pitch, resonance, and voice quality. Children with different types of CP have been found to share perceptual speech characteristics (Workinger *et al.*, 1991; Hustad, Gorton and Lee, 2010). For example, breathiness, harsh voice, and imprecise consonant production have been observed in children with spastic and dyskinetic CP (Nordberg, Miniscalco, Lohmander and Himmelmann, 2013; Byrne, 1959). The developmental nature of motor speech disorders or the presence of mixed disorders may cause this overlap of speech characteristics (Pennington, 2012).

Acoustic speech characteristics are qualities of speech sound wave which are measured instrumentally. They capture data from spectrograms and waveforms and complement perceptual analysis. Acoustic speech characteristics include duration, intensity, fundamental frequency (F_0), and formant frequencies, which are discussed in more detail below. There can be pairings between perceptual features and their acoustic correlates (e.g., ‘loudness’ vs. ‘intensity’), but there is no guarantee that acoustic features will consistently align with perceptual evaluations (Kent *et al.*, 1999).

1.5.1.1. Respiration

An impairment in the respiration subsystem can result in reduced or uncontrolled breath support. Weak respiration causes quiet voice (asthenia), which is an inability to produce or weak production of plosives due to insufficient intraoral pressure (Pennington, 2012; Allison and Hustad, 2018a). Impaired respiratory support may also manifest as excessive loudness variability (Wang *et al.*, 2021).

Vocal intensity is the acoustic counterpart to vocal loudness; thus quiet, weak speech has low intensity. Impairments in the range and control of intensity have been observed in speakers with CP (Patel, 2003) and is associated with intelligibility (Pell, Cheang and Leonard, 2006; Patel and Campellone, 2009; Gao and Ma, 2024). Quieter speech can make articulation less distinct. Thus, intensity may cause issues in perceiving different parts of syllables due to weaker articulation, as a result of limited intraoral pressure, and insufficient air pressure changes, both of which are important for distinguishing speech sounds (Pickett, 1956), consequently impairing speech intelligibility.

1.5.1.2. Phonation

Phonation difficulties cause breathy voice, strained or hoarse voice, vocal flutter or tremor, diplophonia and pitch breaks (Pennington, 2012; Allison and Hustad, 2018b). Vocal tremor and flutter are caused by involuntary muscular contractions of the vocal cords. Vocal tremor refers to tremors occurring at a frequency of around 4-6Hz whereas the tremors associated with vocal flutter are much quicker at a frequency of over 10Hz (Brajot and Lawrence, 2018; Kent *et al.*, 1999). Diplophonia is when the voice is perceived as producing two pitches simultaneously and it is due to the vocal folds vibrating in a quasi-periodic/irregular manner. Breathy voice can be identified by low harmonic-to-signal ratio (HSR) and hoarseness is identified by prominent F_0 intensity and high harmonic-to-noise ratio (HNR) (Kent *et al.*, 1999; Chandrashekar, Karjigi and Sreedevi, 2019). HSR is the mean ratio between the energy of the harmonic components and the total energy of the signal whereas HNR is the ratio between periodic and non-periodic components of speech sound (Chandrashekar, Karjigi and Sreedevi, 2019).

1.5.1.3. Articulation

Articulation deficits cause irregular articulatory breakdown. Articulation errors are perceived as imprecise consonant production, particularly of fricatives and affricates, slurred speech, and distorted vowels (Byrne, 1959; Platt, Andrews, Young and Quinn, 1980). Articulatory control is the primary factor influencing intelligibility among speakers with CP (Lee, Hustad and Weismer, 2014; Nip, Arias, Morita and Richardson, 2017).

The affricate-fricative contrast relies on the difference in the duration of the fricative noise, the mean rise time, and the occurrence of an initial burst. For fricatives, rise time is measured from the onset of frication to the point where intensity peaks. For affricates, rise time is measured from the start of the plosive burst to the point of maximum intensity (Li, Bunta and Tomblin, 2017). Fricatives have a longer duration and mean rise time than affricates (Ansel and Kent, 1992) and an initial burst often occurs in affricates (Huei-Mei Liu, Chin-Hsing and Tsao, 2000). People with CP have been found to produce initial bursts on 18% fricatives compared to 1% in typical speakers (Huei-Mei Liu, Chin-Hsing and Tsao, 2000). This obscures the contrast between affricate and fricative productions. The occurrence of initial bursts indicates the difficulty that some people with CP have coordinating articulatory movements when constricting the vocal tract to accurately produce fricatives.

Contrasts between high-low vowels, front-back vowels, tense-lax vowels, and fricative-affricate consonants have significant influence on intelligibility (Ansel and Kent, 1992; Platt, Andrews and Howie, 1980; Platt, Andrews, Young and Quinn, 1980). High-low vowels are defined based on the highest position of the tongue. High vowels, i.e., /i/ (e.g., ‘sheep’), are produced with the tongue high towards the roof of the mouth. Low vowels, i.e., /æ/ (e.g., ‘cat’), are produced with the tongue low in the mouth. Front-back vowels are defined based on tongue advancement/retraction during the articulation of the vowel. For example, /i/ is a front vowel as the tongue is pushed forward in the mouth and /u/ (e.g., ‘rule’) is a back vowel as the back of the tongue is raised towards the soft palate. Tense-lax vowels vary in terms of length, articulation, and occurrence. Lax vowels are shorter than tense vowels of comparable height, i.e., /ɪ/ (e.g., ‘ship’) is shorter than /i/ (e.g., ‘sheep’). In terms of articulation, the oral musculature is relatively looser when articulating lax vowels compared to tense vowels. Lax vowels usually occur in single syllable words ending in consonants, whereas tense vowels usually occur in word-final position of single syllable words. /ɪ/ is an example of a high, front, lax vowel.

The vowel space is a visual representation of the range of vowels in a language, typically depicted using a two-dimensional illustration (Story and Bunton, 2017; Sandoval *et al.*, 2013). It plots vowel location in either the acoustic or auditory space. In terms of the auditory space, the graph represents positions that differ in equidistant auditory steps, sometimes corresponding to equidistant articulatory steps as well. When representing the acoustic vowel space, the y-axis represents the first formant (F1) frequency, and the x-axis typically represents the frequency gap between F1 and the second formant (F2) (see Figure 2 (Hitch, 2017)). F1 generally relates to the size of the oral cavity created by jaw displacement, while F2 relates to the shape of the oral cavity created by tongue position (Sandoval *et al.*, 2013). Higher tongue positions lower F1 and more fronted tongue positions increase F2 (Liu, Tsao and Kuhl, 2005).

The acoustic properties of vowels are extremely important for speech intelligibility. They inform acoustic cues for consonants through formant transitions for consonant-vowel and vowel-consonant sequences as well as prosodic patterns of speech (Vorperian and Kent, 2007). Vowels carry a considerable amount of prosodic information through pitch, duration and intensity (Im, 2023). Due to their restricted orofacial muscle movements, children with CP have a reduced vowel working space area compared to typically developing speakers (Liu, Tsao and Kuhl, 2005). A reduced acoustic vowel space impedes a speaker's ability to achieve extreme tongue positionings, formant frequencies are affected. The reduced range of phonemes accurately produced by children with CP is often due to their limited lip and tongue muscle control (Strand, 1995).

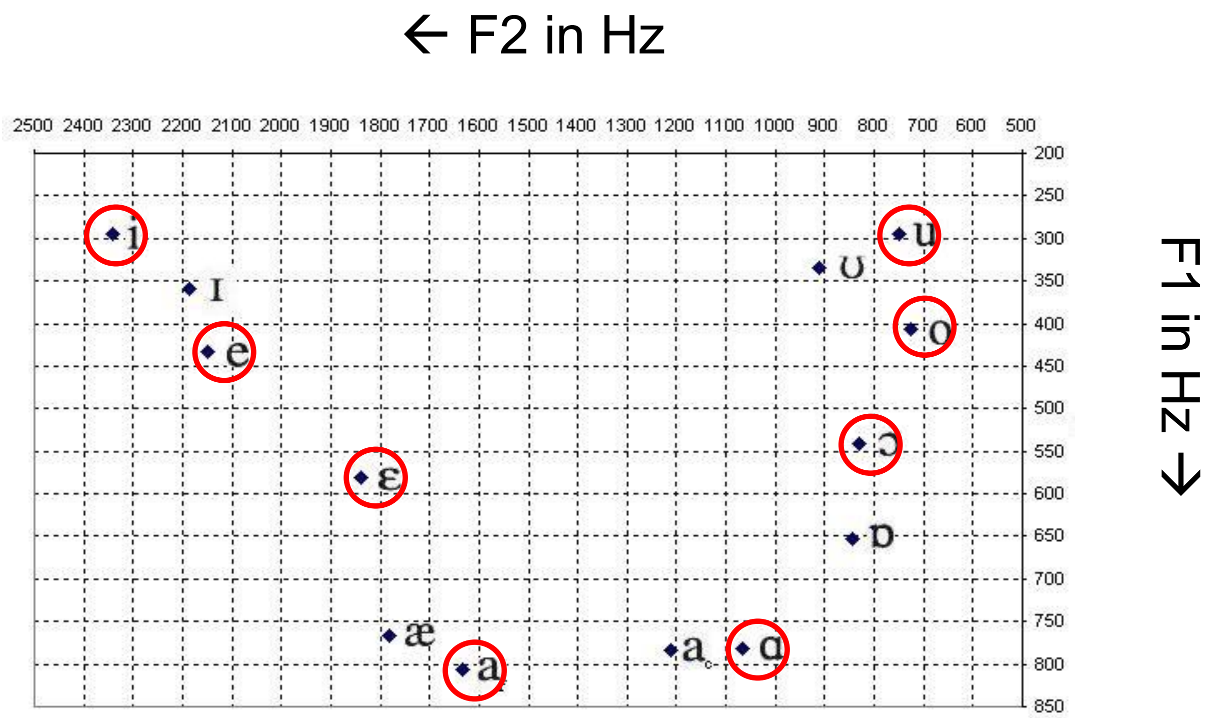

Figure 2 F1 And F2 Of English Vowels Produced by a Typically Speaking American English Adult Male

1.5.1.4. Resonance

Hypernasality and hyponasality are due to problems with resonance and limited control of the velum. Hypernasality is caused by air escaping through the nasal cavity because of incomplete closure of the soft palate and it can cause certain consonants to sound weak or even be omitted. Acoustically this can be seen as decreased overall energy of vowels, increased formant bandwidth, the presence of low-frequency nasal formant, slightly raised F1 and lowered F2, presence of anti-formants (Dam and Ivaskó, 2024; Ansel and Kent, 1992). Hyponasality is due to a lack of air escaping through the nasal cavity which results in speech sounding ‘stuffy’. Hyponasality results in a weakened nasal formant and reduced low-frequency energy (De Boer and Bressmann, 2016). Another resonance disorder is known as cul-de-sac resonance. This occurs when the airflow becomes trapped in the oral or nasal cavity causing speech to sound muffled.

1.5.1.5. Prosody

Prosody refers to relative perceptual changes in pitch, loudness and rate of speech (Pell, Cheang and Leonard, 2006). Acoustically, these changes are characterised as changes in F_0, intensity, and duration respectively. Prosody is dependent on laryngeal and respiratory control (Strand, 1995; Duffy, 2020). If problems occur within this subsystem, it is likely people will experience reduced, equal or excessive stress, mono-pitch, unexpected or lengthy silences, and fluctuating or inappropriate speech rate (Tjaden and Liss, 1995; Patel, 2003).

The perceptual marker of stress and signalling the question-statement contrast is pitch which is related to the regulation of the acoustic feature F_0 (Patel and Campellone, 2009; Tjaden and Wilding, 2011b; Kuschmann, Miller, Lowit and Pennington, 2017). People with CP and dysarthria are known to display less variation in F_0 (Patel, 2003; Patel and Campellone, 2009; Hixon and Hardy, 1964). Reduced range of F_0 is perceived as monopitch and this impacts a dysarthric speaker’s ability to mark different speech contrasts and stress patterns, reducing speech intelligibility (Laures and Weismer, 1999; Sheard, 2001).

Excessively fast or slow speech rate has been observed in speakers with CP and dysarthria (Patel, 2003). Acoustically, this is measured as duration (syllables per second), with shorter duration measures indicating faster speech rate and longer duration measures indicating slower speech rates. Dysfluencies, non-linguistic speech material (e.g., sounds and gestures) and pauses are included in speech rate measurements (Gold, 2018).

Fast speech rate reduces precision of articulatory movements, which exacerbates intelligibility deficits already caused by their motor disorder in speakers with CP and dysarthria. A fast speech rate may lead to undershooting articulatory targets, resulting in imprecise phoneme production or blurred phoneme and word boundaries (Turner and Weismer, 1993), further impacting speech intelligibility. The speech rate of children with CP and dysarthria is often perceived as fast when it is beyond their neuromuscular control (Blanchet and Snyder, 2010; Yorkston, 1999). However, their rate is usually slower than typically developing speakers (Hustad, Gorton and Lee, 2010; Nip, 2013; Hodge and Gotzke, 2014b; Workinger *et al.*, 1991; Allison and Hustad, 2018a; Turner, Tjaden and Weismer, 1995).

Reduced speech rates in children with CP is attributed to slower articulation rates, and less efficient movement of the articulators, and longer pause durations (Haas, Ziegler and Schölderle, 2022; Nip, Arias, Morita and Richardson, 2017; DuHadway and Hustad, 2012; Darling-White, Sakash and Hustad, 2018; Darling-White and Jaeger, 2023). Articulation rate is a measure of speech rate which does not capture dysfluencies and silent pauses (Gold, 2018). It measures the speed at which articulators move and is typically measured in syllables per second (Walker and Archibald, 2006; Haselager, Slis and Rietveld, 1991). The definition of a pause varies across the literature, being classified as a period of silence of at least 150 milliseconds (ms) (Darling-White and Banks, 2021; Darling-White, Sakash and Hustad, 2018), 200ms or more (Turner and Weismer, 1993), or over 250ms in duration (Allison, Yunusova and Green, 2019).The reduced articulation rate in children with CP and dysarthria suggests that these children need more time to execute articulatory movements than typically developing children (Nip, 2013). Slow speech rate can impact intelligibility as it can strain the listener’s short term memory and negatively affect comprehension during longer interactions (Hustad, 2008). It can also disrupt natural intonation and rhythm, making speech sound monotonous which can reduce communication effectiveness (Le Dorze, Ouellet and Ryalls, 1994).

1.5.1.6. Summary of Impaired Speech Subsystems

Speech Subsystem	Impact on Speech if Impaired
Respiration	• Shorter phrases • Excessive loudness variation • Uncontrolled loudness • Inability to produce/weak production of plosives • Reduced control and range of intensity
Phonation	• Mono-pitch • Inappropriate pitch levels • Breathy voice • Strained or hoarse voice • Vocal flutter or tremor • Diplophonia • Pitch breaks • Reduced control and range of F_0
Articulation	• Irregular articulatory breakdown • Slurred speech • Imprecise consonant production (particularly of fricatives and affricates) • Distorted vowels • Reduced vowel space (affecting formant frequencies) • No plosive burst/low intensity burst
Resonance	• Hypernasality • Hyponasality • Cul-de-sac resonance
Prosody	• Reduced, equal or excessive stress • Unexpected or lengthy silences • Fluctuating or inappropriate speech rate • Slower articulation rates

Table 3 Table Showing the Perceptual and Acoustic Speech Characteristics Associated with Impaired Speech Subsystems in People with Cerebral Palsy

1.6. Intelligibility

Intelligibility is the degree to which a listener can understand a speaker's speech. Intelligibility can be signal-dependent or signal-independent. Signal-dependent intelligibility requires a listener to decode the speech signal solely from the clues provided in the acoustic signal such as the supra-segmental features such as stress, syllable boundaries and intonation, the segmental features, i.e., consonants and vowels, and phonotactic probability. Phonotactic probability describes the likelihood of phonological segments and segment sequences occurring in a language, e.g. in English, /tɹ/ occurs more frequently in WI position compared to /fɹ/ (Gupta and Tisdale, 2009). Signal-independent intelligibility, which is also known as contextual intelligibility or comprehensibility (Yorkston, Strand and Kennedy, 1996), incorporates verbal cues such as syntax and semantics, and non-verbal cues including gestures, facial expressions, and body language, alongside the acoustic signal. These additional cues often enhance a degraded speech signal (Miller, 2013). More recently, researchers and clinicians have reserved the term intelligibility as signal-dependent and comprehensibility as signal-independent information (Pommée *et al.*, 2020).

Speech intelligibility and comprehensibility both play vital roles in clinical decision making and monitoring, being fundamental for successful communication and social participation (Hustad, 2012). Improving or maintaining intelligibility is often the primary target of SLT for people with dysarthria (Miller, 2013), and is recommended for children with CP by the Royal College of Speech and Language Therapists (RCSLT) and the National Institute for Health and Care Excellence (NICE) **.**

1.6.1. *Factors Influencing Speech Intelligibility*

1.6.1.1. Speaker Influences

Intelligibility is influenced by speech loudness. Louder speech is associated with slower speech rate which often improves articulation due to the speaker having more time to precisely place their articulators (Tjaden, Sussman and Wilding, 2014), and it may enhance intelligibility due to improvements in the signal-to-noise ratio (SNR) (Neel, 2009).

Vocal tract shape and vowel space size influences speakers' intelligibility. A bigger vowel working space is associated with more intelligible speech (Bradlow, Torretta and Pisoni, 1996). As described above, young children and people with dysarthria have poor intelligibility because they have a small vowel space and cannot differentiate vocal tract shape necessary to accurately produce corner vowels, i.e. /i/, /a/, and /u/ (Liu, Tsao and Kuhl, 2005; Levy *et al.*, 2016; Vorperian and Kent, 2007).

The rise and fall of a speaker's F_0 contour (perceived as pitch) is used to emphasise key words in utterances (Laures and Weismer, 1999). Speakers often employ stress to enhance intelligibility because stress patterns are used by listeners to decode the speech signal and identify word boundaries for lexical access (McClelland and Elman, 1986).

Intelligibility is more likely to improve when a speaker voluntarily adapts aspects of their speech signal, particularly when speaking to listeners who have difficulty processing speech, e.g., those with hearing impairment (Van Engen, Chandrasekaran and Smiljanic, 2012). However, speakers' ability to adjust their speech signal in response to listener reactions may be limited due to underlying conditions affecting speech production, age, or cognition (Ho, Bradshaw, Iansek and Alfredson, 1999; Ho, Iansek and Bradshaw, 1999; Goberman and Elmer, 2005; Smiljanic, 2013).

1.6.1.2. Listener Influences

Listeners implement both bottom-up and top-down strategies help to overcome speaker intelligibility deficits caused by dysarthria (Klasner and Yorkston, 2005). The pronunciation of utterances can vary considerably between speakers of different dialects and accents even when the content and communicative environment are constant (McCloy, Wright and Souza, 2015). The acoustic-phonetic and lexical knowledge is already available when a speaker's dialect is the same as, or familiar to, the listener's (Clopper and Bradlow, 2008), and can aid intelligibility even when other factors act to reduce intelligibility, such as background noise. Listener familiarity with listening to a speech disorder and the test material can also influence intelligibility scores (Liss, Spitzer, Caviness and Adler, 2002; Borrie *et al.*, 2012; Hustad and Cahill, 2003b; McCloy, Wright and Souza, 2015). Higher intelligibility ratings are linked to greater familiarity.

A listener's age can impact intelligibility ratings as elderly listeners may have presbycusis (age-related hearing loss), causing difficulty with speech recognition

(Humes *et al.*, 1994). Listener cognition will also influence intelligibility as processing a degraded speech signal has greater effects on wider cognitive functions such as attention and recognition memory (Van Engen, Chandrasekaran and Smiljanic, 2012).

1.6.1.3. Environmental Influences

Environmental factors, such as the volume of competing background noise or the availability of additional cues, such as visual prompts, influence intelligibility. Background noise is a form of masking which interferes with the speech stimuli (Harmon, Dromey, Nelson and Chapman, 2021). Background noise has been found to adversely impact the intelligibility of people with neurological speech disorders. The intelligibility of dysarthric speech is reduced more than typical speech due to the inherent source of degradation in the speech (Yoho and Borrie, 2018). However, when visual information is available, in addition to the speech signal, speech recognition is enhanced, even with background noise (Tseng *et al.*, 2019).

1.6.1.4. Linguistic Influences

Semantics, morphology, and syntax affect intelligibility. Semantics play a role in supporting speech intelligibility. The more semantic context available, the easier it is to understand the speech signal (Obleser and Kotz, 2010). The greater the semantic predictability of a sentence, the easier it will be to understand, even when the speech signal is degraded (Obleser and Kotz, 2010; Obleser, Wise, Dresner and Scott, 2007). Furthermore, words presented in sentences with rich semantic contexts are more intelligible than words in abstract sentences or single words, especially when the speech signal is degraded (McGettigan *et al.*, 2012).

Distinct word boundaries enhance speech intelligibility. Increased speech rate reduces the clear boundaries between words, but other cues can help determine them, such as the aspiration of plosives on stressed words or glottal stops preceding vowels word initially in English (McClelland and Elman, 1986; Nakatani and Dukes, 1977). If phonetic cues are insufficient for listeners to locate word boundaries semantic and syntactic context convey particular advantage by limiting the word possibilities and aid speech segmentation (Cole and Jakimik, 1980; McClelland and Elman, 1986).

1.7. Intelligibility of Children with Cerebral Palsy and Dysarthria

Dysarthria characteristics such as reduced or varying vocal loudness, fluctuating speech rate, strained voice, and imprecise articulation cause deficits in speech intelligibility (Chang *et al.*, 2024; Allison and Hustad, 2018a; Tjaden and Wilding, 2004).

The phonetic features with the greatest impact on speech intelligibility in dysarthric speakers are articulation errors including less precise fricative and affricate production, less precise voiceless coronal (e.g., /t/ or /s/) and labial obstruents (e.g./p/ or /f/) due to the co-ordination needed between laryngeal and supra-laryngeal mechanisms, greater misarticulation of word-final consonants compared to word-initial, voicing and devoicing errors, and failure to employ extreme positions in the vowel articulatory space resulting in inaccurate vowel production (Platt, Andrews, Young and Quinn, 1980; Platt, Andrews and Howie, 1980; Nordberg, Miniscalco and Lohmander, 2014; Love, 2000; Pennington *et al.*, 2023; Schölderle, Haas and Ziegler, 2020).

Specifically for children with dysarthria and CP, the main features contributing to their speech intelligibility include articulation rate, maximum utterance length, and vowel space area (DuHadway and Hustad, 2012; Lee and Hustad, 2013). Children with CP and dysarthria demonstrate variable or decreasing intelligibility as utterance length increases (Allison and Hustad, 2014). Both adults and children with CP and dysarthria experience problems regarding the place of articulation (PoA) and manner of articulation (MoA) of consonants (Byrne, 1959; Platt, Andrews, Young and Quinn, 1980). Deficits in the articulatory subsystem were hypothesised to contribute the most to reductions in speech intelligibility in children with CP and dysarthria (Lee, Hustad and Weismer, 2014; Levy *et al.*, 2016). However, respiratory, prosodic, and articulatory deficits have been observed and thought to be strong predictors of intelligibility in both children and adults with CP and dysarthria (Lee, Hustad and Weismer, 2014; Schlöderle *et al.*, 2016). Therefore, all speech subsystems should be targeted when assessing intelligibility in individuals with CP and dysarthria (Schlöderle *et al.*, 2016).

1.8. Impact of Reduced Intelligibility on Children with Cerebral Palsy and Dysarthria

Poor speech intelligibility can have serious adverse impacts for children, including poor school attainment and employment prospects, frustration, being subject to bullying and a lack of interest from their communication partners (Coppens-Hofman, Terband, Snik and Maassen, 2016; Felsenfeld, Broen and McGue, 1994; Sweeting and West, 2001). Effective communication is a critical health outcome for both children with a neurodisability and their parents (Morris *et al.*, 2014) and improving speech intelligibility is often a fundamental goal for children with CP and dysarthria (Chang *et al.*, 2024). The NICE guideline for the assessment and management of CP in under 25s (NICE, 2017) and the RCSLT (RCSLT, 2006) recommends provision of intervention to improve speech intelligibility and facilitate social participation.

1.9. Summary

CP is the most common cause of motor disorder in childhood and many children with CP have dysarthria. Epidemiological research into CP shows patterns of association across children. However, CP is an umbrella term; children with CP are heterogeneous in terms of the presence and severity of their motor, cognitive, and sensory impairments, as well as their speech patterns. Dysarthria can impact any of the speech subsystems supporting speech production, resulting in various speech deficits. In CP of the most common speech deficits include a weak voice, breathiness, a hoarse or strained vocal quality, monotonous speech, imprecise affricate, fricative and vowel production, fluctuating speech rate and variable intensity. These speech characteristics reduce intelligibility making children with CP and dysarthria difficult to understand. Poor intelligibility impedes children's abilities to communicate with others and can result in reduced participation and poorer QoL, particularly if the motor disorder and speech impairment are severe. It is vital that these children receive SLT to improve their intelligibility and support and encourage communication. A secondary benefit is for improved intelligibility to hopefully increase social participation and improve QoL in this population.

1.10. Overview of Thesis

The next chapter (Chapter 2. Literature Review) critically appraises the existing dysarthria interventions and discusses the vocal cues aiming to promote intelligibility gains. It addresses the research questions and aims investigated in this study. Chapter 3. Methodology: Intelligibility and Its Measurement provides justification for the choice of method used to collect the data as well as evaluating other methods which have been used in similar research. The methods used for recruiting participants, delivering the intervention, data collection, conducting the listener study, and analysing the perceptual and acoustic data are discussed in Chapter 4. Method. The group findings from the perceptual data can be found in Chapter 5. Results: Perceptual Analysis and the exploratory acoustic findings for each participant are reported in Chapter 6. Acoustic Results. The Perceptual and Acoustic Results chapters reveal the effect of the personalised intervention on intelligibility and discuss what may have accounted for the change in intelligibility. A third Results chapter (Chapter 7. Reflection on the Process, Acceptability, and Feasibility of the Online Personalised Intervention) reflects on the process of the intervention and touches on the feasibility of using acoustics to inform the intervention. Chapter 8. Discussion contextualises the results in relation to existent research, addressing the study's strengths and limitations, its implications, and recommendations for clinicians, as well as any unanswered questions and future research stemming from this study.

Chapter 2. Literature Review

2.1. Summary

The previous chapter provided information on CP, dysarthria, and the impact these disorders have on children's speech intelligibility. Although certain characteristics are said to be related to specific dysarthria types, most children with CP and dysarthria present with shared speech characteristics, e.g., breathy, hoarse/strained vocal quality and a monotone voice (Workinger *et al.*, 1991; van Mourik *et al.*, 1997). Hence, classifying dysarthria by severity of symptoms may be more beneficial for planning SLT compared to classification associated with the location of a brain lesion.

As the previous chapter explained, the disordered speech characteristics experienced by children with CP and dysarthria, e.g., weak plosive production, voicing errors, distorted vowels, and misarticulation of affricates and fricatives, can greatly reduce intelligibility. This chapter begins by discussing vocal cues which can be given to children with CP and dysarthria to promote intelligibility gains by targeting different speech subsystems, depending on what speech characteristics are perceived. It then goes on to evaluate the different interventions that have been used for people with dysarthria and children with CP and dysarthria. The final section of this chapter reviews the need for personalising dysarthria intervention so that it targets individual children's speech characteristics, the possible approaches to individualise the intervention, and the perceptual changes to children's speech predicted to occur through the personalised intervention.

2.2. Vocal Cues to Promote the Greatest Intelligibility Gains

As mentioned previously, children with CP and dysarthria have reduced intelligibility due to their motor speech disorder affecting control of the speech subsystems needed to support speech production. It is essential for these children to receive support and therapy to improve their intelligibility.

The ICF recommends addressing an individual's functioning and disability within the broader context of their environment (WHO, 2001). This approach moves away from defining an individual solely in terms of their disability, a practice that has faced criticism for being unethical (Hurst, 2003; Threats, 2010). Frequent communication partners (i.e., family and teachers) can be trained to tune into the speech of children with CP and dysarthria by familiarising themselves with their speech characteristics and errors. This can result in children with CP and dysarthria being more intelligible to familiar listeners (Flipsen Jr, 1995; Mei *et al.*, 2014). However, children with CP and dysarthria encounter lots of different people in various environments where speaking and listening conditions are not always ideal. Subsequently, training all communication partners to tune into the child's speech is not practical. Therefore, it may be more efficient to teach children ways to adjust certain aspects of their speech.

Children with CP and dysarthria may be able to manipulate certain perceptual speech characteristics if they are under volitional neural control, e.g., reduced pitch, fluctuating intensity, breathiness, and imprecise articulation. Vocal cues are verbal instructions given to speakers to direct their attention to the perceptual speech characteristics which could potentially be adapted (e.g., rapid, quiet, or slurred speech) to enhance their intelligibility. Vocal cues include 'clear' (Levy, Chang, Ancelle and McAuliffe, 2017; Park, Theodoros, Finch and Cardell, 2016), 'loud' (Levy, Chang, Ancelle and McAuliffe, 2017) and 'smooth' (Pennington, Lombardo, Steen and Miller, 2018; Stocks, Dacakis, Phyland and Rose, 2009). Due to their developing cognition and language understanding, children may require simple vocal cue names/instructions to target the different speech features. Therefore, cue names vary between studies depending on whether the participants are adults with dysarthria or children with dysarthria. Children have been found to respond negatively to the cues 'speak clearly', stating that they were often told to do this in a scolding manner, and 'loud', which resulted in vocal strain in some children (Levy, Chang, Ancelle and McAuliffe, 2017). Child-friendly cues including 'big mouth', 'strong voice' (Levy, Chang, Ancelle and McAuliffe, 2017) and 'nice and easy' (Pennington, Lombardo, Steen and Miller, 2018) have been developed. Levy et al. (2017) associates 'big mouth' and 'strong voice' to 'clear' and 'loud' respectively. 'Nice and easy' is the child-friendly cue for 'smooth speech'.

2.2.1. *Smooth Speech/Nice and Easy*

'Smooth speech' targets the speech subsystems of respiration, prosody, and articulation as well as speech rate. The cue promotes consistent respiratory effort across a phrase, initially at a slow rate of speech and then at gradually increasing speech rates.

The intended outcomes of 'smooth speech' would be (a) controlled breath support throughout a phrase so more aerodynamic energy is preserved to modulate pitch and mark stress to better convey their communicative intentions, and (b) control speech rate, allowing more time to make precise articulatory movements to improve their overall speech production, and hence intelligibility. Better coordination of respiration with phonation is predicted to generate a clearer vocal signal which supports the production of longer utterances by reducing air wastage according to the Source Filter Model (Kent and Read, 1992). As a result of this increased coordination, speech may sound louder and it may allow for speakers to produce a greater range of pitch (Duffy, 2005), even though these features are not directly targeted. Reducing speech rate allows more time to accurately place articulators to increase differentiation of individual phonemes and hence improve intelligibility.

A comprehensive and intensive therapy programme based on 'smooth speech' has previously been trialled with a female adult with ataxic dysarthria (Stocks, Dacakis, Phyland and Rose, 2009). The therapy involved employing gentle onsets, sliding in to phonemes or words, longer vowel durations and controlled exhalation to link words, initially at a slow speech rate and then at gradually increasing speech rates to see if the skills could be maintained. Findings from 'Smooth speech' included improved production of prosodic speech features, with the individual being able to produce a higher modal pitch, a greater pitch range, better stress patterning and an increased speech rate. Improvements were also found in the participation and activity domains of the World Health Organization's (WHO) International Classification of Functioning, Disability and Health (ICF) (Dickinson *et al.*, 2007; WHO, 2001). Although speech 'naturalness' improved, , 'smooth speech' did not increase speech intelligibility or reduce the articulatory impairments associated with ataxic dysarthria, for example imprecise speech movements (Stocks, Dacakis, Phyland and Rose, 2009). Therefore, ‘smooth speech’ may not be appropriate for improving the intelligibility of those with ataxic dysarthria.

Pennington et al. (2010; 2013) used ‘nice and easy’ as a cue for children with spastic and dyskinetic CP who had difficulty initiating movements and inappropriate variability in intensity, in their study of the SSA approach.. As a group, the children were shown to make intelligibility gains. However, different vocal cues, including ‘strong voice’, ‘loud’ and ‘big mouth’, were used with other children for whom ‘nice and easy’/’smooth’ was not appropriate for. The vocal cues were not separated in the evaluations nor were any comparisons made between them, so it was not possible to conclude that ‘nice and easy’/’smooth’ contributed to the intelligibility improvements. This uncertainty reinforces the need for further research on the impact of ‘smooth speech’/’nice and easy’ on the intelligibility of children with CP and dysarthria.

2.2.2. *Loud Speech/Strong Voice*

The vocal cue ‘loud speech’/’strong voice’ targets the respiration, phonation, articulation, and resonance speech subsystems. The mechanism involves increasing aerodynamic energy, leading to greater aeroacoustic energy and thus increased speech intensity across utterances, and increased vowel space, due to the changes in F1 and F2 associated with increased loudness (Tjaden *et al.*, 2013).

The intended outcomes of ‘loud’/’strong’ include the ability to (a) generate a strong signal and maintain it to the end of an utterance so that all phonemes can be perceived; and (b) produce more accurate articulation due to louder speech making speech errors more audible, thus more detectable, thereby facilitating adjustments for improved articulatory precision.

Increasing vocal intensity can have positive effects across the speech subsystems without targeting them directly (Dromey, Ramig and Johnson, 1995; Sapir *et al.*, 2007). Increased loudness improves articulatory precision because loud speech results in increased movement of the articulators, particularly jaw displacement, and lip rounding and spreading (Schulman, 1989; Tasko and McClean, 2004). This indicates an overlap with the cue ‘big mouth’ which encourages increased oral tract displacement to achieve more distinctive articulation- this is required for intelligible speech (Nip, 2024; Mefferd, 2017). ‘Loud speech’ as a cue has been found to improve intelligibility at sentence and word level (Neel, 2009). Increases in vocal intensity have been found to be accompanied by reduced speech rate in dysarthric speakers (Tjaden *et al.*, 2013) and have also had impact on prosodic impairments by improving F_0 variation for example (Tjaden and Wilding, 2011b). Increased vocal intensity has been found to be related to other types of segmental changes including enhanced spectral distinctiveness for plosives as well as increased movement velocities and displacements (Sapir *et al.*, 2007; Tjaden and Wilding, 2004).

Similar improvements have been found in children with CP. Children with CP and dysarthria demonstrated longer speech durations after employing ‘loud’ (Levy, Chang, Ancelle and McAuliffe, 2017) as well as increased articulatory precision, with better range and speed or oro-motor movements (Nip, 2024). Improvements in vocal quality of children with spastic CP and dysarthria has also been found, with reduced strain and breathiness post therapy targeting ‘loud’ speech (Fox and Boliek, 2012). ‘Loud’/’strong’ speech may enable children with CP and dysarthria to generate more accurate speech productions with fewer phonetic contrast errors and to reduce the weakness and breathiness of their voice.

2.2.3. *Clear Speech/Big Mouth*

It is thought that ‘clear speech’ may be a global cue affecting all the speech subsystems. The mechanisms of ‘clear speech’/’big mouth’ involve hyperarticulation through increased orofacial muscle movement, decreased speech rate due to a larger articulatory space increasing the time it takes to reach articulatory targets (Levy, Chang, Ancelle and McAuliffe, 2017; Bradlow, Kraus and Hayes, 2003), and subsequently more accurate speech production as speakers have more time to place articulators precisely.

The child-friendly cue ‘big mouth’ focuses on increased jaw displacement and most closely resembles the techniques used for eliciting overenunciated clear speech in adults (Bradlow, Kraus and Hayes, 2003; Moya-Galé, Keller, Escorial and Levy, 2021).

The proposed outcomes of ‘clear speech’ are increased articulatory movement through hyperarticulation (Ferguson and Kewley-Port, 2002; Perkell, Zandipour, Matthies and Lane, 2002; Lam and Tjaden, 2013), reduced speech rate (Park, Theodoros, Finch and Cardell, 2016; Yorkston, Beukelman, Strand and Hakel, 2010; Srinivasan and Narayanan, 2024), and more accurate speech production due to better articulatory control (Martel-Sauvageau, Breton, Chabot and Langlois, 2021; Yorkston, Beukelman, Strand and Hakel, 2010; Srinivasan and Narayanan, 2024), hence improving speech intelligibility.

Improvements in intelligibility are predicted as an outcome as typically developing speakers have been perceived as 17% to 26% more intelligible after employing the ‘clear speech’ cue compared to their habitual speech by both hearing impaired listeners (Payton, Uchanski and Braida, 1994; Picheny, Durlach and Braida, 1986) and healthy listeners in noise (Payton, Uchanski and Braida, 1994). Intelligibility gains have also been observed in speakers with dysarthria who have used ‘clear speech’. Stipancic et al. (2016) found that the sentence intelligibility of dysarthric speakers with Multiple Sclerosis (MS) and PD was greater when using ‘clear speech’ (and ‘loud speech’) compared to their habitual speech.

‘Clear speech’ was applied as a therapy technique known as ‘Be Clear’ which has been trialled with adults with non-progressive dysarthria (Park, Theodoros, Finch and Cardell, 2016). This intensive intervention yielded improvements in everyday communication measures as well as short-term (immediately post-therapy) and long-term (one to three months post-therapy) increases in perceptual speech intelligibility. Improvements in speech intelligibility were observed in both those who had stroke and those who experienced a traumatic brain injury (TBI). Since there are no known neurophysiological contraindications to using ‘clear speech’, it may be an appropriate cue for children with CP and dysarthria. However, as they may find the cue difficult to understand, using a more child-friendly term, such as ‘big mouth,’ could be more effective (Levy, Chang, Ancelle and McAuliffe, 2017).

However, there is a lack of research regarding the most effective way to implement ‘clear speech’ as a potential intervention. As a control group was not used in Park et al.’s (2016) study, it is unknown whether the outcomes of ‘Be Clear’ differ from interventions currently used by SLTs in a clinical setting. Furthermore, as the study sample size was small (n = 8), the findings cannot be generalised.

Children with spastic CP have been found to make significant improvements in intelligibility at both sentence and word level using this prompt (Levy, Chang, Ancelle and McAuliffe, 2017). Levy et al. (2017), found that 'big mouth' led to significantly greater gains in SW intelligibility than 'strong voice' for children with CP and dysarthria. However, the sample used in this study was small, consisting of only eight children with spastic CP, and therefore this conclusion cannot be generalised to the population of children with CP and dysarthria. Nonetheless, this finding is consistent with results obtained from 'clear speech' versus 'loud speech' studies on adults with dysarthria and PD (Tjaden, Sussman and Wilding, 2014).

A recent study by Chang and colleagues (Chang *et al.*, 2024) found that 'big mouth' resulted in significantly better ease of understanding (EoU) in Korean-speaking children at SW level compared to children's everyday speech. They also found the same result for 'strong voice', however 'strong voice' also improved EoU at sentence level, whereas 'big mouth' did not. Chang et al.'s findings suggest that 'big mouth' may be more beneficial for stress-timed languages. As 'big mouth' lengthens syllable durations, it may adversely impact prosody and make speech sound less natural which could reduce intelligibility (Chang *et al.*, 2024). Reduced naturalness as a result of reduced speech rate has been reported in American English speakers (Tjaden, Sussman and Wilding, 2014), Korean-speaking children (Levy, Chang, Ancelle and McAuliffe, 2017), and French-speaking children (Levy *et al.*, 2020).

'Clear speech' also causes acoustic-phonetic modifications including decreased speech rate, increased F_0 and frequency range, longer pause duration and a larger vowel space (Picheny, Durlach and Braida, 1986; Bradlow, Kraus and Hayes, 2003). Changes in vowel formants, particularly F1 and F2, have been observed in children with dysarthria and CP when speaking using 'big mouth' compared to their habitual speech (Levy, Chang, Ancelle and McAuliffe, 2017). This was likely due to greater jaw displacement (predicted from the higher F1 in the production of the low back vowel /a/) and a more fronted tongue when producing front vowels (predicted from changes in F2, which were similar to findings found in Ferguson and Kewley-Port's (2007) study).

No obvious relationships have been found between child age and dysarthria severity in response to 'strong voice' and 'big mouth' (Levy, Chang, Ancelle and McAuliffe, 2017). Further exploration is needed to discover which cue yields stronger intelligibility gains for certain children. However, acoustic measures indicate that children can produce positive differential changes in speech in response to both cues, implying that they are appropriate prompts to incorporate into SLT for children with CP and dysarthria. Furthermore, ‘clear’ and ‘loud’ have demonstrated similar magnitudes of increased speech intelligibility suggesting feasibility of using either of these two cues (Tjaden, Sussman and Wilding, 2014).

As CP and dysarthria are heterogeneous disorders, causing different speech characteristics, vocal cues are likely to have varying success rates across children. Thorough assessment of the child’s acoustic and perceptual speech characteristics must be completed before intervention and different cues trialled with each child until the most efficient is determined. It is possible that for some children, more than one vocal cue may need to be employed over the course of therapy depending on the severity of their dysarthria and their response to the cue.

2.2.4. *Summary of Vocal Cues*

Vocal Cue	Speech System Target	Mechanism	Perceptual Outcomes	Acoustic Outcomes	Evidence in Speakers with Dysarthria	Evidence in Children with CP
Smooth Speech / Nice and Easy	• Respiration • Prosody • Articulation • Rate of Speech	• Supports initiation of movements at the beginning of speech • Improves coordination of all the speech components • Promotes consistent respiratory effort across a phrase • Promotes controlled breath support so more energy is preserved for prosodic elements such as pitch modulations & stress marking	• Greater pitch range • Better stress patterns • Steadier speech • Steady loudness across utterances	• Higher modal pitch/F_0 • Reduced fluctuations in intensity across utterances • Increased but steady speech rate	• (Stocks, Dacakis, Phyland and Rose, 2009): - Higher modal pitch & greater pitch range - Better stress patterning - Increased speech rate - Improved participation & activity - Improved speech naturalness but not intelligibility - No changes in articulatory impairments	• Improvement in intelligibility for both SWs & CS (Pennington, Miller, Robson and Steen, 2010; Pennington *et al.*, 2013)
Loud Speech / Strong Voice	• Respiration • Phonation • Articulation • Resonance	• Greater aerodynamic energy → greater aeroacoustic energy → increased speech intensity & steadier intensity across utterances • Promotes increased vowel space across utterances	• Louder speech • Stable loudness across a phrase • Reduced vocal weakness & breathiness • Longer utterances • Slower speech	• Increased intensity • Reduced speech rate • Improved spectral distinctiveness for plosives • Increased movement velocities & displacements • Increased vowel space	• Increased vocal intensity • Reduced speech rate • Improved articulatory precision • Improved intelligibility at word and sentence level	• Increased vocal intensity • Longer speech durations • Better EoU at SW & sentence level

Vocal Cue	Speech System Target	Mechanism	Perceptual Outcomes	Acoustic Outcomes	Evidence in Speakers with Dysarthria	Evidence in Children with CP
Clear Speech / Big Mouth	• Respiration • Phonation • Articulation • Resonance • Prosody	• Promotes hyper-articulation through increased orofacial muscle movement • Promotes slower speech as more time is required to reach articulatory targets • More time to precisely place articulators resulting in more accurate speech production • Respiratory-phonatory adjustments accompany clear speech	• Slower speech • Increased pitch range • Better articulatory control • More precise phoneme production • Greater pitch range • Louder speech	• Decreased speech rate & articulation rate • Increased duration of speech sounds • Longer pause duration & increased pause frequency (Bradlow, Kraus and Hayes, 2003) • Increased vowel space • Increased jaw displacement & more fronted tongue • Increased F_0 & frequency range • Changes in vowel formants F1 & F2 • Increased vocal intensity (Levy, Chang, Ancelle and McAuliffe, 2017)	• Improved sentence intelligibility	(Levy, Chang, Ancelle and McAuliffe, 2017): • Improved intelligibility at word & sentence level • Increased sentence & word duration • Increased vocal intensity

Table 4 Table Illustrating How Different Vocal Cues Address Intelligibility Impairments and their Outcomes

2.3. Dysarthria Interventions for Children with Cerebral Palsy

2.3.1. *Intensive Therapy Programmes*

All the interventions discussed in this section follow principles of motor learning including high effort, intensive dosage, repetitive practice, and 'attentional focus' (Maas *et al.*, 2008). Attentional focus involves consciously directing attention toward a particular aspect of a task, such as focusing on a bodily sensation or movement (Wulf, 2013). For example, in speech motor speech learning the focus may be on articulator movement, i.e., "how does that feel", or auditory perceptual (acoustic) goals, i.e., "how does that sound?" (Lisman and Sadagopan, 2013). Frequent practice of new speech motor behaviours should help children with CP and dysarthria acquire and retain new speech behaviours (Yorkston, Beukelman, Strand and Hakel, 1999; Strand, 1995). The intensive therapy programmes involve models of the target speech being provided, limiting the cognitive load and making the interventions accessible for children with intellectual impairment (Langlois *et al.*, 2020)**.** Previous behavioural interventions for children with CP have been criticised because delivery of therapy was not standardised (Butler and Darrah, 2001). The following interventions address these criticisms as they follow a strict protocol.

2.3.1.1. Speech Systems Approach

Intervention to improve the speech intelligibility of children with dysarthria and CP usually resembles that provided to adults with acquired dysarthria. The Speech Systems Approach (SSA) (Pennington, Miller, Robson and Steen, 2010; Pennington *et al.*, 2013; Pennington *et al.*, 2019) is an intensive therapy programme consisting of three sessions per week for six weeks and each session is around 35 to 40 minutes long. Children are given speech cues to encourage them to use the new speech behaviours. Children progress through a structured hierarchy of exercises to practice using their cues, with utterance length and cognitive load gradually increasing, whilst feedback decreases. The programme begins with monosyllabic words and progresses on to polysyllabic words, phrases, and finally conversational speech. Advancement to the next speech level requires 90% accuracy. This intervention targets coordination of the phonation and respiration speech subsystems whilst maintaining a steady speech rate. Treating respiratory-phonatory control for speech before or alongside articulation treatment in children with motor speech disorders is recommended (Strand, 1995).

Pennington et al.'s (2010; 2013) exploratory studies involved 16 and 15 children respectively with various types of CP: spastic, dyskinetic, mixed, ataxic and Worster-Drought syndrome. Vocal cues were tested on the children at the beginning of the intervention programme based on their individual speech characteristics: 'big voice', 'strong voice', 'nice and easy' and 'clear voice'. The children received the intervention, focusing on controlling respiration, phonatory effort, speech rate and syllables per breath, three times a week for six weeks at school. Initially the children employed the strategies to sustained vowels and then to SWs and connected speech (CS).

The results found that intensive blocks of therapy targeting controlling respiratory and phonatory effort, as well as slowing the rate of speech, facilitates more precise articulation and increases intelligibility. The intervention was found to improve speech intelligibility of SWs and CS for both younger (aged 5-11 years) and older children (12-18 years) with CP and dysarthria, and improvements were observed for both familiar (members of school staff who worked with each child) and unfamiliar listeners. Maintenance of speech intelligibility gains were observed 12 weeks post-intervention, illustrating that this intervention is effective for retaining speech intelligibility improvements in children with dysarthria and CP. Recent research which used the data from 42 children who received the intervention face to face studies (Pennington *et al.*, 2019; Pennington *et al.*, 2013; Pennington, Miller, Robson and Steen, 2010) investigated the mechanisms of change of the SSA (Pennington *et al.*, 2023). The study aimed to detect perceptual and acoustic patterns of change post-therapy to determine which factors have the greatest influence on intelligibility. The research found varying responses to the SSA between and within children in terms of patterns of acoustic change, changes in phoneme identification, changes in the number of consonants perceived correctly post-therapy compared to pre-therapy. Overall, more word-initial (WI) and word-final (WF) consonants and consonant clusters were perceived correctly post-therapy. Gains were greater in SWs. Differences between children were greater in CS and improvement was less marked than in SWs. The acoustic results revealed that children who demonstrated the greatest improvement in SW intelligibility exhibited slower and stronger speech signals post-therapy. Increases in intensity and duration in SWs were also observed in children who did not demonstrate changes in intelligibility. For CS, no clear relationship was found between speech rate, intensity, and the children who achieved the greatest gains in intelligibility. Intensity of obstruent sounds increased more in both WI and WF positions of SWs compared to CS. However, acoustic data was not available for all participants and very few children's CS was available. The small sample size meant that associations between the children's responses and dysarthria characteristics were not able to be tested (Pennington *et al.*, 2023). Therefore, analyses of acoustic patterns require further study.

Findings from the SSA research also indicate potential for increasing social participation and promoting more independent communicative interaction, as measured by the Focus on the Outcomes Under Six (FOCUS) questionnaire (Thomas-Stonell, Oddson, Robertson and Rosenbaum, 2010). However, no relationship was found between increases in intelligibility and communicative participation (Pennington *et al.*, 2013).

A qualitative study (Pennington, Rauch, Smith and Brittain, 2020) was also carried out which investigated children with CP and their parents' perceptions of the SSA. Prior to the therapy children reported their frustration when not understood and how they limited spoken conversation with unfamiliar listeners and in noisy environments such as the classroom and playground. Parents reported anxiety and self-esteem issues in their children which they believed were linked to children's limited intelligibility. Following therapy, children reported increased self-esteem and confidence, and changes in participation such as reading aloud in class or putting their hand up to ask questions. Parents and children described more frequent communication post-therapy, with children participating more in communicative interactions and speaking for longer within these interactions. Furthermore, children's independence improved, with them carrying out conversations without support from familiar listeners. Children's ability to self-monitor their speech improved, allowing them to use their new voice when needed, e.g. in noisy environment, with unfamiliar listeners and to repair conversation breakdowns. They reported having more breath, talking with a stronger voice, and being understood by friends when using a slower speech rate. Not all children noted improvement in their speech, with one child reporting that her voice was ‘the same’ post-therapy. However, her mother stated that listeners noticed improvements in her child’s voice and understood her more frequently. Similarly, some parents did not notice substantial changes in their child’s speech and others were only made aware when listeners outside of the family reported speech changes. Changes in articulation were described by some parents, suggesting that increased control over breath support and speech rate arising from the cues ‘big voice’, ‘strong voice’, ‘nice and easy’ and ‘clear voice’ has hypothesised positive outcomes in the articulatory subsystem. Overall, the therapy was viewed as effective by children and their families and worthwhile, despite it sometimes being tiring for the children and difficult to schedule due to the intensive nature.

2.3.1.2. Lee Silverman Voice Therapy LOUD (LSVT)

Lee Silverman Voice Therapy LOUD (LSVT) (Ramig *et al.*, 1988) consists of 16 individual 60 minute sessions on four consecutive days for four weeks. LSVT LOUD concentrates on a single target of developing healthy vocal loudness as well as developing self-monitoring. This intervention was originally developed for people with PD and has been effective at improving speech intelligibility (Fox, Morrison, Ramig and Sapir, 2002). The focus on one speech target is suitable for children with CP as it limits the cognitive load (Nugent and Mosley, 1987). Furthermore, the ability to manipulate loudness is somewhat preserved in children with dysarthria secondary to CP (Patel, 2003; Nip, 2024), and therefore loudness appears to be a highly relevant treatment cue for them. Just like in the SSA, speech behaviours are modelled to the children to limit verbal instructions. Modelling sentences may not be standardised as it is difficult to reproduce speech in the exact same way. A pre-recorded model would improve the reliability of this.

LSVT has been trialled with children with CP and dysarthria (Fox and Boliek, 2012; Fox and Boliek, 2016; Boliek and Fox, 2017; Fortin *et al.*, 2023; Boliek and Fox, 2014). Fox and Boliek’s 2012 study involved five children, and their 2017 study involved seven children with spastic-quadriplegia CP. The intervention is delivered at home or at school by an expert LSVT therapist. The sessions begin with three tasks: (1) maximum duration sustained vowels, (2) optimum frequency range and (3) five repetitions of 10 functional phrases. This is followed by speech hierarchies, first targeting SW production before moving on to CS. The speech hierarchy materials are individualised, focusing on topics of interest for each child. Children are regularly cued to increase their vocal loudness and effort and asked whether they can feel/hear the difference in their voice. Homework involves children using their loud voice in their daily living environment, e.g., saying good morning to the bus driver, and homework tasks were practiced in the therapy sessions. Fox and Boliek's (2016) study investigated the maintenance effects of LSVT for ten children with CP and dysarthria using the LSVT Companion Technology System. The children received the above LSVT treatment 12-weeks prior to the maintenance study. During the 12 weeks maintenance phase they completed homework daily and the amount and quality of homework practice was recorded.

Listeners preferred children's speech characteristics following LSVT LOUD, with preference for all the perceptual variables (overall loudness, loudness variability, overall pitch, pitch variability, overall voice quality, and articulatory precision) for the SW repetitions and most of the variables for the sentence repetitions post-therapy (Fox and Boliek, 2012). In contrast, a clear preference for voice and speech characteristics was not found immediately post-therapy on untrained phrases in Fox and Boliek's (2017) study. However, like the 2012 study, they did prefer voice quality and articulatory precision at the follow-up. Children demonstrated positive outcomes in acoustic measures such as vocal sound pressure level (SPL), maximum duration of sustained phonation, and maximum frequency range in the 2012 study, whereas only improvements in SPL were found in the 2017 study. Results from the 2016 study indicated that maintenance of vocal SPL in sentences may have been greater if more practice using the Companion occurred during the 12-weeks, but the technology did motivate some children to continue their practice schedule post-therapy. Similar parent ratings were given in both studies, with increases in vocal loudness, naturalness and attempts to communicate, decreases in hyponasality and hypernasality, and reductions in frustration levels reported.

Although intelligibility increased by 7.28% immediately post-therapy and around 7% six weeks after therapy (Fox and Boliek, 2012; Boliek and Fox, 2017), speech changes were not maintained at the 12-week follow-up. Fox and Boliek's (2012) results are limited in the sense that they used a single-subject design, all the children had spastic CP, and the sample size was very small. The 2017 study moved from a single-subject design to a small group of seven children, but this sample size still makes reduces generalisability of the findings.

Recent research by Langlois et al. (2020) investigated the effects of LSVT on articulatory function in children with CP and children with Down Syndrome (DS) as there is evidence indicating that LSVT has spreading effects to the articulatory speech subsystem, despite it being thought to only directly target the phonatory subsystem (Wenke, Cornwell and Theodoros, 2010; Youssef, Anter and Hassen, 2015). The study involved 26 children, 17 with CP and 9 with DS, all of whom were diagnosed with dysarthria. The severity of dysarthria varied across children, ranging from mild to severely dysarthric. They each received the full dose of LSVT from a certified therapist, and the intervention followed the standard LSVT protocol, as described above. Speech samples of both SWs and sentences were collected one week pre-, one week post-, and 12 weeks post-intervention. This study concentrated on the acoustic speech changes, including dB SPL, vowel duration, acoustic vowel space, and F1 and F2 measures, because of their importance for speech perception and intelligibility (Delattre, Liberman, Cooper and Gerstman, 1952). The results of their study suggest that LSVT results in intelligibility improvements and gains in vocal dB SPL for both children with CP and DS. The vowel durations within sentences produced by children with CP increased immediately post-therapy. The children with CP demonstrated increased vowel acoustic space in SW productions, and the children with DS demonstrated increased vowel acoustic space in sentence productions. These increases in vowel acoustic space suggest LSVT promotes changes in jaw and tongue movement, particularly when producing the low vowel /ɑ/ and high vowel /u/.

However, some surprising findings were made. The vowel acoustic space of children with CP decreased in the sentence production condition. A smaller acoustic vowel space is associated with reduced intelligibility (Liu, Tsao and Kuhl, 2005) but the intelligibility of children with CP increased from pre- to post-therapy, and pre-therapy to the follow-up assessment. Due to the heterogeneity of the children in terms of age, CP type, dysarthria type and dysarthria severity, the within-group repeated measures study design may have masked treatment effects by combining results from strong, weak, and non-responders. Another possible cause of this unexpected finding is that only measuring vowel working space using the three corner vowels /ɑ/, /i/, and /u/ may not be sensitive enough to gain an accurate portrayal of articulatory function, and formant measurements of every vowel may be required. A third possibility is that children with CP employed greater articulatory precision through less F1 variation and hence better vowel distinctiveness, to compensate for a reduced vowel working space. No statistically significant results were observed for acoustic vowel space in the DS group for the SW condition, but this may have been due to the small sample size.

The effect of LSVT on acoustic measures for children with dysarthria and CP differed to that found in adults with PD, with children with CP making minimal acoustic changes in maximum performance tasks, remaining two standard deviations below the mean compared to their typically developing peers (Fox and Boliek, 2012). In contrast, adults with PD have been found to make significant changes in maximum performance tasks in response to LSVT (Sapir, Ramig and Fox, 2011). Nevertheless, LSVT may still be an appropriate therapy for those with spastic CP as they have been found to make statistically significant gains in intelligibility. How well results can be generalised to groups of children, e.g., grouped by dysarthria severity/type, is not yet known due to studies only involving small sample sizes.

2.3.1.3. Speech Intelligibility Treatment (SIT)

Speech Intelligibility Treatment (SIT) (Levy, 2018; Levy, Chang, Hwang and McAuliffe, 2021) aims to increase intelligibility and promote generalisation to new communication partners and new environments through encouraging communicative participation. Like SSA, SIT considers the cognitive, mobility and visual limitations associated with CP (Bleyenheuft and Gordon, 2014). SIT was trialled at a summer camp, where children received 6.5 hours of therapy per day, five days a week for three weeks (Levy, Chang, Hwang and McAuliffe, 2021). SIT employs a dual-focus strategy combining ‘speak with your big mouth and strong voice’. The programme has a hierarchical structure, targeting SWs initially and moving up to the children’s highest linguistic level as the weeks progress. The final week is known as ‘generalisation week’, and this requires the children to use their new speech behaviours in conversations with unfamiliar listeners. This is beneficial as it provides insight into the treatment effects outside of the study environment. Children are also given daily homework tasks.

Levy et al. (2021) investigated the effect of SIT on the intelligibility of 17 children with CP and dysarthria. Fourteen children presented with spastic CP, two had ataxic CP and one had dyskinetic CP. Dysarthria severity ranged from mild to severe, as judged by three SLTs. The children were provided with a model of the target productions, prompted to use their ‘big mouth and strong voice’, and given positive feedback after their productions. Minimal pair vowel tasks and barrier tasks were used to elicit speech. The children who received this therapy made significant improvements in both narrative intelligibility, which was elicited through sequenced picture cards, with an increase of 6% in the ease of understanding (EoU) rating task, and communicative participation, with improvements in all participation subcategories bar independence of the FOCUS questionnaire. Improvements were maintained six weeks post-intervention which is consistent with Pennington et al.’s (2010; 2013) findings using the SSA. However, minimal speech changes were observed in the acoustic measurements with no change in SPL, individual vowel formants, articulation rate and F1 between vowels after therapy. There was a significant main effect of time for the formant differences of F2 between the vowels /æ/ and /ɑ/ immediately post-therapy ($F(2, 31.6) = 3.37$, $p = 0.047$), consistent with the relationship found between intelligibility and F2 changes in non-treatment studies (Levy, Chang, Ancelle and McAuliffe, 2017; Tjaden *et al.*, 2013; Ansel and Kent, 1992). This greater contrast between front and back low vowels suggests greater tongue movement along the anterior-posterior plane. The use of a model could have impacted the children’s productions and treatment effect; they may have copied the model’s rate and intensity which might have been different to their habitual speech rate and loudness. This may have impacted the treatment effects. The use of self-generated speech as an outcome measure should be investigated in future research. However, fixed model utterances ensure phrase length is balanced across participants and time points, limiting the variability of productions. Overall SIT shows potential for improving everyday communication in children with CP and dysarthria but responses to the intervention may vary across children. Children with severe dysarthria (classified as an average baseline EoU rating of around 30/100) benefited the least, indicating that there may be a relationship between dysarthria severity and treatment effects.

2.3.1.4. Summary of Intensive Dysarthria Interventions

Intensive Intervention	Setting	Language	Age (years; months)	Perceptual Outcomes with Measures	Acoustic Outcomes with Measures	Intelligibility	Participation
SSA	Mainstream & special schools in the North/North-East of England	English	5-11 (Pennington *et al.*, 2013) 12-18 (Pennington, Miller, Robson and Steen, 2010) 6-18 (Pennington, Rauch, Smith and Brittain, 2020) 5-17 (Pennington *et al.*, 2019)	• % words correct • ↑ % of SWs & CS perceived correctly • ↑ precise identification of WI & WF consonants & consonant clusters in mono- & multisyllabic words (Pennington *et al.*, 2023) • ↑ identification of voiceless coronal & labial obstruents & labial sonorants in SWs • No change in dorsals /g/ & /ŋ/ in SWs • ↑ in coronal consonants in CS	• ↑ acoustic changes in SWs than CS (Pennington *et al.*, 2023) • Slower speech rate & higher intensity (Pennington *et al.*, 2023) • ↑ intensity of obstruents in WI & WF position in SWs (Pennington *et al.*, 2023) • Lower intensity of WF obstruents	• ↑ SW and CS intelligibility (Pennington, Miller, Robson and Steen, 2010; Pennington *et al.*, 2013) • Improvements maintained 12 weeks post-therapy • ↑ frequent & successful conversations (Pennington, Rauch, Smith and Brittain, 2020) • Louder, clearer, slower speech (Pennington, Miller, Robson and Steen, 2010; Pennington, Rauch, Smith and Brittain, 2020; Pennington *et al.*, 2013;	• ↑ participation, independence, self-esteem, & confidence- • Putting hand up more in class • Speaking in from on the class • Reading aloud • Ordering own food in restaurants • Paying for items in the shop • Relying less on communication partners to support conversations

Intensive Intervention	Setting	Language	Age (years; months)	Perceptual Outcomes with Measures	Acoustic Outcomes with Measures	Intelligibility	Participation
						Pennington *et al.*, 2023)	
LSVT	Home or school (Boliek and Fox, 2017) General community (Fox and Boliek, 2016)	English	5-7 (Fox and Boliek, 2012) 8;7-15;8 (Fox and Boliek, 2016) 6-10 (Boliek and Fox, 2017)	• % intelligibility scores • Parent interviews-quantitative analysis • Preference for loudness, pitch variability, and voice quality in SWs & trained phrases post-therapy • Parent reports: ↑ loudness, ↑ naturalness, ↓ hyponasality & hypernasality	• Measures (using Praat): vowel duration (secs), maximum dB SPL, frequency range, average dB SPL and F_0, & change in vocal SPL • Positive outcomes in SPL, maximum duration of sustained phonation, & maximum frequency range (Fox and Boliek, 2012; Boliek and Fox, 2017) • Loudness gains not maintained across untrained phrases	• ↑ SW intelligibility (Boliek and Fox, 2017) • ↑ intelligibility 6 weeks post-therapy (Fox and Boliek, 2012) • Intelligibility gains not maintained 12 weeks post-therapy	• Children more confident in their communication ability, resulting in more participation in school and at home • ↑ communication attempts

Intensive Intervention	Setting	Language	Age (years; months)	Perceptual Outcomes with Measures	Acoustic Outcomes with Measures	Intelligibility	Participation
SIT	Summer camp in Brussels, Belgium (Moya-Galé, Keller, Escorial and Levy, 2021) Summer camp at Columbia University (Levy, Chang, Hwang and McAuliffe, 2021)	French (Moya-Galé, Keller, Escorial and Levy, 2021) American-English (Levy, Chang, Hwang and McAuliffe, 2021)	4;11 to 16;2 (Moya-Galé, Keller, Escorial and Levy, 2021) 4;8 to 17;5 (Levy, Chang, Hwang and McAuliffe, 2021)	• % words correct • Mean naturalness ratings from listener visual analogue scale (VAS) ratings • ↑ intelligibility and EoU • Improvement maintained for 6 weeks	• Minimal acoustic changes • No change in SPL, individual vowel formants, articulation rate & F1 between vowels • ↑ F2 difference between the vowels /æ/ & /ɑ/	• Preliminary support to improve intelligibility • Significant gains in narrative intelligibility • Children with severe dysarthria benefitted the least	• ↑ communicative participation • ↑ in all participation subcategories (except independence) of the FOCUS questionnaire

Table 5 Summary of Intensive Interventions to Target Dysarthria

2.3.2. *Limitations of Online Delivery of Intensive Dysarthria Intervention for Children with Cerebral Palsy*

There are limitations with online therapy as internet connections can become unstable, causing sessions to be disjointed or cut short. Moreover, making sure the environment is quiet can be difficult in busy environments such as schools. The findings from Pennington and colleagues (2019) study confirmed that an RCT investigating the effectiveness of internet delivery of intensive SLT for children with CP is feasible. Parents stated that they would be happy to participate in a RCT as they found the pilot study therapy acceptable. An RCT will indicate whether this delivery method will be effective when put into clinical practice.

2.3.3. *Summary of Intensive Dysarthria Interventions*

Overall, intensive therapy programmes have shown to be appropriate to use with children with CP. Researchers report high compliance during the therapy phase (Pennington, Miller, Robson and Steen, 2010; Pennington *et al.*, 2013; Fox and Boliek, 2012). It appears that intervention targeting multiple subsystems produces a positive outcome for children with dysarthria. Further comparison of single cues could help reveal the specific mechanisms underpinning the speech changes (Levy, Chang, Ancelle and McAuliffe, 2017) and enable the most efficient therapy treatments to be chosen for each child. The logic model below (Figure 3) summarises the intensive dysarthria interventions.

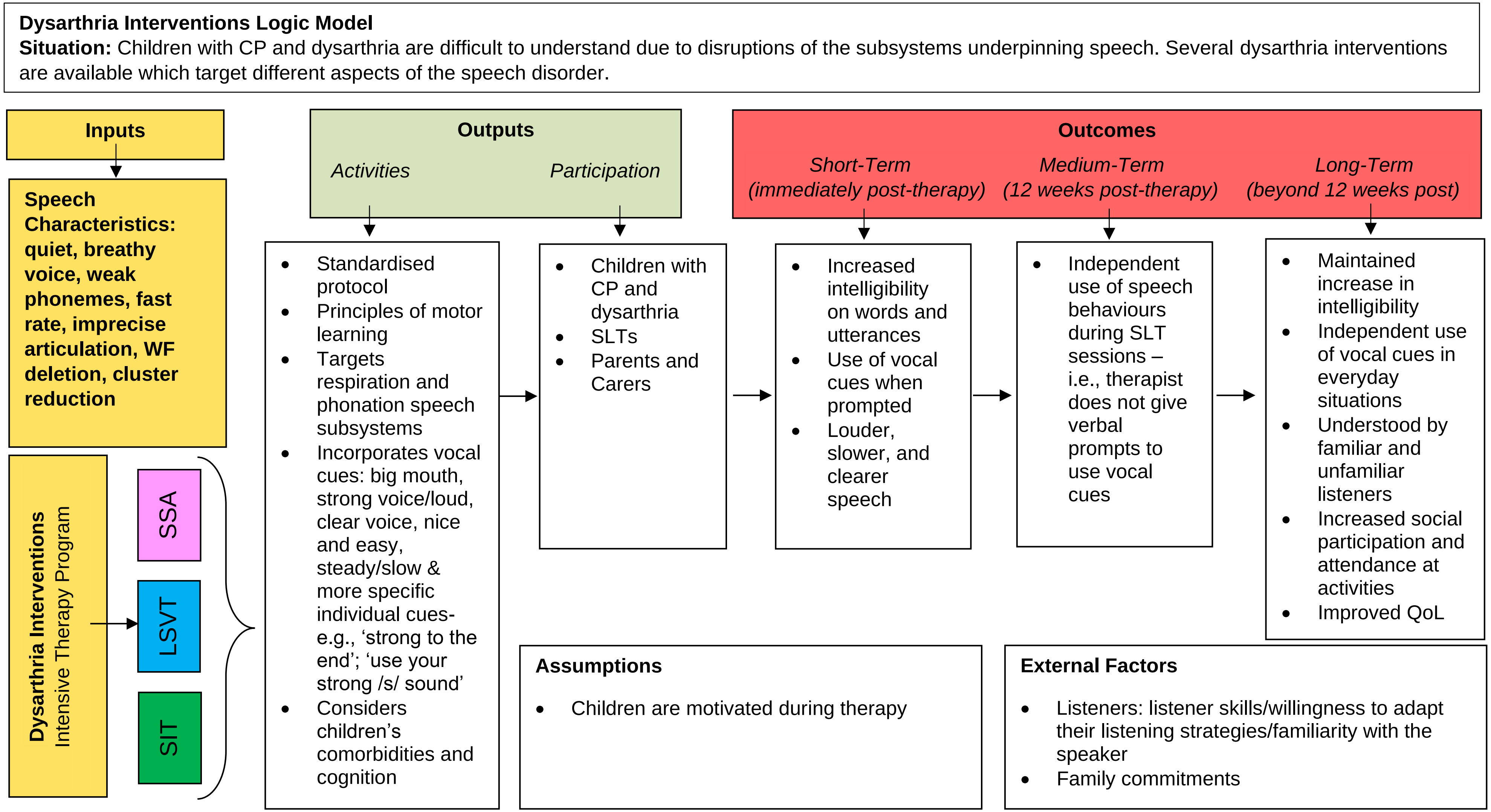

Figure 3 Logic Model Describing the Intensive Dysarthria Interventions and their Short-, Medium-, and Long-Term Outcomes

2.3.4. *Articulation Therapy*

As well as therapy programmes which focus on multiple speech subsystems, there are interventions which concentrate solely on articulation; and target the muscle tone and coordination of only the orofacial muscles to increase speech intelligibility (Marchant, McAuliffe and Huckabee, 2008). As imprecise phoneme production in dysarthric speakers is not just due to articulation impairments but caused by multiple speech subsystems being impaired, children with CP and dysarthria may benefit from intervention targeting respiratory control and reducing speech rate to promote more accurate speech productions and aid intelligibility (Strand, 1995; Yorkston, Beukelman, Strand and Hakel, 1999; Love, 2000) as a first line of treatment. The interventions described below may be considered as a further intervention and are included in this chapter for completeness.

2.3.4.1. Phonetic Placement Therapy (PPT)

Phonetic placement therapy (PPT) is a behavioural intervention aimed at improving articulatory accuracy through direct instruction on the positioning of articulators. Wu and Jeng (2004) compared PPT with a phonological-based intervention for two children with CP. They found that PPT led to a 23% improvement in affricates and fricatives. The phonological intervention showed a smaller improvement (16%) but better generalisation to non-target words, with less regression at follow-up.

Marchant et al. (2008) compared PPT to surface electromyography (sEMG), a technique that uses biofeedback to reduce muscle tone and improve oro-muscle movement. Both therapies improved articulation, especially with voiceless affricates and fricatives. While PPT resulted in greater improvements in speech intelligibility at the word level, similar to the findings by Wu and Jeng (2004), neither therapy affected speech intelligibility at the sentence or paragraph level, which were elicited using the Language Assessment Remediation and Screening Procedure (Crystal, Fletcher and Garman, 1981), conversational analysis profile (Fey, 1986), and profile in semantics (Crystal, 1992). Acoustic changes, such as F2 frequency shifts, were noted, suggesting some improvement in articulation.

The benefits of PPT and sEMG were more apparent in children with mild to moderate dysarthria, while sEMG was found to be ineffective for severe speech disorders, consistent with earlier findings from Finley et al. (1976). It's suggested that combining PPT with sEMG may be particularly beneficial for children with less severe dysarthria. More research is needed to explore whether combining these therapies can further improve intelligibility and whether they can improve communication at both the word and sentence level.

2.3.4.2. Electropalatography (EPG)

Electropalatography (EPG) provides visual feedback in articulation treatment and has been found to be successful at improving articulatory errors in children with CP, particularly those who have responded poorly to conventional SLT approaches (Nordberg, Carlsson and Lohmander, 2011; Gibbon and Wood, 2003). EPG records the durations of locations of tongue contacts with the hard palate during speech and provides visual feedback which can help resolve articulation impairments (Gibbon and Wood, 2003). Nordberg et al. (2011) found EPG to significantly improve the articulatory contact patterns of children with CP and dysarthria and their results yielded helpful guidance for identifying atypical dental and alveolar consonant contact patterns. In Gibbon and Wood's (2003) study, the positive effects were observed in everyday environments a year after EPG intervention, demonstrating maintenance and generalisation effects. The evidence suggests that EPG is the most beneficial in helping children produce new articulations not in their phonetic inventory as it initiates articulatory change in children with articulatory impairments.

2.3.5. *Interventions for Childhood Apraxia of Speech for Children with CP and Dysarthria*

2.3.5.1. Rapid Syllable Transition Treatment (ReST)

Childhood Apraxia of Speech (CAS) is another speech impairment present in 17% of children with CP (Mei *et al.*, 2020b). Like dysarthria, CAS is associated with difficulties in intelligibility in children with CP. Motor speech interventions informed by the Schema theory (Schmidt, 1975) – a theory suggesting that motor programmes are retrieved from memory and then adapted to a particular situation – have been used with children with CAS. Rapid Syllable Transition Treatment (ReST) (McCabe, Thomas and Murray, 2020) is a motor speech intervention informed by the Schema theory. ReST targets accurate speech production while concurrently adjusting fluency and prosody, using the principles of motor learning. ReST incorporates polysyllabic nonwords to target underlying motor patterns and replicate learning of unfamiliar words. ReST involves two phases – the prepractice phase and practice phase. The prepractice phase introduces the skills and stimuli to be trained, with clinician support to make correct productions and recognise errors. The practice phase involves ≥100 trials, training more than one variation of a skill, random presentation of the order of the stimulus, and low frequency feedback. ReST has led to significant improvements in percent vowels correct (PVC) and perceptual and acoustical accuracy of lexical stress production (Staples, McCabe, Ballard and Robin, 2008; Ballard, Robin, McCabe and McDonald, 2010). Improvements have been maintained for between one and six months post-therapy (Staples, McCabe, Ballard and Robin, 2008; Murray, McCabe and Ballard, 2015). Generalisation of treatment effects to real-word stimuli, other nonword strings and connected speech has also been found (Staples, McCabe, Ballard and Robin, 2008; Ballard, Robin, McCabe and McDonald, 2010; Murray, McCabe and Ballard, 2015). This reflects the influence of ReST on children's ability to tackle novel words.

There are similarities in the speech characteristics of children with CP and CAS and CP and dysarthria. For instance, both may experience inconsistent productions, prosodic disturbances, and reduced intelligibility (Duffy, 2020; Nordberg, Miniscalco and Lohmander, 2014; Malmenholt, Lohmander and McAllister, 2017). Given these similarities in the speech presentation of CAS and dysarthria in children with CP, ReST has been delivered to children with CP and dysarthria (Korkalainen, McCabe, Smidt and Morgan, 2023a). In a randomised controlled trial (RCT) involving fourteen children, eight received ReST while six received usual care. The intervention was conducted online via Zoom. Post-therapy, children in the ReST group demonstrated greater improvement in speech accuracy and speech intelligibility at word level, as well as increased speech accuracy at sentence level. These findings align with previous research on children with CAS (Skoog and Maas, 2020), suggesting that interventions focusing on speech accuracy can improve speech intelligibility in children with CP – a key component of effective communication. Additionally, children in the ReST group achieved higher scores on communication participation measures, including the Intelligibility in Context Scale and FOCUS. No statistically significant differences were found between groups in measures of spontaneous speech intelligibility or mean length of utterance, although both groups demonstrated improvement post-therapy.

Considering the shared speech characteristics between children with CP and CAS, as well as CP and dysarthria- and the positive outcomes observed following ReST- this intervention shows potential as an appropriate and effective therapy for improving intelligibility in children with CP and dysarthria.

2.3.5.2. PROMPTS for Restructuring Oral Muscular Phonetic Targets (PROMPT)

PROMPTs for Restructuring Oral Muscular Phonetic Targets (PROMPT) provides tactile-kinesthetic inputs to facilitate articulatory movements by dynamic modelling, resulting in more efficient motor patterns that can be integrated into speech and communication. PROMPT is based on the principles of dynamic systems theory (Hayden, 2006), which proposes that the emergence of new behaviours requires state of disequilibrium. This enables the system to reorganise, facilitating the acquisition of more complex behaviours and ultimately restoring the balance.

PROMPT has been trialled on a small group of children (aged 3-11) with CP (Ward, Leitão and Strauss, 2014) using an A1BCA1 single subject design. Phase A1 was the baseline data collection, Phase B and C consisted of weekly individual therapy blocks, and Phrase A2 was the 12 Week post-therapy data collection. Phase B targeted one level of the PROMPT motor speech hierarchy (e.g., increase jaw open distance on low vowels with return to closure on CVC words) and Phase C targeted one level higher (e.g., facilitate appropriate and rounded lip movements). Phases B and C consisted of once weekly 45-minute therapy sessions for 10 weeks. Speech probes were administered within each study phase to assess speech production accuracy. Speech production accuracy was assessed for both targeted motor speech movement pattern and perceptual accuracy. The speech probes consisted of three groups of 20 words involving both trained and untrained words. Results of this preliminary study revealed that improvement in speech production accuracy was made by all participants and were seen in both the trained and untrained words. No significant changes were observed on the control word-sets, proving that changes in motor speech movement patterns and perceptual accuracy were due to the effectiveness of PROMPT.

As there is limited evidence about the effectiveness of PROMPT for children with CP and dysarthria specifically (not all speech motor delays), a wait-list control group trial protocol has been created describing a RCT based on the evidence suggesting children with CP and dysarthria will benefit from PROMPT (Fiori *et al.*, 2022). The RCT will involve children aged 3 to 10 with CP and dysarthria being allocated to either an immediate PROMPT intervention group or waitlist control group. Children in the immediate group will receive PROMPT twice a day for three weeks, whilst children in the control group will receive standard care. Children will be assessed at baseline, immediately after the intervention, and 3 months after the intervention to assess the stability of PROMPT. Results from this RCT will reveal whether PROMPT is an effective intervention for children with CP and dysarthria.

Table 6 below summarises the different speech characteristics associated with dysarthria and the interventions and vocal cues which can be used to target them.

Speech Characteristic	Speech Subsystem Affected	Vocal Cue	Intervention
Fluctuating / Inappropriate speech rate	Prosody	Slow rate	SSA
Weak/breathy voice	Respiration	Loud / Strong Voice	LSVT SSA SIT
Imprecise articulation	Articulation	Clear Speech / Big Mouth Slow rate Loud / Strong Voice	SIT SSA Be Clear PROMPT ReST
Word-final consonant omission	Respiration Articulation	Loud / Strong Voice Clear Speech / Big Mouth	SIT SSA Be Clear PPT sEMG
Weak plosive production	Respiration Articulation	Loud / Strong Voice Clear Speech / Big Mouth	SIT SSA Be Clear PPT sEMG EPG
Imprecise consonant cluster production	Articulation	Slow rate Clear Speech / Big Mouth Loud / Strong Voice	SSA SIT PPT sEMG EPG PROMPT ReST
Monotonous speech	Phonation Prosody	Smooth Speech / Nice and Easy Clear Speech / Big Mouth	SSA SIT Be Clear ReST
Harsh / strained voice	Phonation	Smooth Speech / Nice and Easy	SSA
Equal / excessive stress	Prosody	Smooth Speech / Nice and Easy	SSA ReST
Hypernasality / hyponasality	Resonance	Slow rate Clear Speech / Big Mouth	SSA SIT EPG

Table 6 Examples of Impaired Perceptual Speech Characteristics and How to Target Them

2.3.6. *Systematic Review for Motor Speech Interventions for Children with Cerebral Palsy*

A systematic review researching motor speech interventions for children with CP has been conducted (Korkalainen, McCabe, Smidt and Morgan, 2023b). Eight databases were searched, and searches were limited to studies between January 1st 2000 and December 31st 2021 which were written in English. The intervention outcomes had to be speech-related, e.g., intelligibility, articulation, or prosody.

The systematic review identified eight motor speech interventions: SSA, LSVT Loud, PPT, PROMPT, SIT/Modified Speech Intelligibility Treatment (mSIT) (Carl, Levy and Icht, 2022), EPG, Beatalk (Carl, Levy and Icht, 2022), and transcranial direct current stimulation (Lima *et al.*, 2016). mSIT is the SIT intervention with a modifed dose. Beatalk is an intervention which has two stages: (1) acquisition and (2) rehearsal. Children learn basic beatbox sounds and then produce the sounds in simple and complex rhythms. The rhythms vary from repeating a single phoneme to producing a pair of sounds or sequence of three sounds. Transcranial direct current stimulation is non-invasive brain stimulation which facilitates cortical activity to enhance therapeutic outcomes.

The quality of the evidence was graded moderate (SIT/mSIT) to very low (transcranial stimulation). All other interventions were rated as low-quality evidence. EPG, PPT and transcranial stimulation were the only interventions not based on the speech subsystems approach. Instead, they use instruments to improve speech production. Every intervention was found to improve different measures of speech accuracy, with SSA, LSVT Loud, PPT, PROMPT, and SIT also reported to improve intelligibility at word and sentence level. Beatalk, EPG, and transcranial stimulation were reported to only improve target phoneme production. Communicative participation increased following SIT.

Currently, the evidence base for motor speech interventions for those with CP is limited due to low sample sizes, lack of studies available, and lack of detail in the studies conducted. Higher quality evidence such as RCTs assessing the effectiveness of motor speech interventions for children with CP are required. They should look at the interventions themselves as well as the active ingredients within the interventions, e.g., the dose.

2.3.7. *Limitations with Dysarthria Intervention Research*

In general, there is a lack of research in the field of SLT, and research surrounding dysarthria interventions is limited. There is little evidence to guide therapy, particularly when it comes to effective methods of delivery and the use of specific treatment techniques (Finch, Rumbach and Park, 2020). There is a shortage of sufficiently powered RCTs meaning SLTs must rely on less in-depth study designs to guide clinical decision making in terms of which dysarthria interventions to use (Finch, Rumbach and Park, 2020).

The literature review highlights the continuing limitations in research on dysarthria interventions that were identified nearly a decade ago (Pennington, Parker, Kelly and Miller, 2016). The findings of the 2016 Cochrane Review on SLT for children with dysarthria align with those of Finch et al.'s (2020) systematic review on dysarthria interventions for adults with non-progressive dysarthria. The authors of those two reviews concluded that the main limitations of the research are sample size justification, validity of outcome measures, the absence of a comparison or control group, and insufficient participant descriptions. To address these gaps, future research should involve rigorous single-case experimental designs to evaluate interventions on individuals from potential subgroups who may not meet typical inclusion criteria. Additionally, RCTs are needed to comprehensively assess the effectiveness of SLT for this population (Pennington, Parker, Kelly and Miller, 2016). Such studies should measure changes in intelligibility, include comparisons between experimental and control groups, and document both short-term and long-term outcomes. Furthermore, they should explore how SLT influences social and communicative participation, thereby addressing functional and holistic aspects of dysarthria management.

2.4. Telehealth

The interventions mentioned above were designed for face-to-face delivery. However, the coronavirus pandemic has caused a global transition from in-person therapy to telehealth (Campbell and Goldstein, 2022). Delivering online therapy is relatively new to most SLTs. However, research shows that SLTs have learned and quickly adopted telehealth, and many have stated that they plan to continue delivering therapy remotely well into the future (Campbell and Goldstein, 2022; Campbell and Goldstein, 2021).

Telehealth may be the only method for some individuals to access SLT services; this can be due to geographical and/or economic reasons, and hence it serves an invaluable purpose. Furthermore, research shows that telehealth is of great importance to families of children with different communication disorders and disabilities (Tohidast, Mansuri, Bagheri and Azimi, 2020). As well as reducing travel time and costs, tele-SLT also has benefits including reducing waiting lists, supporting patients with motor impairments (e.g., children with CP), and increased access to specialist provision (Bayati and Ayatollahi, 2023).

Telehealth practices in the field of SLT have been trialled on several populations including adults with acquired brain injury (ABI) (Coleman, Frymark, Franceschini and Theodoros, 2015), children with hearing loss (Werfel *et al.*, 2021), children with autism spectrum disorder (ASD) (Ashburner, Vickerstaff, Beetge and Copley, 2016), and children with CP (Pennington *et al.*, 2019).

Positive findings from tele-speech studies have been observed across different populations. Coleman and colleagues' systematic review (2015) found that response to assessment and treatment of cognition and communication skills in adults with ABI was consistent across telepractice and in person therapy. Participants across the studies reported that they were comfortable and satisfied with the use of telepractice. However, only ten studies were included in the systematic review. This causes the risk of publication bias as it is possible that more studies with significant findings were published than studies where the results had no statistical significance. Furthermore, only studies written in English were included in the systematic review. Studies written in other languages may have conflicting findings to those included in this systematic review. A pilot study investigating the transition from in person SLT assessment to online assessment for preschool children with hearing loss (Werfel *et al.*, 2021) found that most speech and language measures had high or adequate test-retest reliability when administered online, concluding that SLT assessment can be delivered successfully online for this population. Furthermore, Behl and colleagues (2017) found that children with hearing loss who received telepractice treatment aimed at improving receptive and expressive language development achieved similar, if not better, scores than children who attended therapy in person. Research investigating the use of remote early intervention for children with ASD (Ashburner, Vickerstaff, Beetge and Copley, 2016) found many advantages with this delivery method including enabling families to access support from home, providing support in the child's natural environment (instead of an unfamiliar clinical setting which can be difficult for children with ASD), and enabling sharing of resources such as visual symbols. However, technical difficulties were a disadvantage which resulted in frustration amongst parents/carers. Furthermore, all participants reported that remote therapy should support in person clinician contact but not completely replace it.

Research investigating the reliability of administering assessments and delivering therapy via telepractice has been carried out. A study comparing speech and language assessment scores of in person and online delivery for children with hearing loss revealed very high test-retest reliability (0.715-0.955) for measures including articulation, morphosyntax, phonological awareness, and vocabulary (Werfel *et al.*, 2021). However, timed measures for phonological processing (e.g., rapid naming tasks) had low test-retest reliability, and no alternative mode of administration was developed for these measures. Low test-retest reliability in timed measures is likely due to unstable internet connection. Timed measures should be replaced with appropriate untimed measures where possible when using telehealth. Werfel and colleagues then tested the transition of speech and language assessment from in person to online and develop tips for optimising telehealth assessment procedures. Findings showed that administering assessments virtually provided many benefits which were not found when delivering sessions in person. These included flexible scheduling, elimination of challenges imposed by clinic opening hours and travel time, more efficient test administration, and increased engagement during assessment sessions. All the resources required for the session could be found in one location and this ready access to materials reduced data loss due to SLTs forgetting or losing resources whilst travelling to different locations. Researcher suggestions for increased engagement included regularly providing performance feedback, more-so than when administering in person; providing breaks where the children could do another activity such as show and tell with personal items or a movement activity; and allowing them to use the whiteboard feature to draw. Similar findings were found in a study investigating the reliability and feasibility of administering child language assessment via telehealth (Campbell, Lawrence and Goldstein, 2024). Five master's-level SLTs delivered therapy to 100 children between the ages of 3 and 12 years. No significant language scores or behaviour differences were found between the testing conditions on all three versions of the Clinical Evaluation of Language Fundamentals (CELF) (Wiig, Secord and Semel, 2013).

As well as SLT assessment, research has also concluded that remote SLT intervention has its benefits. A systematic review of the use of telehealth in speech, language and hearing sciences (Regina Molini-Avejonas, Rondon-Melo, de La Higuera Amato and Samelli, 2015) reported that speech interventions delivered remotely were as efficient as face-to-face delivery and more cost-effective and successful. 30% of these papers concerned dysarthria in both paediatric and adult populations. The remaining papers focused on stuttering, people with cleft palate, children with language disorders, and childhood speech disorders (e.g., articulation and phonetic-based speech disorders (Grogan-Johnson, Alvares, Rowan and Creaghead, 2010; Grogan-Johnson *et al.*, 2013). Patient and family satisfaction with telehealth for speech intervention was reported. The systematic review also found teletherapy for language to be considered as valuable by patients as face-to-face therapy.

2.5. Online Delivery of Intensive Dysarthria Intervention for Children with Cerebral Palsy

Pennington et al. (2019) investigated the effectiveness of the SSA for children with CP and dysarthria via telehealth, in a single blind randomised controlled trial (RCT), where 11 children received therapy via Skype and 11 children (the control group) received their usual therapy. This sample size is just fewer than the recommended 12 participants per group, which is thought to be reasonable to consider feasibility and accuracy in parameter estimation (Julious, 2005). The control group were offered Skype therapy once the study was complete. The Skype intervention adhered to the SSA protocol. The results suggested intensive SLT via Skype may be effective and feasible, with all the children's parents reporting at least moderate intelligibility improvements 12 weeks post-intervention. All children found their own speech to have improved post-therapy, with all but one child judging their speech to be a ‘great deal better’. Parents reported that their children became more independent, which was an unforeseen benefit.

2.6. Individualisation of Dysarthria Therapy

As the speech characteristics of children with CP and dysarthria are heterogeneous, the patterns of change are likely to vary across children depending on the type and severity of their dysarthria. The review of the literature above highlights differences in children’s responses to intensive dysarthria therapy programs. For instance, the SSA program has elicited inconsistent patterns of acoustic change between and within children (Pennington *et al.*, 2023). Furthermore, not all parents have reported noticeable improvements in their child’s speech in response to the SSA (Pennington, Rauch, Smith and Brittain, 2020). Similarly, responses to LSVT have varied, with some studies reporting positive acoustic outcomes in SPL, duration, and frequency range (Fox and Boliek, 2012), while others have noted improvements limited to SPL (Boliek and Fox, 2017). Children with severe dysarthria have shown the least communicative benefits in response to SIT (Levy, Chang, Hwang and McAuliffe, 2021).

A detailed profile of each child’s clinical presentation is vital to understand what features impact their intelligibility so that the intervention can be specifically tailored. The literature has enabled predictions to be made about the types of errors which may be susceptible to change and the vocal cues/intervention techniques which may facilitate these improvements.

Recommendations for future research suggest that children with CP may benefit from individualised cues addressing speech rate and intensity to maximise their speech intelligibility (Pennington *et al.*, 2023). Cues may need to focus on specific phonemes or parts of words, e.g., ‘use your strong /s/ sound’ or ‘stay strong to the end’. The order and number of cues introduced, and in which session, may vary across children and vocal cues may need adapted throughout the therapy block depending on how well each child responds to them. Acoustic results from Pennington et al.’s (2023) study suggest that CS could be addressed sooner in personalised therapy (recommended by the PPI in Pennington et al.’s 2023 study) and vocal cues introduced earlier to give more time for potential acoustic changes to be perceived by ear and for children to work on their speech errors.

The NICE guidelines recommend the provision of interventions that are tailored to the individual needs of children with CP, reinforcing the need for this personalised therapy (National Institute for Health and Care Excellence, 2017). This project involves personalisation of the SSA to determine the effectiveness of personalised dysarthria therapy at improving intelligibility in children with CP. The SSA has been selected because; (a) the evidence indicates that it is appropriate for children with CP and dysarthria; (b) online delivery is feasible; (c) the previous studies which employ this technique assess intelligibility in a similar way to this research; (d) it has strong intelligibility maintenance effects; and (e) it facilitates personalisation as different vocal cues can be implemented within the intervention. This project is an essential initial step towards establishing whether personalised speech intervention will result in greater improvement in speech intelligibility in children with CP and dysarthria. If the results prove personalised intervention to be efficient, they will be used to inform a future RCT to explore whether it can be implemented in clinical practice.

2.7. Research Question

My research aims to answer the question, 'Does personalised speech and language therapy improve the speech intelligibility of children with cerebral palsy and dysarthria?'.

2.7.1. *Null Hypothesis*

Personalising the SSA based on the individual speech characteristics of children with CP and dysarthria will result in no change in intelligibility compared to their usual treatment.

2.7.2. *Alternative Hypothesis*

Personalising the SSA based on the individual speech characteristics of children with CP and dysarthria will result in greater gains in intelligibility compared to their usual treatment.

2.7.3. *Aims and Objectives*

My primary aim is to assess the effectiveness of personalised dysarthria intervention in improving speech intelligibility.

The objectives are to:

1. assess the effect of personalised cues on individual children's perceptual and acoustic speech characteristics
2. assess the feasibility of collecting acoustic measures (duration, intensity, and individual exploratory measures) during online therapy to inform the intervention

Chapter 3. Methodology: Intelligibility and Its Measurement

3.1. Introduction to the Chapter

This chapter discusses the methodology underpinning this study. It begins by describing the ways in which intelligibility can be measured perceptually and then discusses the speech samples which can be elicited to measure intelligibility. Next it discusses the acoustic properties of phonemes in terms of manner of articulation and the acoustic measures appropriate to investigate for each. Finally, the chapter evaluates the methods used to elicit speech, justifying the method used in this study.

3.2. Methods of Measuring Intelligibility

Measuring intelligibility can guide diagnosis, prognosis and intervention approaches (Miller, 2013). Intelligibility measures provide an overall rating of the speech disorder based on listener ability to identify what is being said. These measures enable SLTs to monitor the dysarthria during therapy. There are two main methods used to measure speech intelligibility: item identification and scaling (Ertmer, 2011).

3.2.1. Objective Measures: Identification Tasks

Word recognition/identification tasks are objective measures of speech intelligibility, quantifying the integrity of the speech signal, (Hustad, 2006b) by comparing the words perceived by listeners with those produced by a speaker, when target words are known. Confirmation of the words actually produced is not always possible in spontaneous speech as identifying exact targets from disordered speech can be difficult, especially if the context is unknown.

There are several types of word recognition tasks, which vary in response method: orthographic transcription, multiple-choice and completion tasks.

3.2.1.1. Orthographic Transcription

Orthographic transcription is classified as an open-set word identification approach (Gordon-Brannan and Hodson, 2000). It requires listeners to write word-for-word what they believe the speaker has said. Their transcription is then compared to the speaker's actual production and the speaker's intelligibility score is calculated from the percentage of words correctly transcribed. This method is considered the gold standard for measuring intelligibility in dysarthric speakers (Stipancic, Tjaden and Wilding, 2016) as it reflects the percent of words correctly transcribed by the listener (Hirsch, Thompson, Kim and Lansford, 2022). The Sentence Intelligibility Test

(Yorkston and Beukelman, 1996), a commonly used clinical tool for measuring intelligibility (Duffy, 2013a), employs this measure. Generally, the transcribed words are considered correct if they phonemically match the target word (Hustad, 2006b; Hustad, Jones and Dailey, 2003), with spelling errors and homonyms also marked as correct. Some studies allow for small morphological errors affecting tense and plural to be accepted as long as there is no change to the syllable structure (Liss, Spitzer, Caviness and Adler, 2002).

3.2.1.2. Multiple-Choice Tasks

Multiple-choice tasks are closed-set word identification tasks (Gordon-Brannan and Hodson, 2000) which require listeners to identify what words a speaker has produced by selecting from a list of phonetically similar words. An example is the Children's Speech Intelligibility Measure (CSIM) (Wilcox and Morris, 1999), which measures SW intelligibility. CS can also be measured using multiple-choice tasks, e.g., identifying a target word from sentences which only differ by a single word or completing sentences where a target word is omitted. Speakers generally achieve the highest intelligibility scores on multiple-choice tasks (Yorkston and Beukelman, 1978).

Objective measures appear to form a hierarchy of task difficulty, with speakers achieving the greatest intelligibility scores from multiple-choice tasks, intermediate scores from completion tasks and the lowest intelligibility scores from transcription tasks (Yorkston and Beukelman, 1978). There is a subjective element to these measures as they do not necessarily test exactly what was said, but what was heard – i.e., they may not capture the phonetic errors which can be identified through acoustic measures.

3.2.2. Objective Measures: Acoustic Measures

There is a lack of one-to-one correspondence between acoustic phonetic measures and perceptual evaluations (Kent *et al.*, 1999). Listeners may write what they think is plausible or choose an option which is as close to what they heard as possible in perceptual measures. Thus, intelligibility scores calculated from perceptual objective measures may over or underestimate actual changes in intelligibility which can be seen acoustically.

Pommée et al., (2020) described acoustic measures as objective intelligibility measures. They found that 79% of experts agree that measuring consonant, vowel, and glide acoustics, as well as inter-phoneme formant transitions, is the best way to assess intelligibility. These acoustic measures can be employed on single phonemes, syllables, non-words, and sentences. Acoustic measures can also assess voice quality and suprasegmental features which both contribute to intelligibility as they can impact phonemic contrasts.

However, some argue that acoustic measures have a subjective element because they are executed by humans, meaning they are subject to bias in terms of the recording method, choice of stimuli, and analysis setting (Pommée *et al.*, 2020).

3.2.3. Subjective Methods: Scaling

Scaling methods are subjective techniques that rely on listener estimates to measure intelligibility (Yorkston and Beukelman, 1978). Scaling methods include a range of scales, each with unique features to capture listener judgements.

Rating scales allow listeners to rate intelligibility along a spectrum, which may include numbers, percentages, or descriptors (e.g., “not at all”, “seldom”, or “always understood”) (Ertmer, 2011). Equal appearing interval (EAI) scales use equal intervals, typically on a 5-point or 7-point scale, with higher scores representing lower intelligibility. Likert scales are similar in structure to EAI scales, with listeners rating the severity of speech disorder along a 5-point or 7-point scale of descriptors, where ‘1’ indicates very high intelligibility and ‘5’ indicates very low intelligibility (Schuster *et al.*, 2006; Bolognese, Schnitzer and Ehrich, 2003). Likert scales are assumed to have equal intervals for practice purposes, but in reality this assumption may not hold true without empirical validation.

Visual analogue scales (VAS) are used for characteristics that are difficult to measure directly (Gould, Kelly, Goldstone and Gammon, 2001), e.g., voice quality (Kempster *et al.*, 2009). They typically span a 100mm horizontal line, anchored by descriptive endpoints such as “profound speech disorder” to “no speech disorder”. Raters mark their perception of intelligibility along this line, and scores are derived by measuring from the left endpoint to the mark. Percentage estimates require listeners to gauge the percentage of speech they understood, from 0% (none) to 100% (all).

Direct magnitude estimation (DME) is a perceptual ratio scaling technique whereby listeners compare a speech sample to a standard 'modulus' by assigning numerical estimates indicating its relative intelligibility, i.e., twice or half as intelligible as the standard (Whitehill, Lee and Chun, 2002; Gescheider, 1976; Schiavetti, 1992). A fixed modulus representing either high, middle, or low intelligibility is often used for consistency in data analysis (Weismer and Laures, 2002; Engen, 1971; Schiavetti, 1992).

3.2.4. Evaluation of Measuring Techniques

Scaling is less time consuming and cheaper than objective intelligibility measures and used frequently in SLT (Enderby, 1980; Goetz *et al.*, 2008). Transcriptions are labour-intensive, requiring listeners to write and assess entire speech samples. Computerised scoring can expedite the process (Stipancic, Tjaden and Wilding, 2016), but listener responses still need to be checked for errors such as spelling mistakes.

Despite being efficient, scaling methods have limitations. Scaling methods can be challenging to administer and interpret (Bolognese, Schnitzer and Ehrich, 2003). They provide an overall intelligibility rating rather than identifying specific deficits. Listeners have been found to give the same rating to speakers with 25% to 90% objectively measured intelligibility (Samar and Metz, 1988); therefore, scaling methods may lack sensitivity for tracking improvement in speakers with mid-range intelligibility unless a substantially higher level of intelligibility is achieved. Research has shown that VAS and percentage estimates tend to yield lower intelligibility scores than transcription, partly due to scoring inconsistencies (Stipancic, Tjaden and Wilding, 2016; Hustad, 2006b). However, the various protocols which can be employed during orthographic transcription can yield statistically different results. Only marking exact phonemic matches as correct is likely to result in lower intelligibility scores than if minor morphological differences were accepted (Hustad, 2006a). This is because it is easier for listeners to interpret the meaning of words than decipher precise forms of the same words. These discrepancies in raw scores must be considered when deciding which methods to employ in clinic and/or research. Methods like DME may bias listener perception due to the choice of comparison sample, influencing what factors they believe cause the variation in intelligibility between the modulus and speaker (Weismer and Laures, 2002).

Reliability across scaling methods is variable. The subjective nature leads to poorer inter-rater and intra-rater reliability as listener opinions on speech disorder severity differ, making comparison difficult (Miller, 2013). However, percentage estimates were found to have good intra-rater reliability when measuring the intelligibility of dysarthric speakers (Yorkston and Beukelman, 1978), with 82.4% of raters' first intelligibility estimates within 14% of their second. VAS was also found to have slightly higher inter-rater and intra-rater reliabilities than transcription when measuring the intelligibility of speakers with MS and PD (Stipancic, Tjaden and Wilding, 2016). Nonetheless, objective measures address some of the reliability concerns associated with subjective measures. By allowing for multiple samples from a speaker—such as scoring 20 words—objective measures enable the calculation of a mean intelligibility score from a larger set of responses. This approach helps minimize variability across listeners, thereby enhancing the consistency of the results (Yorkston and Beukelman, 1978).

Clinical outcome measurement tools need to be sensitive to small changes in performance across a range of dysarthria severities. DME is thought to have greater sensitivity than transcription for non-segmental aspects like prosody or voice quality, potentially offering a more comprehensive representation of certain speech disorders (Weismer and Laures, 2002). VAS is noted for its finer gradations compared to Likert scales, allowing for more nuanced listener judgements and broader statistical analyses, with potential for greater statistical power (Chang and Little, 2018; Baylis, Chapman and Whitehill, 2015). However, subjective measures are generally less sensitive and reliable than objective measures, with subjective intelligibility estimate scores demonstrating substantially larger critical differences within speakers (Cox, Alexander and Rivera, 1991).

3.3. What Speech to Elicit

When measuring intelligibility, typically both single words (SWs) and connected speech samples (CS) are taken. The speech samples should have low predictability, e.g. minimal word pairs, unpredictable sentences or non-words, when assessing intelligibility perceptually (Pommée *et al.*, 2020). SW elicitation reduces the contextual/signal-independent cues which may aid listeners' abilities to decode the signal. These cues are not always available, so it is important to rate intelligibility without additional context. Some dysarthric speakers are limited to SW productions and therefore SWs may be more representative of their typical speech intelligibility (Miller, 2013). The SWs assessed should cover all sounds, sound combinations and sound positions in the speaker's language (Enderby and Palmer, 1983).

CS needs to be elicited as not all dysarthric speakers are limited to single word productions and it provides insight into important intelligibility influences such as stress, rhythm, and intonation, which cannot be properly observed in SW productions.

3.3.1. Tasks Used to Elicit Speech

Speech samples can be elicited spontaneously, through imitation/repetition, or using reading or naming tasks. Different elicitation methods may result in different intelligibility scores, even when assessing the same speaker on the same test item (Tjaden and Wilding, 2011a). Therefore, the same task must be used in follow-up assessments to ensure comparisons between intelligibility pre- and post-intervention are valid.

3.3.1.1. Spontaneous Speech Samples

Spontaneous/continuous CS samples are favoured for measuring intelligibility as they are more representative of children's typical speech production abilities (Gordon-Brannan and Hodson, 2000). Spontaneous CS is the most ecologically valid context (Flipsen, Hammer, & Yost, 2005) and considered the gold standard for evaluating children's speech (Hodge and Gotzke, 2014a). However, the phonetic, semantic and morphosyntactic content produced by speakers' spontaneous speech is likely to vary considerably (Flipsen, Hammer, & Yost, 2005), making comparisons between speech samples problematic. Furthermore, it can be difficult to create accurate target transcriptions for speech samples produced by severely dysarthric speakers. Any measure investigating individual phoneme performance must be compared to a specific target, meaning that only the segments of speech understood by the listener transcribing the target can be analysed, resulting in a biased sample (Flipsen, Hammer, & Yost, 2005).

Facilitative procedures, such as promoting conversation through play, is valuable for eliciting continuous speech samples from children (Iacono, 1998). Spontaneous CS samples can also be elicited through picture description tasks (Pennington, Miller, Robson and Steen, 2010; Pennington *et al.*, 2013; Gordon-Brannan and Hodson, 2000), open-ended questions (Iacono, 1998), requests for information such as personal or procedural information (Brookshire and Nicholas, 1994; McHenry, 2011) and story retell (Kuschmann and Neill, 2015). Open-ended questions and story retell provide a more structured format with some context and this may be more suitable for children with low intelligibility who are reluctant to speak spontaneously.

Video description has mainly been used in previous studies to elicit spontaneous CS. Researchers have used video narration tasks with a range of populations including people with aphasia, non-native speakers of English, children with language impairments, children with brain injury and typically developing children (Croot *et al.*, 2015; Dollaghan, Campbell and Tomlin, 1990; Pashek and Tompkins, 2002; Tomlin, 1984). Demands of the speaker are lowered in video description tasks compared to conversational speech due to constraints in the topics addressed (Croot *et al.*, 2015; Conroy, Sage and Ralph, 2009). However, video description reduces the difficulties associated with glossing spontaneous speech as it provides semantic context. Results from a study by Dollaghan and colleagues (1990) concluded that video narration is a potentially effective method for eliciting speech samples as it resulted in children producing more utterances per unit of time and longer mean length of utterances compared to conversational speech samples.

3.3.1.2. Imitation/Repetition

Both SW and CS samples can be elicited through imitation/repetition. The Children's Speech Intelligibility Measure (CSIM) (Wilcox and Morris, 1999) and Preschool Speech Intelligibility Measure (P-SIM) (Morris, Wilcox and Schooling, 1995) have been used in dysarthria intervention studies to elicit SWs (Pennington, Miller, Robson and Steen, 2010; Pennington *et al.*, 2013; Gordon-Brannan and Hodson, 2000). Both involve children imitating 50 words from a word list.

CS can also be imitated. Gordon-Brannan and Hodson (2000) asked children to repeat ten sentences which were five words long and described activities on "Cartoon Boards" (Speech & Language Materials, 1967). The Test of Children's

Speech (TOCS+) employs software to elicit sentence productions of increasing utterance length through direct imitation of pre-recorded audio models, supported with associated images and text. This measure was designed to be more signal-dependent, requiring the listener to decode the speech signal from just an audio-recording, without the availability of other contextual cues.

The TOCS+ also assesses speech rate, as does the Sentence Intelligibility Test (Yorkston, Beukelman, Hakel and Dorsey, 1996). Speech rate should be examined when assessing speech intelligibility as children with CP are prone to slower speech than their peers (Nip, 2013) and speech rate is often the focus of SLT interventions for children with CP and dysarthria (Levy, Ramig and Camarata, 2013; Pennington *et al.*, 2013; Pennington, Miller, Robson and Steen, 2010). The number of intelligible words per minute is thought to be a more sensitive measure of dysarthric speech than intelligibility ratings alone (Yorkston and Beukelman, 1981).

3.3.1.3. Reading Tasks

Reading involves an external visual cue, i.e. a printed script, which may enhance intelligibility performance compared to spontaneous or self-initiated speaking tasks (Tjaden and Wilding, 2011a). Literacy skills must be considered when deciding whether to use reading tasks. Reading tasks can be challenging for children with CP and dysarthria as they often have reading impairments (Sandberg, 2001; Wotherspoon, Whittingham, Sheffield and Boyd, 2023). The use of reading to measure intelligibility has been used frequently with people with PD. Case studies completed by Canter and Van Lanker (1985) and Kempler and Van Lanker (2002) on individuals with PD found speaker intelligibility to be greater when obtained from reading tasks compared to spontaneous speech. However, Tjaden and Wilding (2011a) found no significant differences in intelligibility estimates between paragraph reading and spontaneous speech, both at group and individual levels. Bunton and Keintz (2008) also found no significant group differences between reading tasks and spontaneous speech. Caution should be taken in generalising results from individual case studies to wider populations. Case studies may not accurately represent speech patterns of the target population. Additionally, the controlled lab setting in which speech was elicited may have contributed to more consistent performance across tasks, contrasting with the variability likely seen in less structured, real-world settings.

3.3.1.4. Naming Tasks

Single word samples can be elicited through naming tasks, most commonly in the form of picture naming. Picture naming has been used with various populations including people with dysarthria and hearing-impaired children to measure speech intelligibility (Havstam, Buchholz and Hartelius, 2003; Huttunen and Sorri, 2004). Pictures may illustrate everyday objects and activities, e.g. those used in Remes (1975) articulation screening test. Pictures often target single words containing all the phonemes in a language and consonant clusters, e.g. Havstam et al. (2003) targeted all the Swedish phonemes.

3.3.2. Advantages and Disadvantages of Imitated and Spontaneous Speech Samples

Imitated speech samples are less time consuming to collect and analyse compared to spontaneous speech. For example, the TOCS+ was used by Hodge & Gotzke (2014a) and the transcription analysis only took around 15 minutes whereas the conversational speech sample took 2 hours to analyse. As the target words are already known, a gloss does not need to be created, reducing administration time (Johnson, Weston and Bain, 2004). Imitation appears suitable for eliciting children's speech, as children have enjoyed and engaged well in the TOCS+ (Hodge and Gotzke, 2014a). The TOCS+ also has criterion-related validity for children with CP and a range of dysarthria severities; this cannot be obtained from spontaneous speech samples.

However, imitated speech samples do not replicate natural speaking conditions and they may overestimate or underestimate children's intelligibility. Careful consideration is needed if assessing speech rate through imitation as children's speech rate may be influenced by the model. This could result in children producing speech at a slower or faster rate than their habitual spontaneous speech.

Imitated speech samples can control for linguistic factors, such as the number of repeated content words and function words, and utterance length. These factors can influence intelligibility, for example, function words appear to be transcribed significantly more accurately than content words or modifiers (Hustad, 2006a).

Eliciting single words through imitation may result in lower intelligibility scores than imitated sentences or connected speech intelligibility as broader contextual cues, such as semantics and suprasegmental prompts, will be available from sentences and connected speech but not from single word productions.

Hodge and Gotzke (2014a) found that intelligibility scores from imitated speech showed greater variability than intelligibility scores from spontaneous speech, suggesting the TOCS+ is a more sensitive tool for measuring intelligibility in CS compared to conversational samples where children select their own vocabulary. This increased sensitivity may stem from the TOCS+ restriction on repeated content words. The TOCS+ generates a unique 80-word sentence test for each child, tailored to their longest utterance length and without repeating content words. In contrast, spontaneous speech may show less variability, as children tend to use a limited vocabulary, repeating certain words multiple times (Hodge and Gotzke, 2014a). However, imitated speech samples may underestimate the intelligibility of spontaneous speech in children with severe speech disorders and overestimate it in children with milder speech disorders if the number of words or syllables is not capped at the child's longest spontaneous utterance. This discrepancy arises because imitated speech tasks may contain longer utterances and a wider range of vocabulary than the typical conversational speech of children with severe disorders. Conversely, for more intelligible children, imitated speech may be easier due to the reduced cognitive load and sentence length may be shorter than what they would typically produce (Hodge and Gotzke, 2014a). Therefore, it is crucial to consider the severity of an individual's speech disorder and speech characteristics when selecting elicitation techniques.

3.3.3. Diagnostic Intelligibility Testing (DIT)

After speech samples have been elicited through reading, naming or repetition tasks, Diagnostic Intelligibility Testing (DIT) (Kent, Weismer, Kent and Rosenbek, 1989) can be carried out. DIT aims to gain insight into the reasons behind unintelligibility, through reading or repeating a list of words. It is based on the principle of minimal contrasts, i.e., words which differ by only one place or manner of articulation). DIT highlights which phonemes are being misperceived and which are being perceived correctly. DIT is useful as the test items represent the range and distribution of sound contrasts within a specific language, and generally appear proportionally to their occurrence within that language. DIT allows for parallel lists, which match the sound distributions and syllable structures, to be formulated for follow-up assessments, meaning comparisons can be made pre- and post-intervention. Intelligibility is then scored by calculating the total number of words recognised by the listener. Diagnostic decisions and SLT goals can be made by analysing the listener's misperceptions; for example, what sound contrasts did listeners struggle to distinguish and in what word positions.

Assessments following the DIT approach have been used both in clinic and in research for acquired and developmental disorders (Kent, Weismer, Kent and Rosenbek, 1989; Yorkston and Beukelman, 1981; Hodge and Gotzke, 2014a). However, representing all speech contrasts in every possible word position within a language is extremely time consuming and may be impractical. There are also disputes over the reliability of the intelligibility estimates due to differences in administering and scoring the test, and interpreting the results (Miller, 2013).

After eliciting speech samples, summarising the misheard words and utterances, e.g. documenting the word/utterance length, syllable structure, and complexity, might help clinicians make decisions regarding suitable SLT techniques.

3.3.4. Determining Phrases from Connected Speech Samples

The number of words gathered in connected speech samples will vary amongst children. Some children may only produce two or three words at a time, whereas others may talk at length, producing multiple utterances at a time. Therefore, an appropriate method of determining what constitutes a phrase needs to be determined as this can impact listener ability to orthographically transcribe the chosen phrases. For example, working memory will impact the transcriptions. Listeners may experience memory limitations in processing disordered speech signals (Yunusova, Weismer, Kent and Rusche, 2005); consequently, longer phrases may be subject to lower intelligibility scores due to listener inability to recall all the words produced. Protocols used by researchers to determine phrases from large connected speech samples include the first 'X' many phrases containing eight or nine syllables (Weismer and Laures, 2002)- with 'X' being the number of phrases requiring transcription and/or analyses.

3.4. Acoustic Analyses of Speech

Acoustics is a branch of physics that studies sound. Speech acoustics studies both the physical structure of the sounds of speech and the perception of these sounds (Nasser and Abolfazl, 2006). Acoustic analysis refers to the study of soundwave production and measurement. It enables the features of the speech sound stimuli perceived by our ears to be determined (Fry, 2009). Acoustic analysis of speech involves studying the acoustical characteristics of both typical and atypical speech and it looks at the physical aspects of spoken language, e.g., using waveform and spectrogram analyses. Acoustic analysis is quantitative and can be informative for describing and supporting the associated perceptual judgements of speech including vocal loudness, vocal quality, and speech disorder (e.g., dysarthria type).

3.4.1. Acoustic Properties of Sounds

Every speech sound has its own individual acoustic characteristics. Similar characteristics can be seen within sounds which come under the same manner, place, and voicing. Some features can be observed by looking at key visual patterns within the waveform and spectrogram; this is known as acoustic profiling and can provide qualitative information, whereas other aspects require measurements to be taken. For example, plosives are characterised by a burst, which signifies the release of the sound. However, sometimes this release is not clearly identifiable due to the presence of adjacent plosives (e.g., 'actor' [ak̚tʰə]), resulting in a prolonged hold in the waveform and spectrogram. In other instances, the release phase may be absent, especially in cases of unreleased stops, such as at the end of a sentence in English. This absence appears as a straight line on a waveform and as a blank area on a spectrogram. For word initial (WI) plosives, the closure is not recognisable unless it occurs within an utterance, although closure duration can be measured for plosives in word final (WF) positions. Consonant clusters can be recognised through acoustic profiling by identifying the distinct features associated with two different consonant productions. It is common for the release of only one consonant in a cluster to be clearly visible on a spectrogram. In the absence of an expected consonant, the duration, intensity, and voicing patterns of the surrounding sounds should be investigated to see if partial acquisition of a cluster was achieved.

3.5. Acoustics of Dysarthric Speech

Disordered speech often has different acoustic features to what is expected. For example, the burst in a plosive produced by a person with dysarthria may be weaker than that produced by a typical speaker, due to poorer breath support which can cause quieter speech. This may result in plosives not being perceived by listeners, with [p] being particularly vulnerable as it has the lowest frequency and sometimes the intensity of its burst can be so low, even when produced by a typical speaker, that it can be difficult to see on a spectrogram (Ladefoged and Johnson, 2014). A study of typically developing children (Macken and Barton, 1980) showed that children's initial attempts at both voiced and voiceless plosives (e.g., /p/ and /b/) are indistinguishable both perceptually and acoustically. This was followed by a phase where an acoustic difference was observed but not a perceptual difference known as covert contrast. Finally, children produced the voiced and voiceless plosive so that they are distinguishable both perceptually and acoustically. Children with disordered speech may also make covert contrast, potentially as a response to therapy. Acoustic measures may show change, e.g., phoneme accuracy or phoneme realisation, not observed perceptually.

It is predicted that the children in the study will have weak plosive production because plosives require the tightest constriction and intraoral pressure. This is likely to be difficult for the participants due to their motor disorder impacting the strength and coordination of their oral muscles, impairment of the respiratory subsystem and/or impaired velopharyngeal closure (Allison and Hustad, 2018a). It is likely that acoustic analyses of plosives will show reduced realisation of plosive bursts for both single words and connected speech. Errors of manner due to incomplete closure and errors of place will be likely (Platt, Andrews and Howie, 1980; Kim and Gurevich, 2023).

3.6. Methodological Decision and Clinical Reasoning

The review of methods and procedures above informed the design of my study. Given the reliable and sensitive nature of objective measures, orthographic transcription was used to measure children's speech intelligibility of SWs and CS as it enabled a percentage intelligibility score to be calculated. Both SW and CS samples have been elicited in other studies measuring the intelligibility of participants with CP and dysarthria (Pennington, Miller, Robson and Steen, 2010; Pennington *et* *al.*, 2013; Natzke, Sakash, Mahr and Hustad, 2020; Chang *et al.*, 2024; Pennington *et al.*, 2019; Pennington, Lombardo, Steen and Miller, 2018), and the intelligibility of other populations with speech disorders (Gordon-Brannan and Hodson, 2000; Yorkston and Beukelman, 1978; Sussman and Tjaden, 2012).

3.6.1. Single Words

Some children with CP only produce SWs, and therefore SW speech samples may be more typical of their everyday speech patterns. SW productions enable intelligibility scores to be obtained without influence from signal-independent factors such as semantics or syntax, which can increase intelligibility (Yorkston, Strand and Kennedy, 1996). SW speech samples were elicited using pre-determined word lists balanced in terms of word length, frequency, complexity and VPM components. The words were elicited from a picture naming task, so that productions reflected children's speech patterns rather than an imitation of the models' speech characteristics, e.g., their pitch and/or volume. Picture naming tasks have been used in similar studies (Pennington *et al.*, 2013; Pennington, Miller, Robson and Steen, 2010; Pennington *et al.*, 2019).

3.6.1.1. Creation of the Single Word Lists

To reduce learning effects of both the child and listener two single word lists were created to elicit the SWs used for measuring intelligibility. One list was used at 6-weeks pre-therapy and 1-week post-therapy and the other list was used at 1-week pre-therapy and 12-weeks post-therapy.

The lists were designed to suit the youngest child's vocabulary (age 5) to ensure all words were developmentally appropriate. Using monosyllabic words alone was insufficient to represent language or assess speech features like rate and syllable reduction, so a mix of monosyllabic and polysyllabic words was included. Each list contained eleven monosyllabic words, seven bisyllabic words, and two three-syllable words. Parameters ensured phonological similarity between lists and targeted a range of phonemes and processes, particularly those challenging for children with CP and dysarthria (e.g., fricatives, affricates, word-final consonants, and clusters). Easier phonemes (e.g., nasals) were also included to reduce frustration and allow for accurate articulations. It is acknowledged that some of the younger children may not have acquired all phonemes of words in the lists and this was considered during analysis. However, creating a word list without the later developed phonemes /ɹ/, /θ/ and /ð/ (Dodd, Holm, Hua and Crosbie, 2003) would not have allowed accurate and detailed phonological assessment of most of the participants.

The parameters can be seen in Table 7 below.

Word Number	List 1 (6 Weeks Pre & 1 Week Post)	List 2 (1 Week Pre & 12 Weeks Post)	Parameters
Practice	Pig	Book	
1	Bell	Bin	WI voiced labial plosive & WF sonorant
2	Face	Fish	WI voiceless coronal fricative
3	Jam	Juice	WI voiced coronal affricate
4	Rug	Log	WF voiced dorsal plosive
5	Wave	Rose	WF voiced coronal fricative & WI sonorant
6	Match	Watch	WF voiceless coronal affricate
7	Lamb	Mail	WI and WF coronal sonorant
8	Star	Ski	WI 2-consonant cluster voiceless-voiceless
9	Square	String	WI 3-consonant cluster
10	Hand	Pond	WF 2-consonant cluster voiced-voiced
11	Box	Desk	WF 2-consonant cluster voiceless-voiceless
12	Pepper	Waiter	WM voiceless coronal plosive, fricative or affricate
13	Camel	Carrot	WI voiceless dorsal plosive
14	Pizza	Feather	WM voiceless coronal affricate
15	Sandwich	Windmill	WM cluster
16	Ladder	Water	WI sonorant
17	Trumpet	Glasses	WI 2-consonant cluster voiceless-voiced
18	Diamond	Forest	WF 2-consonant cluster
19	Kangaroo	Cucumber	3 syllable word
20	Alien	Elephant	3 syllable word

Table 7 Single Words Word Lists for Assessing Intelligibility

The therapy word lists used during therapy for acoustic analyses were shorter due to the time-intensive nature of the analysis. Parameters in Table 8 were based on the parameters used in the pre- and post-therapy assessments and dysarthria research in children with CP. Obstruent consonants (e.g., plosives and fricatives) were targeted for their tight constriction and high intraoral pressure demands, as they are reported to be the most identifiable sounds post-therapy (Pennington *et al.*, 2023). Consonant clusters were included due to limited research on their intelligibility in children with CP. Sonorant consonants, requiring less coordination and pressure, were anticipated to be easier pre-therapy. Each list included five monosyllabic and one bisyllabic word.

Word Number	List 1	List 2	List 3	List 4	List 5	List 6	Parameters
Practice	cake	fork	whale	shoe	girl	heart	
1	pillow	king	beach	goose	tooth	doll	WI plosive
2	hug	road	rat	lock	web	rope	WF plosive
3	van	zoo	thumb	fairy	sock	shower	WI fricative
4	bath	house	leaf	nose	bush	kiss	WF fricative
5	drum	spider	snowman	train	flower	glove	WI cluster
6	mask	wolf	gold	band	fence	nest	WF cluster

Table 8 Single Words Word List for During Therapy Acoustic Analyses

3.6.2. Connected Speech

Spontaneous CS samples were elicited through a video description task as this has been described as a reasonable compromise between a naturalistic conversational speech task and a structured task, such as picture description or repetition (Dollaghan, Campbell and Tomlin, 1990).

Performance and capacity were assessed at the pre- and post-therapy recordings. The performance condition demonstrated children's typical speech as they were not prompted to use their vocal cues, highlighting their ability to generalise their new skills outside of therapy, self-monitor, and independently fix breakdowns in communication. The ICF describes capacity as the ability to execute a task in a controlled environment (WHO, 2001). Children's vocal cues were reinforced, and they were frequently reminded to use their target voice in the capacity condition. It enabled their maximum intelligibility to be identified. Speech in the capacity condition was expected to be more intelligible due to the support provided, though ceiling effects for children with higher baseline intelligibility and floor effects for those with severe dysarthria were possible due to motor constraints.

Acoustic measures, informed by findings from Pennington et al. (2023) and individual speech characteristics, were also taken for both SWs and CS to detect changes in speech which were not yet heard perceptually by listeners.

3.7. Study Design

The overall study design of this PhD research is an interrupted time series (ITS) which is a quasi-experimental design. A quasi-experimental design seeks to establish a cause-and-effect relationship between an independent and dependent variable but does not rely on random assignment to study groups. An ITS involves consistently gathering data before introducing a product/service/intervention (in this case the dysarthria therapy), during the intervention, and after withdrawing it to ascertain whether changes are occurring in the outcomes being assessed (i.e., speech intelligibility) (Anaby *et al.*, 2014; GOV.UK, 2020).

As this study design requires repeated measurements to be taken over the course of the research, fourteen speech samples were taken over ten time points: two speech recordings at both six weeks and one week pre-therapy, one speech recording each week during the six-week intervention, and two speech recordings at both one week and twelve weeks post-therapy. This enabled changes in speech intelligibility and acoustic speech characteristics from pre- to post-therapy to be determined, as well as indicating at what point during the therapy the changes in acoustic properties occurred and what these changes were. The more frequent measurement during the therapy programme was recommended by the Patient and Public Involvement (PPI) involved in Pennington et al.'s (2023) study looking at the impact of the SSA on intelligibility for children with CP. The acoustic measurements were important to establish what underlay any changes in intelligibility, particularly if changes were observed that could not be heard by ear.

For feasibility sample size was limited to 15 participants. This sample size took into consideration the length of the school day and academic year, as well as how many children and young people (from herein 'children') could be seen over the course of a year. This study design was successfully employed in previous studies by Pennington et al., (2010; 2013) and detected a difference in pre- and post-therapy intelligibility with 16 and 15 children respectively.

This study focused on personalising the SSA based on the children's individual speech characteristics, making an ITS a suitable study design as it allowed for manipulation of the therapy throughout the intervention period.

3.8. Summary of Chapter

This chapter discussed and evaluated the different methods of measuring intelligibility and provided the rationale for the methods used in this study. It briefly explained the acoustic characteristics children with CP and dysarthria may present with to support decision making on how to analyse acoustic properties of certain phonemes. The Methods chapter which follows provides detail about the recruitment process, participants, and study outcomes. It explains in detail the methods used to assess the children's intelligibility and how the data was analysed.

Chapter 4. Method

4.1. Introduction to the Chapter

This chapter discusses and justifies the study design used for this PhD project. The sampling procedure is described, with a rationale provided for the chosen number of participants and the inclusion and exclusion criteria, as well as the recruitment process and screening to identify and select suitable participants. The data collection and the intervention are explained in detail, linking them to the study's outcome measures. Finally, the chapter describes the methods of analysis, presenting the data generated, the format and scale of the data, and the statistical analysis.

4.1.1. Research Question

Does personalised speech and language therapy improve the speech intelligibility of CYP with cerebral palsy and dysarthria?

4.1.2. Research Aim

The primary aim of this study is to assess the effectiveness of personalised dysarthria intervention in improving speech intelligibility.

4.1.3. Study Objectives

The primary objective is to assess the effect of personalised dysarthria intervention on speech intelligibility for the group of participants and individuals to understand the effect of specific vocal cues/groups of cues on children's perceptual and acoustic speech outcomes.

The secondary objective is to assess the feasibility of collecting acoustic measures during online therapy to inform the intervention.

4.2. Participant Recruitment

Criteria from previous research into the SSA (Pennington, Miller, Robson and Steen, 2010; Pennington *et al.*, 2013) were adopted in this testing of its individualisation.

4.2.1. Child Inclusion Criteria

Children were required to be aged five to nineteen years and to have a diagnosis of CP; moderate to severe dysarthria as classified by their local SLT or the researcher during the screening assessment; and English as their first language. If a child was recruited directly from school, and not via their local SLT, then the Mayo Clinic Form (Duffy, 2005) was used to assess their dysarthria (see a blank example of the form in Appendix A). The categories rated to judge the severity of the dysarthria were based on the speech subsystems and were rated from 0 (normal) to 4 (severely deviant).

4.2.2. Child Exclusion Criteria

The participant exclusion criteria comprised (a) bilateral hearing loss greater than 50dB (determined from previous audiological testing), as this would have affected their ability to distinguish between speech contrasts; (b) severe visual impairment which cannot be corrected by wearing glasses (determined from previous eye test), as this will have impeded their ability to see the task materials; (c) severe cognitive impairment (classified by psychologists); or (d) profoundly delayed language comprehension (tested by SLT) in which they are unable to follow simple task instructions, e.g., “copy me” or “speak slowly”.

4.2.3. Recruitment

Children were approached via a variety of NHS Trusts, schools, and charities across UK and via social media. Participant recruitment was delayed until April 2022 due to setbacks experienced by the Research Ethics Committee (REC). These challenges stemmed from disruptions caused by the COVID-19 pandemic, including the rescheduling previously postponed REC meetings. Ethical approval was granted by the Nottingham 1 REC on behalf of the Health and Research Authority and Health and Care Research Wales (REC reference: 22/EM/0064; IRAS: 307437).

4.2.3.1. Participant Identification

SLTs and staff working in schools and independent charities identified potential participants they believed met the inclusion criteria from their case load, school, and organisation respectively. They shared information about the study with the children and their parents/carers to gather interest. Information shared included: that therapy would be given as part of a research project; the intervention would be delivered online via Microsoft Teams; the therapy would be one-to-one and would take place three times per week for six weeks; children’s speech would be recorded; people would listen to the recordings and write down what they perceived.

Parents interested in their child with CP participating gave permission to their local SLT/Headteacher/Organisation Lead to share their contact details with the me by signing a consent form. Parents were contacted via phone/video call to discuss their child's speech, language, and communication needs (SLCN), as well as previous SLT input, to evaluate their eligibility for the study. Parents were sent a Parent Information Sheet (PIS) and Easy Read Young Person PIS to read (see Appendix B), as well as the consent form to those who were interested and eligible for the study. The researcher offered to read the PIS and consent forms to parents over the phone. Parents/carers gave written consent for their child and children provided written assent (if their motor skills allowed them) or verbal assent via telephone or Microsoft Teams video call. Informed consent was obtained before the screening assessment so that the baseline data could be collected once the eligible children had been recruited.

4.2.3.2. Recruitment from Schools and Charity Organisations

The initial recruitment area for participants was the Northeast of England. However, given the setbacks faced during the study because of Covid-19, the geographical recruitment area had to be broadened. Thus, schools in the Northeast of England, The Wirral, Leicester, (Greater) London, and Northern Ireland were contacted. From these areas, eleven schools and one CP charity were approached to partake in the study. From the twelve organisations contacted, eleven offered participants. Nine children were offered from six schools in the Northeast of England, one child was offered from a school in Leicester, two children from schools in (Greater) London, and one child from a charity in the Wirral. No children were offered by the two schools in Northern Ireland.

4.2.4. Screening

Children were invited to a screening assessment to ensure that they were eligible for the study. The screening took place in person at the child's school and lasted approximately 40 minutes. The researcher, child, and a staff member were present at the screening.

Information was collected from the children's parents/carers about (a) their type and distribution of CP (diagnosed by a neurodisability paediatrician/paediatric neurologist); (b) age in years; (c) vision; and (d) hearing. The potential participants' speech, language, and non-verbal cognition were assessed specifically for the project.

The screening comprised: the Test for Reception of Grammar (TROG) (Bishop and Garsell, 2003) to assess language comprehension; the Diagnostic Evaluation of Articulation and Phonology (DEAP) (Dodd *et al.*, 2002) to assess their phonemic inventory and articulatory processes; a video clip description task to assess the severity of dysarthria in connected speech, as well as children's ability to clearly see the materials on the computer screen; following some simple instructions (e.g., "copy me" or "speak slowly"); and a minimal pair task to assess whether they could detect the difference between different speech sounds. Children's attention and perceived motivation to participate in the screening session was also documented.

To pass the screening, children were required to answer all minimal pair items correct and follow all simple instructions correctly. They needed to demonstrate ability to use connected speech (a minimum of two words in a phrase) when communicating in the video description task and be able to see the video resources clearly on the laptop screen as therapy was to be delivered online. Children needed to demonstrate understanding of how to complete each task and be able to maintain attention throughout each task. Although language abilities and articulation were assessed, they were not strictly controlled in this study. No specific articulatory processes were required to be present or absent in the DEAP, and no particular sections needed to be passed in the TROG. This approach allowed for the examination of dysarthria profiles more representative of the wider population of children CP and dysarthria, rather than selecting based on narrowly defined linguistic or articulatory criteria. Similar methodologies have been employed in previous research (Allison and Hustad, 2018b). Results of the TROG can be found in Table 9.

Child	Blocks Passed	Standard Score	Percentile	Age Equivalent	No. of Repetitions	No. of Lexical Errors	Error Type
P1	14	95	37	7;11	0	1	Sporadic
P2	15	106	66	9;0	1	1	Sporadic
P4	7	55	<1	4;11	0	4	Random
P5	18	104	61	>12;0	0	0	Sporadic
P6	4	55	<1	4;0	0	3	Random
P7	8	55	<1	5;3	2	0	Sporadic
P8	19	104	61	12;0	2	0	Sporadic
P9	6	55	<1	Above 4;9	5	0	Sporadic
P10	6	55	<1	4;9	0	0	Sporadic
P11	3	55	<1	Below 4;0	6	1	Sporadic
P12	3	55	<1	Below 4;0	0	3	Sporadic
P13	3	55	<1	Below 4;0	0	3	Sporadic
P14	9	100	50	5;6	3	1	Sporadic
P15	1	55	<1	4;0	0	4	Sporadic
P16	8	67	1	5;3	3	1	Sporadic

Table 9 Table Showing TROG Results

The children who were assessed to be not eligible for the study following the screening were contacted and the reason for their exclusion was discussed directly with their parent/carers. Seventeen children were screened for the study. Sixteen children passed the screening assessment. One of the sixteen children withdrew from the study immediately after the screening assessment as his parents reported that they did not have time to complete the baseline assessments. One child did not pass the screening assessment as they were unable to follow simple instructions or focus on the laptop to complete the single word naming task.

4.2.5. Children and Young People Recruited to the Study

Fifteen children (nine males, six females), ranging between 5 and 18 years of age were recruited to the study. Seven children had dyskinetic CP, seven had spastic CP, and one had Worster-Drought Syndrome. The severity of the children’s dysarthria ranged from moderate to severe. Information regarding the participant's demographics, cognition, communication, and motor disorder, as described by their parents or teachers, can be found in Table 10. Detailed information on the participants' speech characteristics, described using the deviant speech characteristics from the Mayo Clinic Form (Duffy, 2005), can be found in Table 11.

4.2.5.1. Participant Characteristics

Child	Age (years; months)	Sex	CP Type	Dysarthria Severity	Cognition	GMFCS	MACS	CFCS	FCCS	VSS
P1	9;10	F	Dyskinetic: dystonic	Moderate-severe	Below average in school Needs information repeated Long processing time	I	II	II	II	II
P2	7;11	F	Spastic	Moderate-severe	Moderate learning disability (LD)	V	II	III	II	III
P4	14;6	M	Spastic bilateral quadriplegia	Severe	Moderate LD Delayed expressive and receptive language Attention and listening difficulties Needs information repeated	II – III	II	III	III	III
P5	16;2	F	Worster-Drought	Moderate-severe	LD ASD	II	III	IV	II	III
P6	17;1	M	Spastic quadriplegia	Severe	LD	V	V	V	II	III
P7	18;8	M	Bilateral dyskinetic	Moderate-severe	Moderate LD ADHD Poor receptive language Needs information repeated	I	III	IV	II	III
P8	18;4	M	Athetoid/dyskinetic	Moderate	Working at an average, age-appropriate level	Parent: IV P8: IV	Parent: III P8: II	Parent: II P8: II	Parent: II P8: II	Parent: II P8: II
P9	12;3	F	Bilateral Spastic Hemiplegia	Moderate-Severe	Global Developmental Delay (GDD)	II	II	II	II	II
P10	11;6	M	Spastic Diplegia	Severe	LD Delayed expressive language Difficulties reading and writing	IV	I	II	IV	III
P11	7;3	M	Bilateral Dystonia	Severe	GDD	II	III	V	IV	III
P12	11;8	F	Spastic Quadriplegia	Moderate-severe	Below average in school (age equivalent ~8;0) Struggles to retain information	V	III	III	III	II

Child	Age (years; months)	Sex	CP Type	Dysarthria Severity	Cognition	GMFCS	MACS	CFCS	FCCS	VSS
P13	8;1	M	Dystonic Dyskinetic Quadriplegia	Severe	Below average in school	V	IV	III	IV	III
P14	5;10	M	Dystonic Dyskinetic	Severe	Age-appropriate	I	II	II	II	II
P15	14;9	M	Spastic Bilateral Dystonia	Severe	LD Traits of ASD (no diagnosis)	V	IV	III	IV	II – III
P16	9;2	F	Dyskinetic	Moderate-Severe	Below average in school	I	II	IV	III	III

Table 10 Table Showing Participant Demographics and Information on their Cognition, Communication, and Motor Disorder

Child	Baseline Perceptual Speech Characteristics				
	Respiration	***Phonation***	***Resonance***	***Articulation***	***Prosody***
P1	Shallow inspiration	Quiet voice; creaky voice; wet voice	Weak pressure	Voiced /p/ and /k/; cluster reduction; backing; imprecise speech; WF consonant deletion	Fluctuating speech rate; quick rate at ends of utterances; short phrases; fluctuating pitch
P2	Shallow inspiration	Quiet voice; quieter across an utterance; strained-strangled; hoarse; wet quality	Weak pressure	WF consonant deletion; consonant cluster reduction; PoA and MoA errors; sliding articulation; voicing errors; imprecise speech	Fast speech rate; inappropriate high pitch
P4		Uncontrolled vocal volume; excessively loud at times		Stammer; reduced vowel space; cluster reduction	Variable speech rate
P5	Shallow inspiration	Excess loudness variation (often too loud); breathy; wet quality	Weak pressure; hypernasality	Imprecise speech; WF consonant deletion; difficulty with fricatives; voicing errors	Increased speech rate
P6	Shallow inspiration	Uncontrolled loudness variation; breathy	Weak pressure	WF consonant deletion; cluster reduction/deletion; voicing errors; backing; fronting approximants	Increased speech rate
P7		Quiet voice	Weak pressure	Cluster reduction; sliding articulation; voicing errors; vowel errors; lateral release; fronting velars; imprecise speech	Increased rate
P8	Shallow inspiration; frequent breaths; speaking on residual air	Wet voice; breathy voice; hoarseness	Weak pressure	Sliding articulation; vowel errors; voicing errors; lateral release; repetition of WI consonants	Fluctuating speech rate; quicker towards end of phrases
P9	Shallow inspiration; frequent breaths	Breathy	Weak pressure; hypernasality	Backing bilabials; consonant cluster reduction; WM omission; imprecise speech	Increased speech rate
P10	Shallow inspiration; speaking on residual air	Very quiet voice; croaky and hoarse; wet voice	Weak pressure	Imprecise speech; all plosives produced as voiced alveolar; MoA errors; WF consonant deletion; cluster reduction; WM deletion	Increased speech rate; silences / hesitation

Child	Baseline Perceptual Speech Characteristics				
	Respiration	***Phonation***	***Resonance***	***Articulation***	***Prosody***
P11	Shallow inspiration	Quiet voice; breathy; croaky	Weak pressure; hyponasality	Not stimulable for plosives; WF consonant deletion; irregular articulatory breakdowns	Increased speech rate
P12		Quiet voice; breathy; reduced loudness at ends of utterances; wet voice	Weak pressure	Omitted fricatives and velar plosives; WF consonant deletion; cluster reduction; vowel errors; fronting; voicing errors; WI consonant deletion; sliding articulation	Unsteady speech rate; rushed polysyllabic words and longer utterances; silences / hesitation
P13	Shallow inspiration	Quiet voice; breathy; harsh, strained-strangled quality;	Weak pressure	Cluster reduction; imprecise speech	Fluctuating speech rate; prolonged vowels; some inappropriate pitch raises
P14	Shallow inspiration	Very quiet voice; breathy; wet voice	Weak pressure; hyponasality	Consonant cluster reduction	Increased and fluctuating speech rate; speeding up across utterances
P15	Shallow inspiration	Very quiet voice; breathy	Weak pressure	Backing to velars; sliding articulation	Increased and fluctuating speech rate; speeding up across utterances
P16		Generally appropriate volume (some decay in longer utterances); breathy; strained quality;	Weak pressure; hypernasality	Difficulty with bilabial and velar plosives; cluster reduction; voicing errors; imprecise speech	Fluctuating speech rate

Table 11 Table Showing Participants' Perceptual Speech Characteristics Based on Speech Produced at the Baseline Assessment 6 Weeks Pre-Therapy

4.2.6. Listener Recruitment

One hundred and twenty listeners were required to rate and transcribe the participants' speech intelligibility (see Section 4.6.7). Sixty-five listeners were recruited from NU's undergraduate student research participation scheme. The remaining listeners (n= 55) were recruited from friends, family, and word of mouth. Listeners were provided with an information sheet containing details of the PhD study, what the listening task involved, how much time it would take, where it would take place, and the listener inclusion and exclusion criteria. They provided written consent to participate and to confirm that they fitted the research criteria: aged 18 to 50 years (capped to reduce chances of hearing impairments associated with aging); English as first language and limited experience conversing with people with a speech disorder or CP; ability to read and type.

4.3. Measures

4.3.1. Independent Variables

The independent measures comprised speech measures, communication performance and motor performance and description of speech characteristics (see Appendix C for definition of rating levels and scores).

Speech Measures:

- Viking Speech Scale (VSS) – classifies how well children are understood by unfamiliar listeners on a 4-point scale; Level I represents no speech disorder, Level IV represents no understandable speech (Murray, Pennington, Mjøen and Andrada, 2011)
- Intelligibility in Context Scale (ICS) – a seven-item questionnaire which provides data on parent/carer perceptions of their child's intelligibility in different contexts, when speaking with various listeners, using a 5-point scale; 1 represents 'never understood', 5 represents 'always understood' (McLeod, Harrison and McCormack, 2012)
- DEAP Articulation assessment – assesses productions of all speech sounds in English
- Description of children's speech characteristics based on the Mayo Clinic Form of deviant speech characteristics (Duffy, 2005)

- Acoustic measures including the mean intensity and duration of SWs as well as acoustic profiling to look for visual evidence of expected speech sounds

Communication Performance:

- Communication Function Classification System (CFCS) – a 5-point scale which classifies effectiveness of communication between a child and familiar listener in everyday situations, incorporating all methods of communicating, e.g., speech, gesture, facial expression, and AAC and capturing both sending and receiving of messages; Level I represents the most effective, Level V the least effective (Hidecker *et al.*, 2011)
- Functional Communication Classification System (FCCS) – a 5-point scale which classifies how a child typically communicates with both familiar and unfamiliar listeners, with focus on quality of independent communication; Level 1 represents the most effective, Level V the least effective (Barty, Caynes and Johnston, 2016).

Motor Performance:

- The Gross Motor Function Classification System (GMFCS) – a 5-point scale which categorises motor function, looking at a child's ability to sit, walk, and their use of mobility aids; Level I indicates child walks without limitations, Level V indicates they are transported in a wheelchair (Palisano *et al.*, 1997)
- Manual Ability Classification System (MACS) – a 5-point scale which categorises a child's ability to handle objects in daily activities; Level I indicates child handles objects easily, Level V indicates child does not handle objects (Eliasson *et al.*, 2006)
- DEAP Oral Motor screen – assesses oro-motor skills (i.e., speed, strength, coordination, and range of movement of oro-motor muscles) and addresses children's diadochokinetic abilities, taking into consideration their ability to produce the correct sound sequence, their intelligibility, and their fluency (Dodd *et al.*, 2002)

4.3.2. Dependent Measures

Single word (SW) and connected speech (CS) samples were recorded pre- and post-therapy to determine the effects of the intervention on intelligibility and explore any acoustic changes in their speech. Recordings took place 6 Weeks Pre- and 1 Week Pre-Therapy and 1 Week Post- and 12 Weeks Post-Therapy. An intelligibility score was determined for both SWs and CS for each child at each timepoint by calculating the percentage of words perceived correctly by three unfamiliar listeners.

4.3.2.1. Single Words

The children produced 20 SWs at each recording timepoint to measure speech intelligibility. A percentage intelligibility score, based on how many words were perceived correctly, was calculated for each child at each timepoint. Measuring 20 SWs has been shown to produce the same estimates of variability in intelligibility as 50 single words (Pennington *et al.*, 2019). Keep recording sessions short minimised participant burden.

4.3.2.2. Connected Speech

Percentage intelligibility scores were calculated for five phrases per child at each timepoint based on how many words in the five phrases were perceived correct.

4.3.2.3. Acoustic Measures

Five SWs and three of the phrases were selected to undergo acoustic analyses at each pre- and post-therapy timepoint. Acoustic measures for SWs were mean intensity and duration of the whole word; for the CS measures included mean intensity, speech rate, and articulation rate.

These measures were chosen as the therapy aimed to improve coordination of respiration and phonation resulting in a stronger speech signal whilst maintaining a steady speech rate. Individual exploratory acoustic measures were also taken for each child based on their speech characteristics, e.g., acoustic profiling of word final (WF) consonants.

Acoustic measures were also planned to be collected from SW and CS samples taken during the therapy block to inform the intervention. The during therapy SW and

CS speech samples were elicited in the same way as those gathered pre- and post-therapy.

4.4. Feasibility of Using Acoustic Measures to Inform Intervention

As acoustic analysis is a lengthy process, a restricted number of acoustic measures were chosen to be measured during the therapy block. The acoustic measures were to be the same as those proposed to be taken on the pre- and post-therapy speech recordings- mean intensity and duration for SWs and mean intensity, speech rate, and articulation rate for CS. For the during therapy recording sessions, children produced seven SWs (one of which was a practice word), three phrases, and one sustained open vowel (‘ah’) to reduce the number of acoustic measurements required.

To assess the feasibility of collecting acoustic data during the therapy block to inform the intervention, the number of recordings taken and when they were taken was documented. The time taken to receive the recordings via FileDrop as well as the time taken to complete the acoustic analysis was also recorded.

4.5. Capacity and Performance

Both speech intelligibility performance (P) and speech intelligibility capacity (C) were measured pre- and post-therapy. Assessing both capacity and performance involved administering speech measures twice at each pre- and post-therapy recording session. Twenty SWs (plus a practice item) and at least five phrases were recorded. The first recording assessed intelligibility at performance level. The participants were not given instructions to use their target voice. For the capacity recording, they were prompted to use their vocal cues. The vocal cues given pre-therapy were “use a loud and clear voice” because individual cues were not yet identified. The vocal cues targeted in therapy were given to the children at the post-therapy capacity recordings.

4.6. Procedure

4.6.1. 6 Weeks Pre-Therapy

Parents/carers completed the ICS, VVS, CFCS, FCCS, GMFCS, and MACS via telephone or video call (Microsoft Teams). They were sent the scales in advance and were encouraged to get in contact if they had any queries about them.

Parents/carers rated their child's speech, communication, and motor performance based on which level they believed best described their child. Parent ratings can be found in Table 10 and Table 36.

Parents/carers were also asked further questions regarding their child's medical history to understand their child's oral motor function, the impact of difficulties on children's daily lives, and other important information that could influence therapy engagement. The case history covered (a) cause of CP; (b) respiratory difficulties; (c) eating and drinking; (d) cognition; (e) health professional involvement; (f) medication; (g) previous SLT input; and (h) impact of CP on daily life (i.e., in terms of their communication, independence etc…).

The 6 Weeks Pre-Therapy recordings, which are described below, were carried out in-person at the child's school with the researcher, child, and a staff member present.

4.6.1.1. Single Words Elicitation

A picture naming task was used to elicit the SW speech samples. The pictures were stored on Microsoft PowerPoint, with separate PowerPoints for each word list (word lists can be found in Table 7). The PowerPoints were shown to the children via the 'share screen' function on Microsoft Teams. Those supervising the children (Teaching Assistant (TA)/SLT) were asked to ensure full screen mode was activated so that the children could see the pictures clearly. The children were given the initial instruction, "I am going to show you a set of pictures. I want you to name the picture. The word is written on the top of the screen. Here is an example". Each target word had two pictures to reduce ambiguity and the target word was written at the top of each slide to reduce the chances of children producing a synonym of the target (e.g., saying "mat" for "rug"). Prompts were given to those unable to read to encourage them to produce the target. The images were all royalty free creative common images, gathered from Pixabay (Pixabay, 2022) and Pexels (Pexels, 2022).

4.6.1.2. Connected Speech

CS was elicited using a video description task. Children were shown different episodes of the television show Morph via YouTube (MorphOfficial, 2010) at each recording session. The videos were shown to the children using the 'share screen' and ‘share audio’ functions on Microsoft Teams, and full screen mode was required. Episodes were pre-determined, and each video clip was watched in advance to ensure they were age appropriate. Each video clip was one minute to one minute thirty seconds, to keep the children engaged. The video clips were taken from YouTube (https://www.youtube.com). The children were given the initial instruction, “I am going to show you a short video clip of my friend Morph. No one will be speaking in the video. Watch the full video. When it is over, I want you to tell me what happened.” The participants described what happened in the video in their own words. To mirror conversational speech, the children were asked questions and responded to throughout the description task. Phrases were repeated and checked with the children to ensure they were understood correctly and to improve accuracy of the analyses.

For analyses, the recordings were split into individual phrases. Orthographic transcriptions of the target phrases were created and used as a gold standard for comparison against the listener transcriptions. The video clips were watched alongside the creation of the target transcriptions to enhance the accuracy through use of contextual cues.

4.6.1.2.1. Selecting Connected Speech Samples for Perceptual Analysis

CS samples were split into individual sentences. Longer sentences were split into smaller phrases. From these phrases, five were chosen to be listened to and transcribed by the listeners. A protocol was followed to select the phrases to be analysed. The protocol is discussed in brief below. Full details of this protocol can be seen in Appendix D.1.

4.6.1.2.2. Protocol for Selecting Connected Speech Samples

All phrases made grammatical sense when listened to on their own and contained at least two words. Phrases with dysfluencies, fillers or hesitations were avoided where possible. Dysfluencies included repetitions, false starts and repeated but incomplete attempts at words (e.g., ‘my fing- finger’). If a dysfluency was at the beginning of a phrase and there was a pause between the dysfluency and the first word in the phrase, then the dysfluency was omitted from the speech sample to prevent listeners transcribing the dysfluency. Any dysfluencies, fillers or hesitations within the utterance were included in the speech sample so that the phrase was not cut short inappropriately and the meaning lost. Dysfluencies were only included at the beginning of a phrase if they resulted in the first word being cut short or omitted, i.e., there was no boundary between the dysfluency and the first deliberate word in the utterance. Phrases with similar vocabulary, specifically content words, were avoided where possible (e.g., not including three phrases from the same child which contained the word 'pinata'). Also, phrases were selected which contained characteristics of interest, i.e., consonant clusters (e.g., /sp/).

4.6.1.3. Selecting Speech Samples for Acoustic Profiling

The five SWs from word list 2 chosen to undergo acoustic profiling were selected using a random number generator, with the constraint that there needed to be a mix of both monosyllabic and polysyllabic words. The words analysed from list two were *'bin', 'log', 'pond', 'waiter',* and *'feather'*.

4.6.2. 1 Week Pre-Therapy

The 1 Week Pre-Therapy recordings were completed online via Microsoft Teams. Children were accompanied by a staff member if they attended the therapy at school, or by a parent if therapy was completed at home. Children produced the 20 SWs from Word List 2 (see Table 8) and five phrases 1 Week Pre-Therapy. Again, both performance and capacity recordings were taken. Different video clips to those used 6 Weeks Pre-Therapy were used to elicit CS.

4.6.3. During Therapy

4.6.3.1. Online Personalised Intervention

To avoid contamination of intervention effect, children receiving therapy focussed on speech were required to stop that intervention before the therapy block commenced. Their usual SLT sessions could resume 12 weeks after the intervention ended. For the individualised dysarthria therapy, children received one-to-one intervention three times a week for six weeks, with each session lasting approximately 30-40 minutes. Therapy was delivered online via Microsoft Teams, whilst the children were at school/college or at home if preferred. Schools and colleges were set up for online learning and had the technology required for telehealth because of the impact of Coronavirus on education.

The intervention was based on the SSA (Pennington *et al.*, 2019; Pennington, Miller, Robson and Steen, 2010; Pennington *et al.*, 2013). Children practised their target voice initially on single vowel sounds (‘ah’), and then moved on to single words, functional phrases, and applying what they had learnt in conversational speech.

Children began each session producing an open vowel sound /a/ (‘ah’). The aim was to sustain the vowel for as long as possible whilst maintaining optimum volume for speech. Children were required to repeat this exercise 15 times and the length of their sustained phonation was documented. Once children were able to sustain a strong signal for more than 2 seconds on 90% of productions, the number of repetitions dropped to 10 and then to five. They then practised their target voice on automatic sequences - the days of the week and counting to five. Initially children would concentrate on either speech rate or vocal intensity across the sequence and eventually build up to combining both parameters when they could produce the sequences at a slow rate or sustain a strong signal throughout. With help from their parent/TA, each child came up with ten functional phrases in the first session which would be practiced in every session for calibration of an optimum vocal volume and speech rate outside of therapy sessions. These phrases were personal to the child, based on their needs, wants and interests. Three phrases were targeted in each session and each phrase was repeated three times. Children then moved on to using their target voice in novel stimuli, starting with single words and short phrases before moving on to sentences and finally conversational speech. The cognitive demands of the speech tasks increased throughout the therapy block, progressing from picture-naming tasks to free speech tasks (e.g., "Tell me about a time when..."). The criterion for advancement was 90% accuracy. Children needed to sustain their target voice throughout the entire speech act in 90% of their attempts.

The intervention was personalised using vocal cues which were decided based on their speech characteristics that seemed, from clinical judgement of observed speech, to be having the greatest impact on intelligibility. For example, if a child had a breathy, weak voice their vocal cue may have been, “speak with your strong voice”. The cue(s) which worked best for each participant were examined through (a) clinical observation of their ability to employ the cue(s) appropriately, e.g., not shout if given the cue ‘loud’; (b) questioning their knowledge and understanding of the cue(s) “can you explain ‘steady’?”; and (c) giving them choices, e.g., “would you prefer ‘strong’ or ‘loud’?”. Children were asked to provide feedback on how their voice felt and sounded regularly to promote self-monitoring.

Depending on their response to certain cues and their changes in speech behaviours, some participants’ vocal cues changed over the course of the therapy block and others were given cue combinations. If multiple speech characteristics were impacting intelligibility, e.g., imprecise speech and increased speech rate, then they were given cue combinations such as, “Use your big mouth and steady speech”. As each new cue was added, the children were still reminded to use their previous cues, if those cues had improved speech clarity. Full details of the cues provided to each child can be found in Table 12.

Initially, children received frequent feedback after each production which was specific to the sound of their speech and the vocal cue(s) they were assigned– i.e., “That was really strong right to the end” or “Your voice went quiet in the middle of the sentence”. Frequent feedback allowed children to identify mistakes immediately, preventing reinforcement of incorrect movements and reinforcing correct movements. As the children began to use their target voice consistently, feedback was reduced and they were encouraged to use biofeedback, e.g., ‘how did that feel/sound?’. Reduced feedback has shown to be beneficial for motor learning and skill retention as it encourages speakers to self-monitor and generalise skills in different environments (Maas *et al.*, 2008; Bislick, Weir and Spencer, 2012).

Child (Number of Therapy Sessions Attended)	Vocal Cues					
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
P1 (18)	Loud; changed to Strong	Strong to the end; Steady; Strong /s/			Big mouth	
P2 (16)	Big mouth; Loud on /s/ & /z/	Steady	Loud on /f/ & /v/			
P4 (17)	Big mouth; strong to the end		Nice and easy	Steady; Soft		
P5 (18)	Big mouth, Strong /f/ & /v/	Strong to the end	Steady		Strong /p/, /b/, /m/	
P6 (17)	Strong to the end; Nice and easy		Steady			
P7 (18)	Big mouth	Steady	Strong to the end; Strong /s/ & /z/	Strong clusters		
P8 (18)	Nice and easy; Strong to the end	Steady; Strong clusters	Strong /s/ & /l/			
P9 (17)	Strong; Steady	Strong /p/, /b/, /f/, /v/		Slow on long words		
P10 (14)	Strong; Steady	Loud; Slow	Strong to the end; Strong /s/		Strong clusters	
P11 (17)	Strong	Strong /f/ and /v/; Steady		Strong /s/		
P12 (15)	Strong; Steady	Strong to the end	Strong /s/	Strong /f/	Strong /v/	
P13 (15)	Strong; Steady	Strong /s/	Strong clusters			
P14 (18)	Loud	Slow	Strong /s/; Strong /p/, /b/, /m/	Big mouth		
P15 (18)	Loud	Steady	Steady on long words; Big mouth	Loud at the end; Steady at the end		
P16 (18)	Strong; Strong /s/ & /ʃ/	Steady	Strong /p/ & /b/	Strong /ʤ/		

Table 12 Table of Children's Vocal Cues

Session plans were created for each child to record how many productions the children were making using their target voice, to note any speech characteristics (e.g., rate, volume, prosody, phonological errors) and to document any other notable observations (e.g., behaviour, motivation etc…). Detailed notes on participant performance for each session were written up on their case record forms.

4.6.3.2. During Therapy Assessments

The speech samples taken during the six-week intervention period consisted of seven SWs (including a practice item), three phrases, and the open vowel /ɑ/. These solely assessed performance. No listener transcriptions were made as only acoustic speech characteristics were planned to be analysed during therapy. The words and phrases produced at the during therapy recordings were not tested pre- or post-therapy nor used in any intervention sessions to limit priming and learning effects. A different set of SWs and different video clip used to elicit CS were used at each weekly recording session during the six-week therapy block. These recordings were completed online.

4.6.4. 1 Week Post-Therapy

The 1 Week Post-Therapy recordings were completed online. Like the pre-therapy assessment, children produced 20 SWs and five phrases in both performance and capacity conditions. Children were not given any prompts to use their target voice during the performance recordings. To assess capacity, children were prompted to use their individual vocal cues targeted during the intervention before producing the speech samples. Perceptual analysis was carried out on all 20 SWs and five phrases. Five SWs and three phrases were selected to undergo acoustic analyses using PRAAT.

Parents/carers were contacted after their child's therapy block to complete an extended version of the ICS which contained three supplementary questions: (1) Has your child's speech changed since the start of the therapy?; (2) How has your child's speech changed?; and (3) What difference has this made? Parents/carers could write as much or as little as they wanted in response to these questions. This questionnaire provided an opportunity to get service user feedback and qualitative data regarding the effectiveness of the personalised dysarthria intervention. The intelligibility scores from the follow-up assessments were compared to the baseline measurements.

4.6.5. 12 Weeks Post-Therapy

The 12 Week Post-Therapy recordings were completed in person at the child's school, with the researcher, child, and a staff member present. To assess the longer-term and maintenance effects of therapy on intelligibility, children were recorded producing 20 SWs and five phrases 12 Weeks Post-Therapy. Both performance and capacity conditions were assessed. The same SWs analysed 1 Week Pre-Therapy were selected so that comparisons could be made. The same criteria used to select three phrases for acoustic analysis pre-therapy was followed post-therapy. The intelligibility scores from the follow-up assessments were compared to the baseline scores.

It was a relatively short-term follow-up to reduce the chances of children being lost to follow-up (e.g., due moving school/college), prevent missing data and avoid the associated complexities in both the study analysis and interpretation.

4.6.6. Recording Process

Recording sessions took approximately ten minutes to complete. The speech samples obtained during the six-week therapy block were recorded at the beginning of the third session each week. Speech recordings were audio only, taken using a Tascam DR-40X Four Track Digital Audio Recorder or a Tascam DR-05x Stereo Handheld Digital Audio Recorder. Both audio recorders are high-quality and can record every detail in sounds starting at a quiet whisper up to loud sounds reaching 125dB sound pressure level (SPL).

Each participant was provided with a recorder, SD card and tape measure. Recordings were carried out by those supervising the sessions and audio recorders were provided. Assistants were trained on how to carry out and transfer the recordings and were provided with a recording a protocol. The recording protocol stated the following: a standardised microphone to mouth distance of 25cm, with the input bar fluctuating at around -12; format set to WAV 16bit; sample set to 44.1k; manual level mode; mono recording mode; PRE REC on; and connected to PC/MAC. Recordings were to be taken in a quiet room to reduce distortion of the speech signal from background noise. Guidance was in place to ensure standardisation of the recording process across children. The full recording protocol is attached in Appendix D.2.

Assistants transferred the recordings via Newcastle University's (NU) secure file transfer NU File Drop-off (https://dropoff.ncl.ac.uk/). All files transferred using NU File Drop-off are encrypted. The sound files were downloaded from the Drop-off service. The quality of each file was not impaired during the download.

Recordings were cleaned before beginning perceptual and acoustic analyses. Recordings of connected speech were split into utterances and each utterance was saved separately as individual files. All names of people and places, or any other information which made the participant identifiable, were removed. Each recording file was saved on password protected files on the NU server. The passwords were only known by the Principal Investigator (PI) and Chief Investigator (CI) – the researcher and researcher's supervisor. Participant files were identified by their unique identification research code only.

4.6.7. Perceptual Data

To assess speech intelligibility, listeners orthographically transcribed the pre- and post-therapy SWs and CS by typing on a computer what they thought the children said. An intelligibility score was calculated by comparing the listener transcriptions to the actual targets. A gold standard transcript was created for the CS targets and incorrect spellings and homonyms were marked as correct.

To reduce learning effects, listeners were randomly allocated three recordings using a computer-generated sequence on MATLAB, with the constraint that listeners only heard the same participant once. Listeners were blind to the time point at which the recordings were made. Similarly to the method used by Platt et al. (1980), each speech sample was listened to, orthographically transcribed, and rated by three listeners.

The listener task took approximately 20 minutes and was carried out in person in a sound-attenuated booth at NU. The three speech files were played to the listener via a university computer. Listeners used a university laptop to type their transcriptions on a pre-designed spreadsheet. Each word and phrase were only played once. Listeners were given as much time as desired to respond. The audio speakers were set to a standardised volume of 100% on the computer and 50% on the external speaker. Listeners were not allowed to adjust the speakers during the study. The external speakers were placed immediately beside the laptop used by the listener.

Listeners were given a set of instructions at the beginning of the task and shown where to record their answers on the spreadsheet. They were told that the words were real words in English. If a listener wrote a non-word for which a transcription could not be determined- i.e., the vowel written could be pronounced in more than one way (e.g. 'ow' can be pronounced as /əʊ/ or /aʊ/) or the phoneme combination was not possible in English- then their speech samples were reallocated to a new listener. Transcriptions were not reallocated if the transcription of the non-word could be determined; for example, the perceived word rhymed with the target word, but a phoneme perceived turned it into a non-word (e.g., target word /kɑ:/ ('car') transcribed as [vɑ:] ('var')).

4.6.8. Acoustic Data

Acoustic data were collected from the speech samples taken 1 Week Pre- and 12 Weeks Post-Therapy. No acoustic information was collected from speech samples recorded 6 Weeks Pre-Therapy as it was predicted that children's acoustic speech characteristics would remain stable between 6 Weeks Pre- and 1 Week Pre-Therapy. No acoustic data was collected 1 Week Post-Therapy as the word list was different to 1 Week Pre- and 12 Weeks Post-Therapy, so no comparisons could be made.

The recordings of the five SWs chosen to undergo acoustic profiling were listened to and phonetic transcriptions of each word were created. The speech recordings were then uploaded on to the software PRAAT (Boersma and Weenink, 2021). Following Pennington et al (2023), time-aligned transcriptions, known as 'TextGrids', were created on PRAAT. Separate tiers were used to display the target words and phonemes. An error tier was included to display the participant's actual realisations and a notes tier to describe the speech processes and errors occurring and to record any acoustic features of interest shown on the spectrogram and waveform, e.g., a plosive burst.

4.6.9. Summary of Procedure

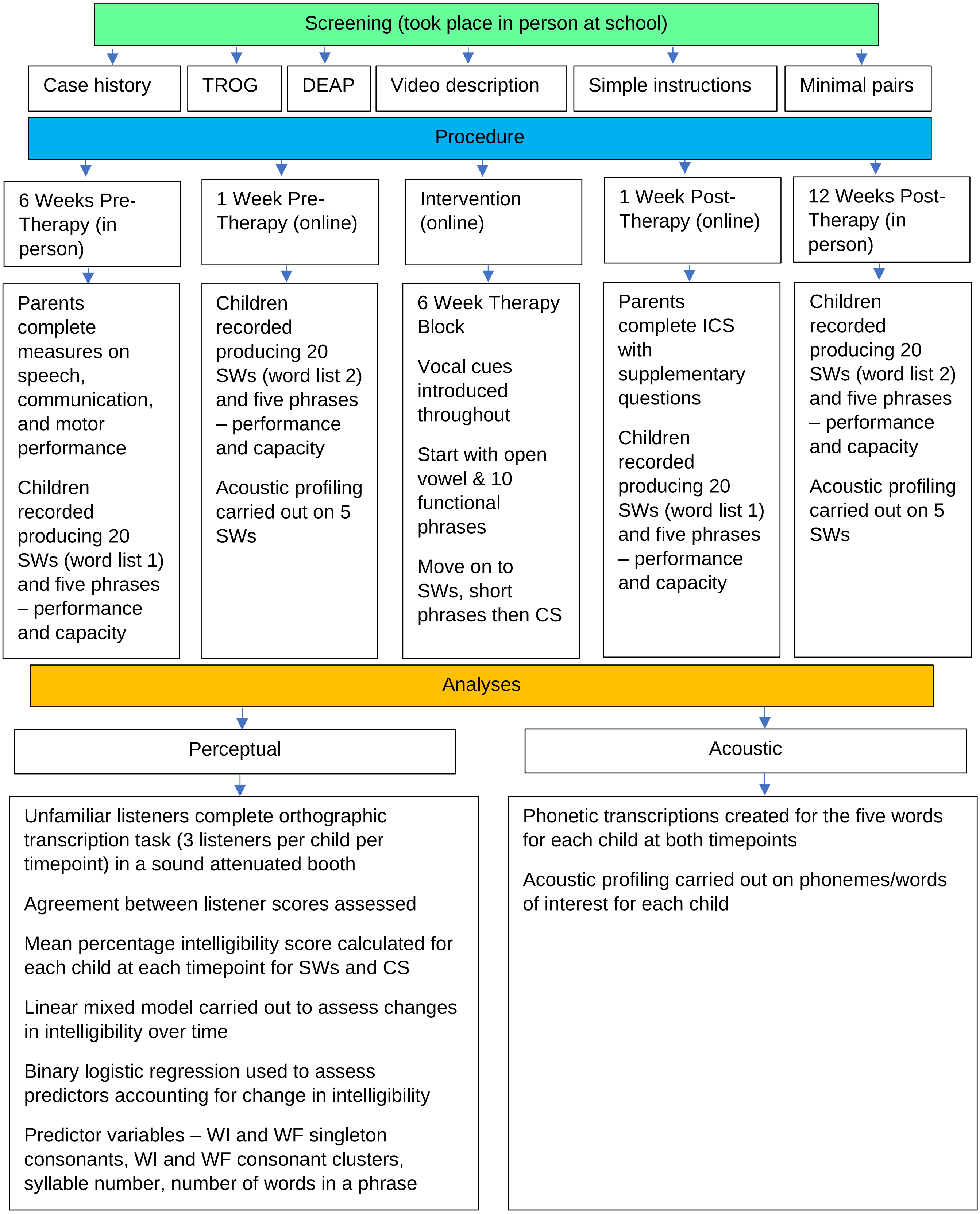

Figure 4 Summary of Procedure

4.7. Methods of Analyses

The speech data gathered for this study were analysed both perceptually and acoustically.

4.7.1. Data Processing

The data collected comprised:

(a) audio files, in a wav format, of the SWs and phrases spoken by the participants;
(b) listener's orthographic transcriptions of the SWs and phrases spoken by the participants.
(c) phonetic transcriptions of five of the children's SWs

4.7.1.1. Format and Scale of the Data

Before completing any analyses, the data were cleaned and prepared. To clean the audio recording data and ensure it was anonymised, the recordings were split into utterances and each utterance saved as an individual file. All names of people and places, or any other information which makes the participant identifiable, were removed. The children were identified by a unique research identification number.

The format and scale of the audio recordings was one wav file (44.1 kHz sample rate and 16-bit depth) per SW and phrase spoken by each child. The approximate file size was between 6300 MB and 12600 MB. The recording protocol stated that the recording mode should be set to 'mono sound'. Any recordings which were made using the 'stereo' mode were converted to mono on PRAAT.

4.7.1.2. Perceptual Database

The SW database showed information for both the target words and perceived words at the four timepoints. Each row on the Excel spreadsheet represented a single listener's transcription of a word. For example, row 2 contained information based on Listener 1's transcription of '*bin'*, row 3 contained information related to Listener 2's transcription of '*bin'*, and row 4 contained information based on Listener 3's transcription of '*bin'*. The information included:

(a) the WI singleton consonant (where present)
(b) the WF singleton consonant (where present)

(c) the WI consonant cluster (where present)
(d) the WF consonant cluster (where present)
(e) the number of syllables (monosyllabic coded as [1] and polysyllabic coded as [2])
(f) whether the word was perceived correctly or not (incorrect coded as [0] and correct coded as [1]) by each listener;
(g) whether each singleton consonant or cluster was perceived correctly or not by each listener (incorrect coded as [0] and correct coded as [1])

The CS database contained all the information above, plus:

- the number of words in the phrase; and
- the position of individual words within the phrase

In the CS database, phrases were divided into individual words, with each row representing information about a single word transcribed by a specific listener. For instance, if the phrase was *'jumped in'*, row 2 contained information based on Listener 1's transcription of *'jumped'*, and row 3 contained information relating to Listener 1's transcription of *'in'*; row 4 recorded information based on Listener 2's transcription of *'jumped'*, row 5 their transcription of *'in'*, and so on (see Appendices E.1. and E.2. for examples of the SW and CS perceptual datasets).

4.7.1.3. Acoustic Database

The acoustic database comprised phonetic transcriptions of the five SWs which underwent acoustic profiling. These were stored in a table on a Word document.

4.7.2. Statistical Analyses

4.7.2.1. Perceptual Analysis

The primary aim was to ascertain if personalised dysarthria intervention improves the intelligibility of children with CP and dysarthria. Intelligibility (defined as percentage words correct) was measured pre- and post-therapy, for both the performance and capacity speech conditions. SWs and CS data were handled separately. For all four conditions (SW performance, SW capacity, CS performance, CS capacity), perceptual analysis followed the same steps described below. At each step, assumptions of the statistical tests being conducted were checked. Normality of the data was assessed using Shapiro-Wilk, for samples < 50 and with Kolmogorov-Smirnov for sample sizes > 50 (de Souza, Toebe, Mello and Bittencourt, 2023; Patrício, Ferreira, Oliveiros and Caramelo, 2017)**.** Normality was assumed if the p-value was > 0.05. QQ plots and histograms were plotted to look at the skewness (asymmetry) and kurtosis (heaviness of tails in the data).

4.7.2.1.1. Agreement Between Listener Intelligibility Scores

Agreement between raters correct identification of words was examined using Intraclass Correlation Coefficients (ICC) to investigate if an average score across raters could be derived for each recording timepoint. ICC assumes data are normally distributed, but with percentage values (0% - 100%), non-normal distribution was expected as the tails were inherently clipped. If the data points were close to normal on the QQ plots, an ICC was carried out as this test is robust to moderate deviations from normality (Norman and Streiner, 2008). A one-way random-effects ICC model where listener effects were random was selected, as each child was rated by a different set of raters. Separate ICCs were carried out for each of the four recording timepoints for both performance and capacity and SWs and CS.

The variability in the range of the three listener scores for each child at each timepoint was assessed to determine whether the variation in scores remained consistent across the four timepoints for each child or if significant differences were present. Depending on the normality of distribution, differences in ranges between time points were analysed using repeated measures ANOVA or non-parametric Friedman test.

if the ICCs showed good to excellent reliability (0.75 to >0.90, with a 95% confidence interval of 0.88 to 0.97) (Koo and Li, 2016), and no statistically significant differences were found in the variability of ranges between listener scores at each timepoint, the mean listener score for each child at each timepoint was calculated and used in the analysis of differences in intelligibility across time.

4.7.2.1.2. Difference in Intelligibility Across Time

Assumption testing for generalised linear mixed models (GLMMs) was conducted. As the number of observations was large (n = 180), the Kolmogorov-Smirnov (K-S) test was used to assess normality. Histograms and QQ Plots were plotted to visually analyse the distribution of the residuals. If residuals deviate from normal distribution, linear regression models often still produce valid results, especially if the sample size is large (>10 observations per variable) (Schmidt and Finan, 2018). Therefore, if results from the K-S test suggested non-normal distribution, but the histogram of the residuals somewhat resembled a bell-shaped curve and the QQ Plot was close to normal, a linear regression was still carried out. Mixed models were used to assess differences in children's intelligibility across time, where the primary outcome was speech intelligibility (defined as word perceived correct), as they account for the nested nature of the data (ratings nested within recordings nested within children).

If the QQ Plot and histogram of the residuals were skewed, a GLMM was not performed. Instead, a repeated measures ANOVA was carried out if the raw data was normally distributed. Timepoint was added as a fixed effect and the effects of child and the interaction between child and timepoint were added as random effect. If the raw data was non-normally distributed, the Friedman test was used.

If results from the GLMM, repeated measures ANOVA, or Friedman test indicated statistically significant differences over time, post-hoc testing was conducted to determine which specific recording timepoints differed from each other. The hypotheses were:

(a) there would be no significant difference between 6 Weeks Pre-Therapy and 1 Week Pre-Therapy indicating a stable baseline and no improvements in intelligibility without intervention;
(b) there would be a statistically significant difference between 1 Week Pre-Therapy and 1 Week Post-Therapy because of improvement in intelligibility following therapy; and
(c) there would be no significant difference between 1 Week Post-Therapy and 12 Weeks Post-Therapy indicating that the new speech patterns learnt and improvements in intelligibility were maintained.

If no statistically significant difference was found between 1 Week Pre-Therapy and 1 Week Post-Therapy but was found between 1 Week Post-Therapy and 12 Weeks Post-Therapy, a pairwise comparison between 1 Week Pre-Therapy and 12 Weeks

Post-Therapy was completed to see whether the effects of the intervention were delayed.

4.7.2.1.3. Individual Change

As children may vary in their response to therapy and an objective of the study was to investigate change for individuals, clinical significance was also assessed. Clinical significance has been classified as an 8% to 10% change in intelligibility (Tjaden, Sussman and Wilding, 2014; Van Nuffelen *et al.*, 2010; Pennington *et al.*, 2013). The more stringent clinical significance level 10% change in intelligibility was used for this study. Changes in percentage intelligibility between timepoints and tabulated for visual inspection. Each child's mean intelligibility at each time point was presented in scatter plots for visual analysis or tables.

4.7.2.2. What accounted for change in intelligibility?

Once change in overall intelligibility had been examined and observed, the predictors accounting for the change in intelligibility were investigated in logistic regression Models. Only the performance data was used in this analysis as it is reflective of children's habitual speech. The therapy is designed to help children produce clearer speech independently in everyday situations and only when needed. The outcome of therapy does not expect children to use their maximum capacity target voice consistently in all environments or be constantly prompted with their therapy cues.

Based on the therapy mechanisms of action – improved respiratory control and phonatory effort and slower rate of speech facilitating precise articulation, and findings from previous research (Pennington *et al.*, 2023), the factors following factors were predicted to contribute to changes in intelligibility:

- perception of word initial singleton consonants;
- perception of word final singleton consonants;
- perception of word initial consonant clusters;
- perception of word final consonant clusters;
- number of syllables in a word;
- number of words in a phrase (CS only).

Further detail on the reasoning behind choosing these predictors can be found in Section 4.7.2.2.1.

The number of observations of each predictor was investigated before including it in the analysis to ensure there were sufficient data for statistical testing. If there were limited data available or no observations of a variable made by children in the study, then those variables were omitted from further analyses. To decide whether a variable should be included in the binary logistic regression model, tests were carried out to see whether there was significant change over time.

Assumption testing was carried out on the WI and WF singleton consonant data for both SWs and CS. The data were the mean percentage of WI or WF singleton consonants perceived correctly for each child at each timepoint. If data were normally distributed at all four timepoints, then a repeated measures ANOVA was conducted to see whether there was a significant effect of timepoint on perceiving a word containing a WI/WF consonant correctly. If data were not normally distributed at some or all the four timepoints then a Friedman test was conducted. If there was a significant effect of timepoint on perceiving the words correctly, then WI/WF consonant was included as a variable in the regression models.

To assess whether syllable structure may have had an effect on intelligibility and change in intelligibility over time, a Chi-Square test was used to see whether there was a statistical difference between the number of monosyllabic words and polysyllabic words perceived correctly at each timepoint for both SWs and CS. If a statistically significant difference was found, then syllable count was included as a predictor. Monosyllabic words were coded as ‘1’ on the data spreadsheet and polysyllabic words (defined as words with two or more syllables) were coded as ‘2’. If syllable number was included in the analysis, then the interaction effect between syllable and time was added as a predictor to see if significantly more monosyllabic or polysyllabic words were perceived correctly post-therapy compared to pre-therapy and help decipher whether number of syllables contributed to improvements in intelligibility.

A binary logistic regression was used to assess whether the predictor variables explained change in intelligibility. The outcome measure of intelligibility was now defined as word perceived correct and was coded as ‘1’ if the target word was perceived correctly and ‘0’ if it was perceived incorrectly. Random effects of child and the interaction between child and timepoint were included in the models to control for the nested nature of the data and allow the variance between children and within children across time to be investigated. Variables were added to the models in a hierarchical manner, with the variables thought to be most influential being added first. The method used to build the models for each of the different phonetic features of interest are described below.

4.7.2.2.1. Word Initial Singleton Consonants Single Words

When assessing the effect of WI singleton consonant on intelligibility, the data was filtered to only include the 16 words from both word lists which contained a word initial singleton consonant. If the WI singleton consonant was perceived correctly it was coded as ‘1’ and if it was perceived incorrectly, it was coded as ‘0’.

WI singleton consonant correct was used as a predictor variable alongside syllable number and the factor variable timepoint. Changing timepoint into a factor variable enabled the effect of each timepoint on perceiving a word correct to be assessed. As it was already known that WI consonant correct would have a large effect on the outcome, because a word could only be perceived correct if the WI consonant was correct, the interaction effect between WI consonant and timepoint was included as a variable. This interaction effect showed whether significantly more consonants were perceived correctly post-therapy compared to pre-therapy, indicating that the WI consonant contributed to improvements in intelligibility over time. The interaction between syllable and timepoint was also added as a predictor variable to the model.

1 Week Pre-Therapy was used as the reference level for timepoint because the biggest change in intelligibility was predicted between 1 Week Pre-Therapy and 1 Week Post-Therapy. The reference level for word initial was ‘0’ (word initial perceived incorrect) and the reference level for syllable was ‘1’ (monosyllabic).

The binary logistic regression model was built up in the following hierarchical manner:

1. timepoint
2. timepoint and WI consonant

3. timepoint, WI consonant, and syllable number
4. timepoint, WI consonant, syllable number, and the interaction between WI and timepoint
5. timepoint, WI consonant, syllable number, the interaction between Wi and timepoint, and the interaction between syllable number and timepoint

Adding variables incrementally meant that multicollinearity and significance of predictors could be identified. Timepoint was considered the primary independent variable, as the main research aim focused on improvement in intelligibility over time; therefore, timepoint was added first. Once an effect of time had been established, WI consonant was then added as it was thought that accuracy and strength of WI phoneme production would improve following the intervention due to increased intraoral pressure and more time to accurately place articulators (Pennington *et al.*, 2023). Syllable number was then added to account for word complexity which may have impacted intelligibility. The interaction effect between timepoint and WI consonants followed by the interaction between timepoint and syllable number were then added to investigate whether improvement in the accuracy of WI consonants and polysyllabic words occurred as a result of the intervention. The interaction effects were added last as they can make models very complex and lead to issues with multicollinearity, causing model break down. For each model, the fixed effect estimates (B), SEs, odds ratios (Exp(B)), 95% CIs, and p-values were reported. A minimum of 20 observations per child was used as a guideline in the analyses as this threshold was used in similar research (Pennington et al., 2023). If there were not enough observations of the speech characteristic of interest, then no further analysis was conducted.

If no interaction effect was found, visual analysis was conducted to see if changes may have occurred which did not reach statistical significance.

4.7.2.2.2. Word Final Singleton Consonants Single Words

The same process used to build up the models and assess WI singleton consonants was carried out for WF consonants and the same results reported. Here, the SW word lists were filtered to include only the words which contained a WF singleton consonant from each word link.

4.7.2.3. Binary Logistic Regression for Connected Speech

The same method used for SWs was followed when analysing the CS data. The CS data was filtered to only include words which contained WI/WF singleton consonants or WI/WF consonant clusters. The same coding system of 0 for incorrect and 1 for the outcome was used. After filtering the data for WI and WF consonant clusters, it was discovered that there were not enough observations to carry out binary logistic regressions on those datasets.

Syllable number was not included as a variable in the CS regressions as the Chi Square revealed that there was no difference between perceiving a monosyllabic word correct or a polysyllabic word correctly in CS. The rest of the variables included in the regression models were the same as those used for SWs, with the addition of number of words in a phrase. The reference level for number of words in a phrase was the least number of words produced.

Again, a hierarchical procedure was used to build the binary logistic regression models. Below is an example for WI consonants in CS:

1. timepoint
2. timepoint and WI consonant
3. timepoint, WI consonant, and number of words
4. timepoint, WI consonant, number of words and the interaction between WI and timepoint

All the statistical analyses were undertaken using IBM SPSS Statistics 29 (for Windows) (IBM Corp., 2023) and R Statistical Software (R Core Team, 2024).

4.7.3. Acoustic Analysis

Word lists used to elicit SW were paired at 6 Weeks Pre- and 1 Week Post-Therapy, and at 1 Week Pre- and 12 Weeks Post-Therapy. Although the two lists were close to being phonetically balanced, there was still some variation. As each word has unique acoustic properties based on its phonemes—for instance, sonorant sounds are typically louder, impacting intensity, and certain vowels are longer than others, impacting duration, acoustic measures such as duration and mean intensity could not be compared across word lists.

Group-level acoustic analysis could not be conducted due to variability in the vocal cues provided to different children (see Table 12), which targeted individual speech characteristics. For example, increasing vocal loudness in SWs was a therapy goal for some children but not for others. Other children were able to maintain a loud voice in shorter utterances or had inappropriately loud speech. Similarly, not all children received cues to slow their speech rate in SWs. While all children had a vocal cue addressing speech rate, some children required to slow down only during CS when their rate would accelerate or fluctuate across longer utterances. Consequently, an overall group increase in duration was also not anticipated.

The acoustic data were limited, with measurements taken from only five SWs and three CS phrases, preventing parametric statistical analysis. For SWs, the acoustic analysis is exploratory. Each child's SW acoustic data was examined visually, looking at the acoustic profiling of the different phonemes, and compared with their own baseline speech characteristics and vocal cues used in therapy. Acoustic profiling was carried out on the data from 1 Week Pre- and 12 Weeks Post-Therapy as the lists were paired and the same words could be analysed over time. For CS, the free speech video description task introduced variability in the number and range of words and constituent phonemes (with differing acoustic properties) produced within and across children at each timepoint. This variability, combined with the limited CS data and time constraints as a result of Covid-19, prevented reliable identification of group or individual patterns, thus no acoustic analysis or acoustic profiling was conducted.

4.7.3.1. Exploratory Measures – Acoustic Profiling

Acoustic profiling was conducted across five SWs to examine the accuracy of all consonants. Acoustic profiling involves looking for distinct acoustic patterns that can identify sounds or sound categories, such as the presence of a plosive burst or formant frequencies. It has been reported that observing the presence or absence of an acoustic property can be as informative as measuring it quantitatively, such as through intensity or duration (Kent, Pagan-Neves, Hustad and Wertzner, 2009).

It was noticed at screening that only a small number of children in this study demonstrated vowel errors, and if vowel errors occurred, they were infrequent. Therefore, vowels were not examined. The spectrogram and waveform were inspected to confirm production of WI, word medial (WM) and WF consonants and identify features specific to the target consonants. If a plosive was expected, i.e., in ‘bin’, ‘log’, and ‘pond’, presence of a plosive burst was investigated. If a plosive burst was present, the intensity was measured to assess any changes over time. If a fricative was expected, e.g., in ‘feather’, the spectrogram and waveform was examined to see if frication was evident. For nasals and approximants, like in ‘log’, ‘pond’, and ‘waiter’, the spectrogram and waveform were inspected for the presence of anti-formants. No analysis was carried out on phonemes which children were able to produce accurately pre-therapy.

The acoustic findings were described in relation to the children’s vocal cues and perceptual speech characteristics. Phonetic transcriptions and acoustic profiling were used to assess changes in acoustic speech characteristics and to see whether the use of vocal cues may have led to these changes. Words containing characteristics of interest, e.g., ‘pond’ if children reduced consonant clusters, were investigated in more detail by comparing the pre- and post-therapy phonetic transcriptions. Examination of the spectrograms and waveforms allowed for covert changes, which may have contributed to improvement in intelligibility, to be explored (e.g., a nasalised vowel instead of a vowel followed by /n/ in *‘pond’)*. The spectrograms and waveforms were examined to see whether acoustic features of the target words were evident, even if they were not heard perceptually, e.g., a WF plosive burst.

Chapter 5. Results: Perceptual Analysis

5.1. Percentage Words Correct

5.1.1. Aim

To investigate whether personalised dysarthria therapy led to overall gains in speech intelligibility in children with dysarthria.

5.1.2. Hypothesis

The percentage of words perceived correctly by listeners would increase post-therapy.

5.2. Single Words Performance

5.2.1. Distribution of Intelligibility Scores (SW Performance)

The Shapiro-Wilk test indicated non-normal distribution ($p < 0.05$) of the raw listener SW performance data (see Appendix F.1). However, as the ICC is generally robust to moderate violations of normality (Norman and Streiner, 2008), and as the QQ plots were close to normal (see Appendix F.2), an ICC was conducted. There was excellent interrater reliability at 6 Weeks Pre-Therapy (ICC = 0.96, 95% CI = 0.90, 0.98), 1 Week Post-Therapy (ICC = 0.97, 95% CI = 0.92, 0.92), and 12 Weeks Post-Therapy (ICC = 0.96, 95% CI = 0.91, 0.99), and good to excellent reliability at 1 Week Pre-Therapy (ICC = 0.92, 95% CI = 0.82, 0.97), indicating that the ICC was robust enough to cope with the violations of normality.

The range of listener scores for each child at each timepoint was also non-normally distributed ($W(60) = 0.91$, $p < 0.001$). The non-parametric Friedman test indicated no statistically significant differences in the range of listener intelligibility scores for each child across the four timepoints ($\chi^2 (3)^* = 2.07$, $p = 0.56$). The distribution of listener scores for each child at each timepoint can be seen in (see Appendix F.3).

As listener agreement was high in both the ICC and range of scores, each child's mean intelligibility score was used to analyse intelligibility over time.

The mean percentage intelligibility score and range of listener scores for each child at each timepoint is shown in Table 13.

5.2.2. Change in Intelligibility Scores Across Time (SW Performance)

Child	6 Weeks Pre Mean % Intell (Range)	1 Week Pre Mean % Intell (Range)	1 Week Post Mean % Intell (Range)	12 Weeks Post Mean % Intell (Range)
1	38.33 (25.00)	51.67 (25.00)	66.67 (5.00)	70.00 (20.00)
2	40.00 (15.00)	30.00 (25.00)	48.33 (5.00)	55.00 (25.00)
4	16.67 (15.00)	16.67 (25.00)	23.33 (10.00)	30.00 (25.00)
5	60.00 (10.00)	43.33 (10.00)	53.33 (10.00)	56.67 (10.00)
6	1.67 (5.00)	3.33 (5.00)	1.67 (5.00)	5.00 (10.00)
7	21.67 (15.00)	23.33 (5.00)	31.67 (35.00)	33.33 (15.00)
8	46.67 (15.00)	50.00 (15.00)	58.33 (15.00)	70.00 (15.00)
9	23.33 (20.00)	15.00 (10.00)	15.00 (10.00)	25.00 (15.00)
10	10.00 (10.00)	10.00 (10.00)	20.00 (10.00)	15.00 (10.00)
11	1.67 (5.00)	5.00 (0.00)	0.00 (0.00)	5.00 (0.00)
12	20.00 (0.00)	20.00 (10.00)	11.67 (15.00)	21.67 (5.00)
13	10.00 (10.00)	10.00 (15.00)	8.33 (5.00)	20.00 (10.00)
14	0.00 (0.00)	15.00 (10.00)	10.00 (10.00)	28.33 (15.00)
15	3.33 (5.00)	6.67 (5.00)	8.33 (15.00)	3.33 (5.00)
16	16.67 (10.00)	38.33 (15.00)	31.67 (10.00)	31.67 (10.00)
Group Mean % Intell	20.67	22.56	25.89	31.33

Table 13 Table Showing the Mean Percentage Intelligibility Scores and Range of Scores per Child per Timepoint for Single Words (Performance)

The residuals of the SW performance data were normally distributed ($D(180) = 0.20$, $p = 0.30$), allowing a linear regression with random effects of child and the interaction of child against timepoint to be conducted to investigate the effect of timepoint on percentage intelligibility. A significant effect was observed ($F(3, 45) = 8.56$, $p < 0.001$). Negative estimates at all timepoints, in comparison to the reference timepoint (12 Weeks Post-Therapy), suggest that the intervention had a positive effect at improving children's speech intelligibility of SWs in the performance condition (Table 14).

Fixed Effects		Estimate	SE	df	t	*p*	95% CI (Lower, Upper)
Intercept		31.33	4.92	17.64	6.37	< 0.001	20.98, 41.69
6 Weeks Pre		-10.67	2.26	45	-4.72	< 0.001	-15.22, -6.11
1 Week Pre		-8.78	2.26	45	-3.88	< 0.001	-13.33, -4.22
1 Week Post		-5.44	2.26	45	-2.41	0.02	-10.00, -0.89
12 Weeks Post [ref]		0^b	0	.	.	.	.
Random Effects							
Residual		52.92	6.83	.	.	< 0.001	41.09, 68.15
Intercept (Child)	*Var*	324.99	122.19	.	.	0.01	155.54, 679.04
Intercept (Child*Timepoint)	*Var*	20.68	8.39	.	.	0.01	9.33, 45.81

**Note: b. This parameter is set to zero because it is redundant.*

-2 Log Likelihood = 1325.03; AIC = 1339.03; BIC = 1361.38; Pseudo R^2 (Marginal) = 0.04; Pseudo R^2 (Conditional) = .87

[ref] = reference level; Var = Variance

Table 14 Table showing Linear Regression Estimate of Fixed Effects Results (Single Words Performance)

Pairwise comparisons using Bonferroni correction revealed there was no significant difference between the pre-therapy timepoints as predicted (p = 0.99, 95% CI -8.13, 4.35), indicating stable baseline intelligibility. No significant difference was found between timepoints 1 Week Pre-Therapy and 1 Week Post-Therapy, contrary to original predictions (p = 0.88, 95% CI -9.57, 2.91).

5.2.3. Exploring Individual Differences in Responses to Therapy

Visual examination of individual children's results showed that despite no statistically significant difference from 1 Week Pre- to 1 Week Post-Therapy, two children (P1 and P10) made clinically significant intelligibility gains (>10% increase) (Appendix F.2). This indicates that some children experienced an immediate positive effect of therapy on SW performance intelligibility.

There was a statistically significant difference between 1 Week Pre-Therapy and 12 Weeks Post-Therapy, indicating that personalised intervention had a delayed but positive medium-term effect on children's intelligibility. Seven children (P1, P2, P4, P7, P8, P13, and P14) made clinically significant gains during this period. It should be noted that despite P2's intelligibility decreasing from 6 Weeks Pre- to 1 Week Pre-Therapy, indicating an unstable baseline, she still made clinically significant gains from 6 Weeks Pre- to 12 Weeks Post-Therapy.

5.2.4. Exploring Grouping within the Data (SW Performance)

The significantly greater variance between children compared to within child across timepoint (Table 14) reflected individual differences in SW intelligibility performance, which are shown in Figure 5. The SD (light grey area representing the variability of individual data points around the mean) was grouped more tightly at the pre-therapy and dispersed post-therapy, indicating that differences between children's mean intelligibility increased over time. The SD in Figure 5 was not a perfect fit for the entire group. Some children's mean intelligibility scores lay outside the range, indicating that they behaved differently to other children in the study. These children appeared to be the most and least intelligible out of the group.

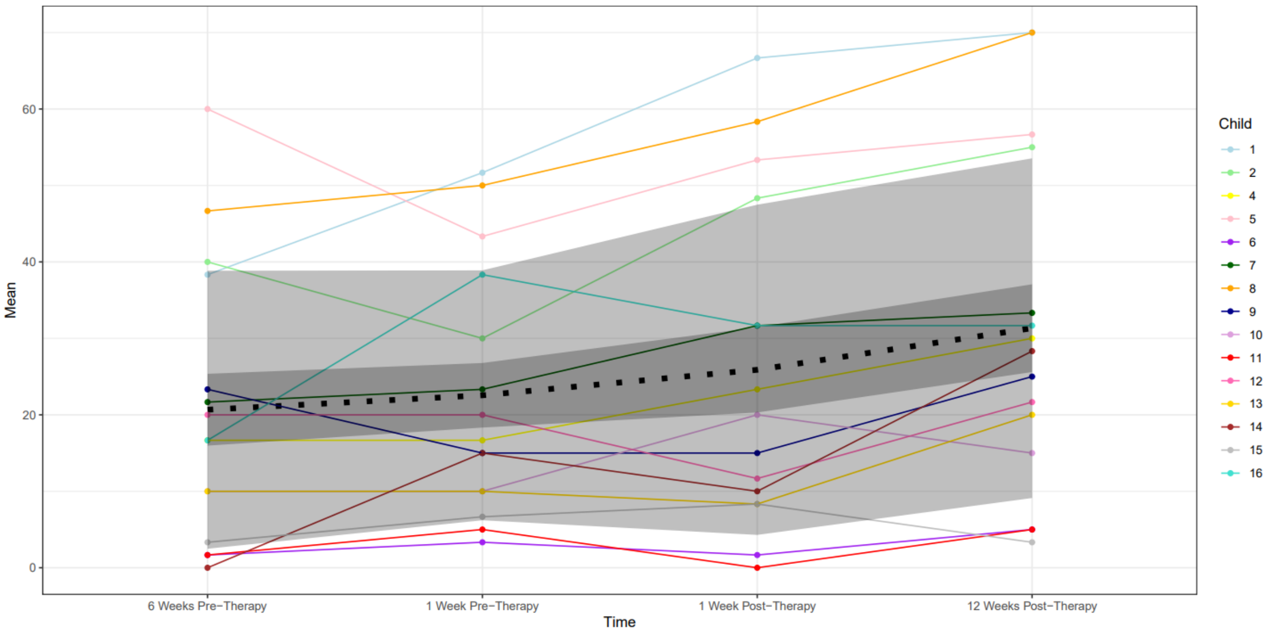

Figure 5 Line graph showing mean intelligibility, group mean, SD and SE across time (Single Words Performance)

A ridgeline plot (Figure 6) also shows the bimodal distribution in intelligibility scores becoming more pronounced at later time points, with some children making gains post-therapy and others not or less so.

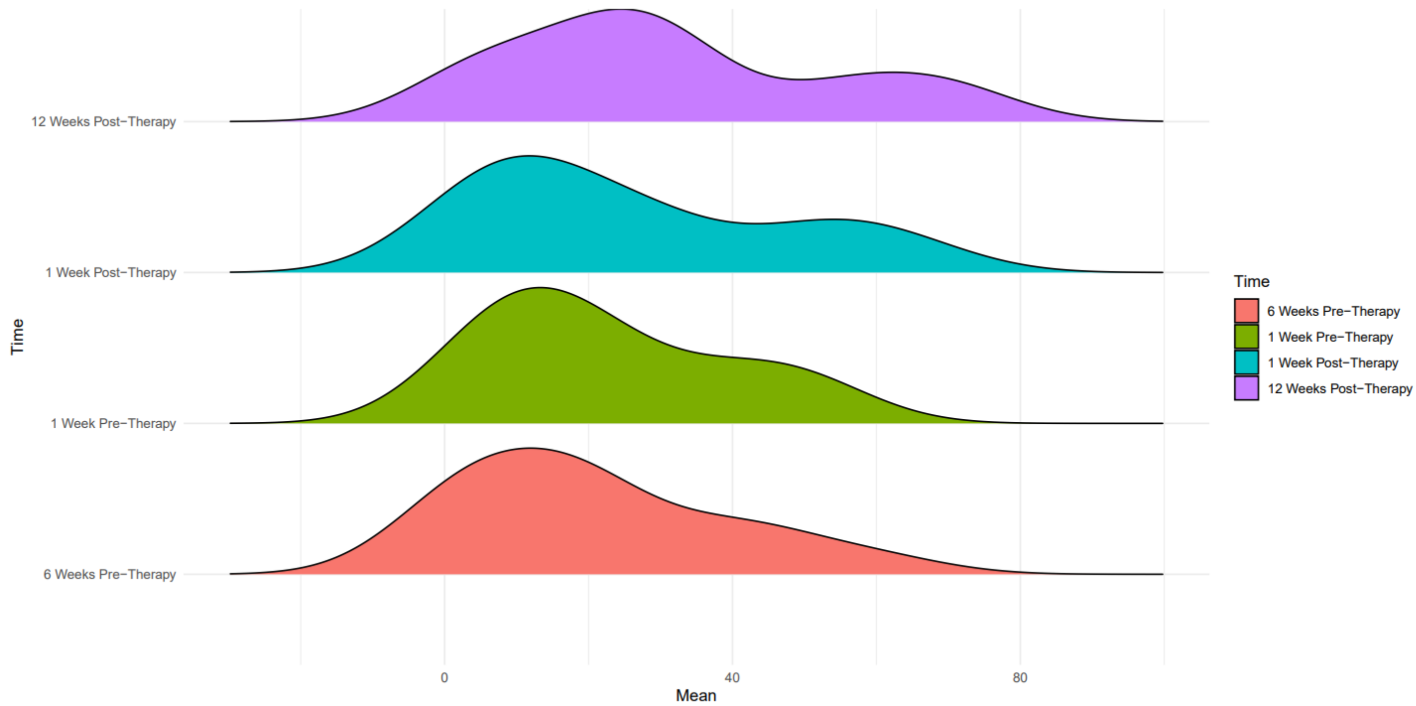

Figure 6 Ridgeline plot showing mean intelligibility distributions at each time point (Single Words Performance)

To investigate the suggestion that there were potentially two groups of children who responded differently to the intervention, children were split into two groups based on their baseline intelligibility. The high intelligibility group (P1, P2, P5, P7, P8, and P16) had mean intelligibility scores above the group mean at 1 Week Pre-Therapy; the low intelligibility group (P4, P6, P9, P10, P11, P12, P13, P14, and P15) had mean intelligibility scores below the group mean. When split into two groups, the SD was a better fit (Figure 7). The most intelligible children mainly fitted into the upper SD range, although P1 still performed slightly better. P4, P7 and P16 appeared to be somewhere between the two groups, performing better than those in low intelligibility group but not as well as those in the high intelligibility group. P6 and P11's intelligibility scores were substantially lower than the other participants, further highlighting the variation in intelligibility across children. The dispersion of both the upper and lower SD was more stable across time, indicating that children within a group were behaving similarly to each other.

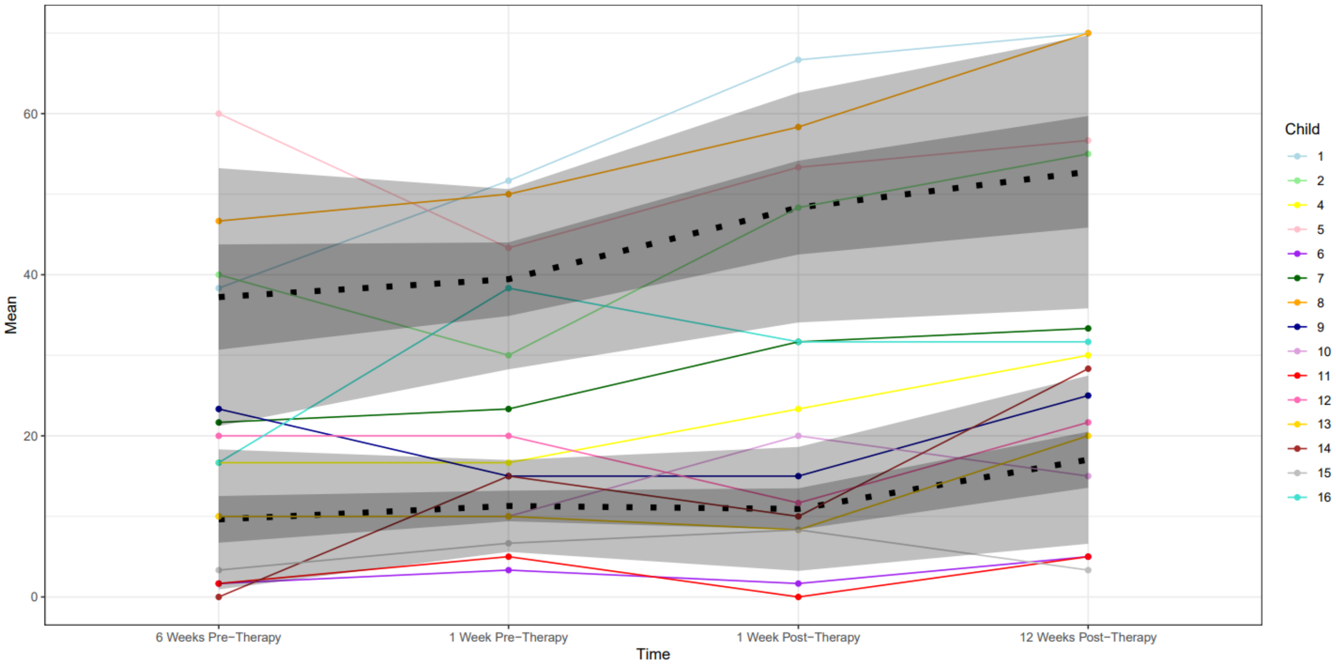

Figure 7 Line graph showing mean intelligibility, group mean, SD and SE across time for bimodal distribution (Single Words Performance)

5.3. Single Words Capacity

5.3.1. Distribution of Intelligibility Scores (SW Capacity)

The raw listener data for SW capacity was not normally distributed at any timepoint (see Appendix G.1). The QQ plots showed slight skewness (see Appendix G.2), but the results indicated good-to-excellent or excellent reliability, ranging from 0.94 to 0.96 (see Appendix G.1), suggesting that the measure is robust against these normality violations.

The range of scores were not normally distributed at 6 Weeks Pre-Therapy (W(15) = 0.81, p = 0.005) and 1 Week Post-Therapy (W(15) = 0.85, p = 0.02). The Friedman Test showed no statistically significant differences in the range of listener scores across the four timepoints ($\chi^2(3, N = 15) = 2.78$, p = 0.43). The distribution of listener scores for each child at each timepoint can be seen in (see Appendix G.3).

Due to high listener agreement, mean listener scores were used to analyse percentage intelligibility change over time due.

5.3.2. Change in Intelligibility Scores Across Time (SW Capacity)

Mean percentage intelligibility and range of listener scores for each child at each timepoint are shown in Table 15.

Child	6 Weeks Pre Mean % Intell (Range)	1 Week Pre Mean % Intell (Range)	1 Week Post Mean % Intell (Range)	12 Weeks Post Mean % Intell (Range)
1	36.67 (10.00)	58.33 (25.00)	66.67 (5.00)	75.00 (30.00)
2	36.67 (10.00)	23.33 (15.00)	63.33 (5.00)	55.00 (35.00)
4	21.67 (10.00)	28.33 (15.00)	16.67 (15.00)	20.00 (10.00)
5	46.67 (5.00)	43.33 (5.00)	61.67 (135.00)	55.00 (25.00)
6	0.00 (0.00)	3.33 (5.00)	0.00 (0.00)	5.00 (10.00)
7	33.33 (20.00)	18.33 (10.00)	41.67 (10.00)	31.67 (5.00)
8	43.33 (30.00)	58.33 (20.00)	63.33 (10.00)	68.33 (25.00)
9	16.67 (5.00)	25.00 (0.00)	21.67 (5.00)	18.33 (15.00)
10	13.33 (5.00)	15.00 (10.00)	20.00 (25.00)	5.00 (0.00)
11	0.00 (0.00)	5.00 (0.00)	1.67 (5.00)	5.00 (0.00)
12	18.33 (5.00)	23.33 (10.00)	15.00 (10.00)	16.67 (15.00)
13	15.00 (10.00)	23.33 (15.00)	13.33 (25.00)	11.67 (10.00)
14	3.33 (10.00)	15.00 (0.00)	1.67 (5.00)	21.67 (15.00)
15	10.00 (10.00)	6.67 (5.00)	6.67 (20.00)	13.33 (10.00)
16	23.33 (10.00)	43.33 (20.00)	26.67 (5.00)	31.67 (35.00)
Group Mean	21.22	26.00	28.00	28.89

Table 15 Table Showing the Mean Percentage Intelligibility Scores and Range of Listener Scores per Child per Timepoint for Single Words (Capacity)

The residuals of the SW capacity data were not normally distributed ($D(180) = 0.08$, $p = 0.01$). However, the histogram plot of the residuals appeared to be somewhat bell-shaped and symmetric, and the number of observations (n = 180) was large (see Appendix G.4), so a linear regression was performed.

The negative estimates indicate that the group percentage intelligibility at all timepoints was less than at the reference level (12 Weeks Post-Therapy), although the fixed effect of time was only statistically significant at 6 Weeks Pre-Therapy (Table 16).

Pairwise comparisons revealed no significant difference in intelligibility between any timepoints compared (see Appendix G.5). Table 15 shows some children's intelligibility increased from 6 Weeks Pre- to 1 Week Pre-Therapy, whilst others decreased (discussed more in Section 5.3.3). This variation in pre-therapy intelligibility may have made it not possible to observe a difference in capacity intelligibility this small group of children.

Fixed Effects		Estimate	SE	df	t	*p*	95% CI (Lower, Upper)
Intercept		28.89	5.15	17.64	5.61	< 0.001	18.13, 39.64
6 Weeks Pre		-7.67	2.99	45	-2.56	0.01	-13.69, -1.64
1 Week Pre		-2.89	2.99	45	-0.97	0.34	-8.91, 3.13
1 Week Post		-0.89	2.99	45	-0.30	0.77	-6.91, 5.13
12 Weeks Post [ref]		0^b	0	.	.	.	.
Random Effects							
Residual		66.25	8.55	.	.	< 0.001	51.44, 85.33
Intercept (Child)	*Var*	330.46	126.84	.	.	< 0.009	155.74, 701.17
Intercept (Child*Timepoint)	*Var*	44.97	14.42	.	.	0.002	23.99, 84.32
**Note: b. This parameter is set to zero because it is redundant.*							
-2 Log Likelihood = 1377.74; AIC = 1391.74; BIC = 1414.09; Pseudo R^2 (Marginal) = 0.02; Pseudo R^2 (Conditional) = .85							

Table 16 Table showing Linear Regression Estimate of Fixed Effects Results (Single Words Capacity)

5.3.3. Exploring Individual Differences in Responses to Therapy

Despite no statistically significant difference over time, visual inspection of individual children's data suggest that some children's intelligibility may have improved post-therapy. Two children (P2, and P5) made clinically significant gains in the mean intelligibility of SWs in the capacity condition from 1 Week Pre-Therapy to 1 Week Post-Therapy (see Appendix G.6). P7's intelligibility appeared clinically significantly higher during this period (Table 15), however the decline in his intelligibility from 6 Weeks Pre- to 1 Week Pre-Therapy meant he did not reach clinical significance post-therapy.

Three children's (P1, P2, and P8) intelligibility gains from 1 Week Pre-Therapy to 12 Weeks Post-Therapy reached clinical significance. This corresponds with the SW performance data, where improvement in intelligibility was not immediate for most children but intervention did have a positive medium-term effect. P1, P2, and P8 also made clinically significant gains in SW performance intelligibility. It initially appeared that P5 and P7 made clinically significant gains during this time, however their post-therapy intelligibility was not 10% above their baseline intelligibility (Table 15).

5.3.4. Exploring Grouping within the Data (SW Capacity)

The SD was grouped more tightly pre-therapy and dispersed post-therapy, indicating an increase in the difference in mean intelligibility between participants over time

(Figure 8). As in SW performance, P1, P5, and P8's intelligibility scores were outside the upper end of the SD and P6 and P11's scores were outside the lower end suggesting these children behaved differently to the other children in the study.

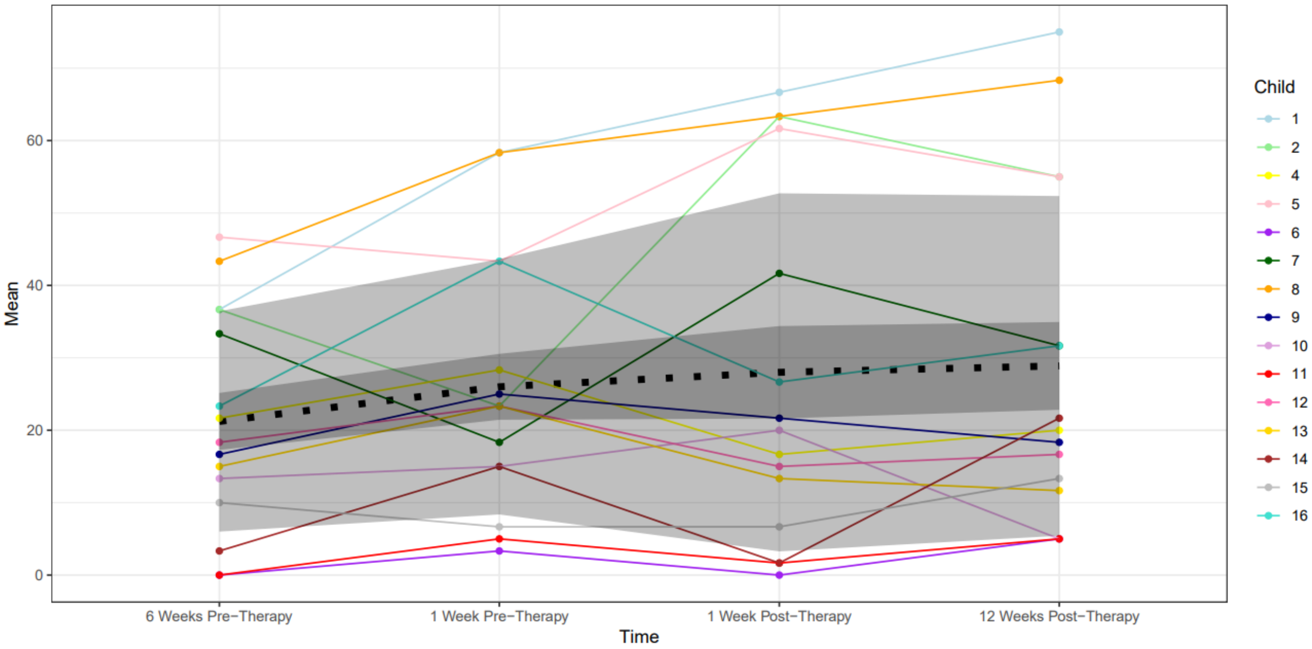

Figure 8 Line graph showing mean intelligibility, group mean, SD and SE across time (Single Words Capacity)

As with the SW performance data, the ridgeline plot (Figure 9) shows two very clear curves 1 Week Post-Therapy and 12 Weeks Post-Therapy indicating potential bimodal distribution of the post-therapy data. Those children with higher intelligibility in SW performance (P1, P2, P5, P7, P8, and P16) also had higher intelligibility in the capacity condition, and thus remained in the high intelligibility group for capacity. Those with lower intelligibility in SW performance (P4, P6, P9, P10, P11, P12, P13, P14, and P15) had lower SW capacity intelligibility and remained in the low intelligibility group for capacity.

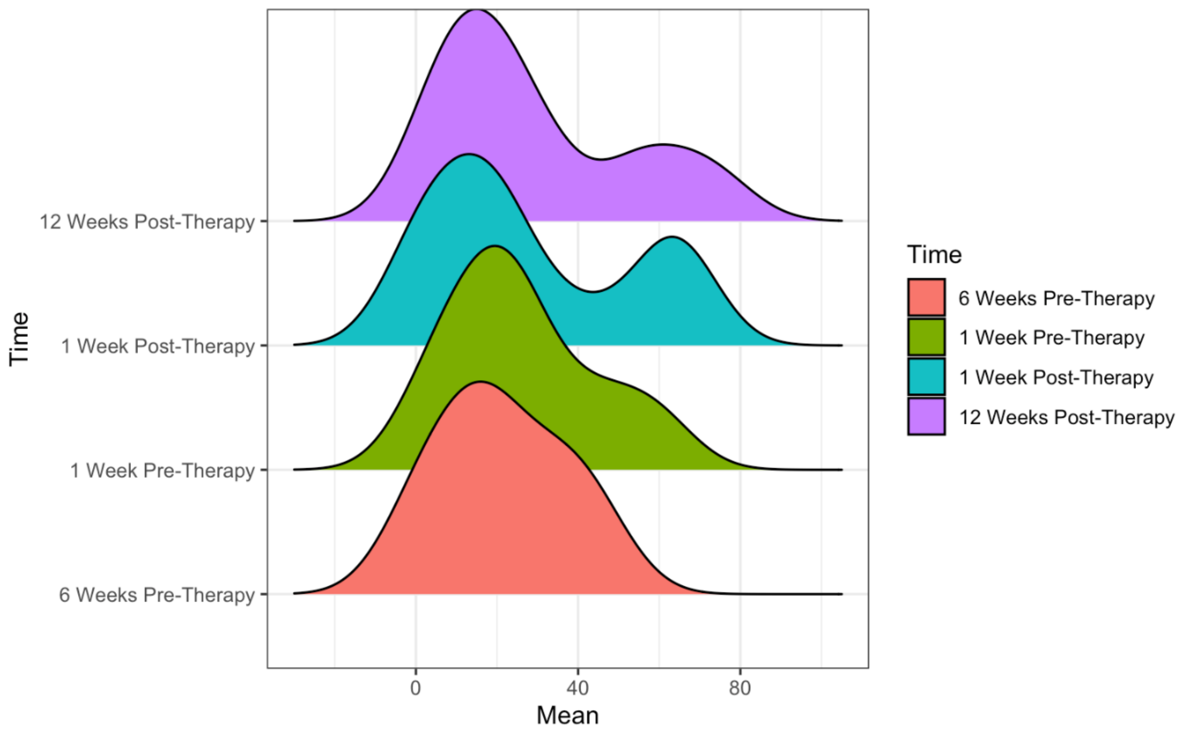

Figure 9 Ridgeline plot showing mean intelligibility distributions at each time point (Single Words Capacity)

When the participants were split into the two groups based on capacity intelligibility, the SD decreased (Figure 10). Again, P7 and P16 appeared to be between the two groups, although P7's mean intelligibility at 1 Week Pre-Therapy fell below some of the children in the low intelligibility group. P6 and P11 performed below the lower SD group. The dispersion of the SD for the more intelligible group (group 1) appeared relatively stable from 1 Week Pre-Therapy to 12 Weeks Post-Therapy, suggesting that there was not a significant increase in differences between children from pre- to post-therapy. For the low intelligibility group, the dispersion seemed to narrow over time, indicating that the differences between children in this group decreased across timepoints, and children began to behave more similarly in terms of SW intelligibility in the capacity condition.

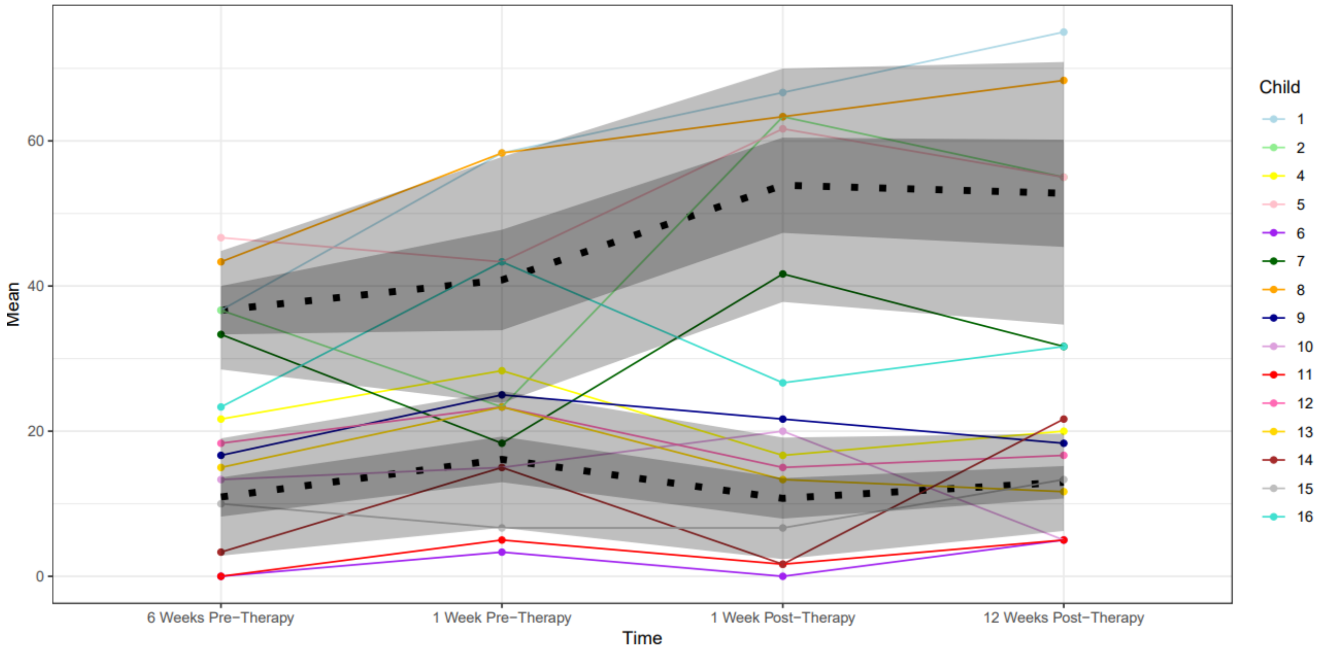

Figure 10 Line graph showing mean intelligibility, group mean, SD and SE across time for bimodal distribution (Single Words Capacity)

5.4. Summary of Single Words Percentage Words Correct

Results from the SW performance data found a statistically significant difference between 1 Week Pre-Therapy and 12 Weeks Post-Therapy, with seven children making clinically significant gains (P1, P2, P4, P7, P8, P13, and P14). This indicates that personalised intervention had a delayed but positive medium-term effect on SW performance intelligibility. Two children made clinically significant gains from 1 Week Pre- to 1 Week Post-Therapy (P1 and P10), indicating therapy had an immediate effect on some children's intelligibility. It must be noted that a small number of children did not have a stable baseline intelligibility and that any clinically significant difference reported is over and beyond any change in intelligibility from 6 Weeks Pre- to 1 Week Pre-Therapy. Children from both the high and low intelligibility groups made improvements in SW performance intelligibility.

No statistically significant difference was observed for the group between 1 Week Pre- and 12 Weeks Post-Therapy for the SW capacity data. However, two children made clinically significant gains from 1 Week Pre- to 1 Week Post-Therapy (P2 and P5) and three children made clinically significant gains from 1 Week Pre- to 12 Weeks Post-Therapy (P1, P2, and P8). Only children who were in the high intelligibility group demonstrated gains in SW capacity intelligibility. P2 was the only child to make improvements in SW capacity immediately following the intervention and sustain these gains 12 Weeks Post-Therapy. Those children who made clinically significant improvements 12 Weeks Post-Therapy in SW capacity intelligibility also did in SW performance intelligibility.

Children's SW intelligibility across performance and capacity was similar. Children in the high intelligibility group (P1, P2, P5, P7, P8, and P16) for SW performance remained in the high intelligibility group for SW capacity, and children in the low intelligibility group (P4, P6, P9, P10, P11, P12, P13, P14, and P15) for SW performance remained in the low intelligibility group for SW capacity. P6 and P11 appeared to be markedly less intelligible than the other children in the study, remaining outside of the SD range in both conditions, whereas P1, P5 and P8 appeared to be noticeably more intelligible at all timepoints for both SW performance and capacity.

5.5. Connected Speech Performance

5.5.1. Distribution of Intelligibility Scores (CS Performance)

CS performance intelligibility scores were normally distributed, and homogeneity of variances were met (see Appendix H.1). All ICC average measures showed good-to-excellent interrater reliability at all four timepoints, ranging from 0.81 to 0.94, although 95% CIs indicated a wider range of reliability (moderate-to-excellent) at 6 Weeks Pre-Therapy (see Appendix H.2).

Variability of the range of the three listener scores for each child at each timepoint was assessed. Repeated measures ANOVA assumptions of normality, homogeneity of variances, and sphericity were met (see Appendix H.3). Results from the repeated measures ANOVA showed no statistically significant differences between the ranges of scores across all four timepoints ($F(3, 42) = 1.18$, $p = 0.33$, partial $\eta^2 = 0.08$). Appendix H.4 shows listener scores for individual children.

As the ICCs showed very high agreement between listeners and the range of listener scores did not vary across timepoints, the mean intelligibility score for each child at each timepoint was used in the analysis.

5.5.2. Change in Intelligibility Scores Across Time (CS Performance)

The mean intelligibility and range of listener scores for each child at each timepoint are shown in Table 17.

Child	6 Weeks Pre Mean % Intell (Range)	1 Week Pre Mean % Intell (Range)	1 Week Post Mean % Intell (Range)	12 Weeks Post Mean % Intell (Range)
1	26.92 (38.50)	31.48 (13.90)	46.24 (35.50)	65.00 (15.00)
2	36.11 (27.8)	42.03 (8.70)	45.98 (27.60)	48.33 (25.00)
4	18.67 (32.00)	14.29 (14.30)	19.05 (21.40)	20.00 (10.00)
5	36.94 (16.20)	59.72 (8.30)	80.00 (10.00)	53.15 (18.90)
6	11.11 (4.20)	2.08 (6.30)	2.56 (7.70)	9.26 (5.60)
7	36.23 (17.40)	17.14 (8.60)	21.84 (10.30)	18.75 (18.80)
8	39.13 (30.40)	47.92 (4.20)	57.02 (34.20)	48.28 (20.70)
9	17.78 (3.30)	0.00 (0.00)	26.32 (15.80)	13.10 (14.30)
10	42.53 (10.30)	15.87 (14.30)	18.89 (20.00)	30.00 (23.30)
11	3.33 (10.00)	0.00 (0.00)	6.67 (5.00)	4.30 (9.70)
12	27.78 (16.70)	19.70 (.50)	24.64 (13.00)	56.52 (34.80)
13	12.00 (16.00)	14.58 (25.00)	7.78 (10.00)	15.00 (15.00)
14	3.17 (4.80)	15.38 (19.20)	12.82 (19.20)	24.64 (4.30)
15	1.85 (5.60)	10.26 (23.10)	7.94 (19.00)	22.92 (18.80)
16	36.00 (28.00)	39.68 (28.60)	45.45 (0.00)	33.33 (15.40)
Group Mean	23.30	22.01	28.21	30.84

Table 17 Table Showing the Mean Intelligibility Scores and Range of Scores per Child per Timepoint for CS Performance

The residuals of the CS performance data were normally distributed (W = 0.99, p = 0.41). Linear regression showed that the fixed effect of timepoint was statistically significant for 6 Weeks Pre- and 1 Week Pre-Therapy, compared to the reference level 12 Weeks Post-Therapy (Table 18). The negative estimates indicate that percentage intelligibility was significantly lower at both pre-therapy timepoints compared to 12 Weeks Post-Therapy, suggesting that the therapy had a medium-term effect on intelligibility.

Fixed Effects		Estimate	SE	df	t	*p*	95% CI (Lower, Upper)
Intercept		30.84	4.65	22.87	6.63	< 0.001	21.22, 40.46
6 Weeks Pre		-7.54	3.38	45	-2.23	0.03	-14.34, -0.73
1 Week Pre		-8.83	3.38	45	-2.61	0.01	-15.64, -2.02
1 Week Post		-2.63	3.38	45	-0.77	.44	-9.43, 4.18
12 Weeks Post [ref]		0^b	0	.	.	.	.
Random Effects							
Residual		92.96	12.00	.	.	< 0.001	72.18, 119.72
Intercept (Child)	Var	238.59	95.05	.	.	0.01	109.28, 520.91
Intercept (Child*Timepoint)	Var	54.70	18.50	.	.	0.003	28.19, 106.15

**Note: b. This parameter is set to zero because it is redundant.*

-2 Log Likelihood = 1425.08; AIC = 1439.08; BIC = 1461.43; Pseudo R^2 (Marginal) = 0.03; Pseudo R^2 (Conditional) = .77

Table 18 Table showing Linear Regression Estimate of Fixed Effects Results (Connected Speech Performance)

Pairwise comparisons using Bonferroni correction showed no statistically significant difference in intelligibility between 6 Weeks Pre- and 1 Week Pre-Therapy, and between 1 Week Pre- and 1 Week Post-Therapy, indicating no immediate effect of the intervention on intelligibility (see Appendix H.5).

5.5.3. Exploring Individual Differences in Responses to Therapy

Although there were no statistically significant gains in CS performance intelligibility between 1 Week Pre-Therapy and 1 Week Post-Therapy, P1 and P5 demonstrated clinically significant improvements (see Appendix H.6). While P9's percentage increase in intelligibility over this period might suggest a clinically significant gain, her drop in intelligibility between 6 Weeks Pre- and 1 Week Pre-Therapy means an improvement in intelligibility was not achieved.

A statistically significant improvement was observed between 1 Week Pre-Therapy and 12 Weeks Post-Therapy, indicating that the personalised intervention had a delayed but positive medium-term effect on children's intelligibility. Three children (P1, P12, and P15) achieved clinically significant gains over this period. Notably, P1 was the only child who exhibited immediate post-therapy gains in CS performance intelligibility and maintained these improvements.

For P9 and P10, intelligibility at 12 Weeks Post-Therapy was clinically significantly higher compared to 1 Week Pre-Therapy. However, their earlier decline in intelligibility from 6 Weeks Pre- to 1 Week Pre-Therapy means their post-therapy gains cannot be classified as clinically significant.

5.5.4. Exploring Grouping within the Data (CS Performance)

There was significantly more variance between children compared to within children across timepoints, reflecting individual differences in intelligibility performance. The variation in mean intelligibility across children is shown in the line graph in Figure 11. The SD increased post-therapy, indicating that the differences between children's mean intelligibility increased over time. The SD was not a perfect fit for the group as some children's mean intelligibility scores lay outside the range, indicating that these children may have behaved differently to other children in the study.

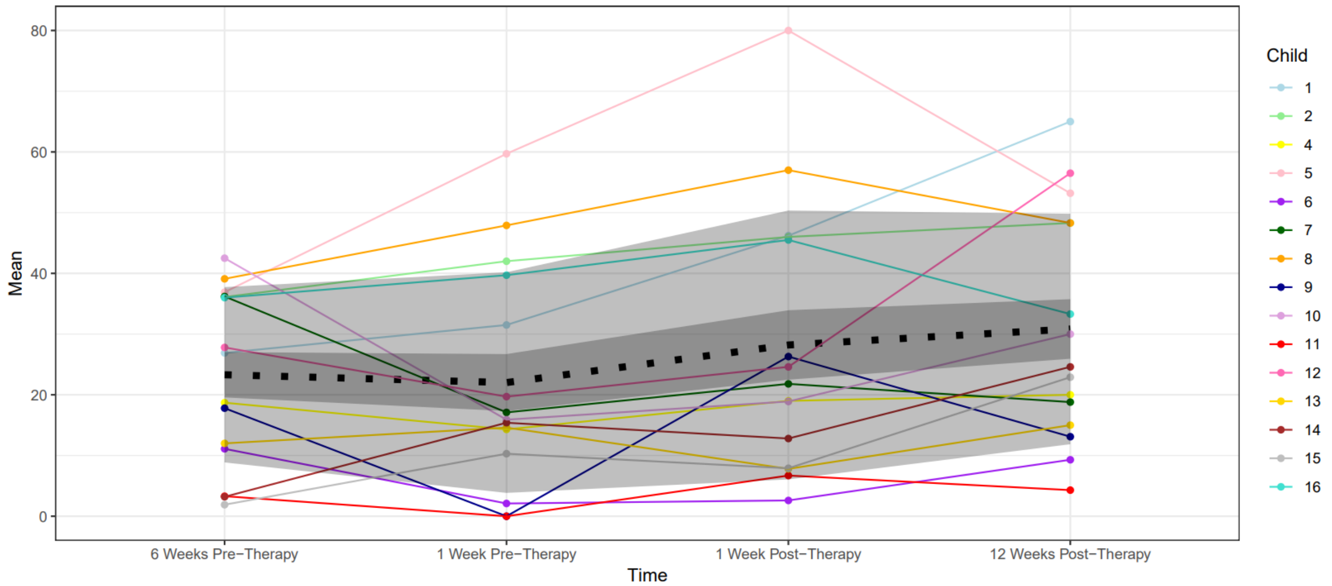

Figure 11 Line graph showing mean intelligibility, group mean, SD and SE across time (Connected Speech Performance)

Like with the SW data, a bimodal distribution was evident. However, for the CS performance data the bimodal distribution could be seen 1 Week Pre-Therapy as well as post-therapy (Figure 12).

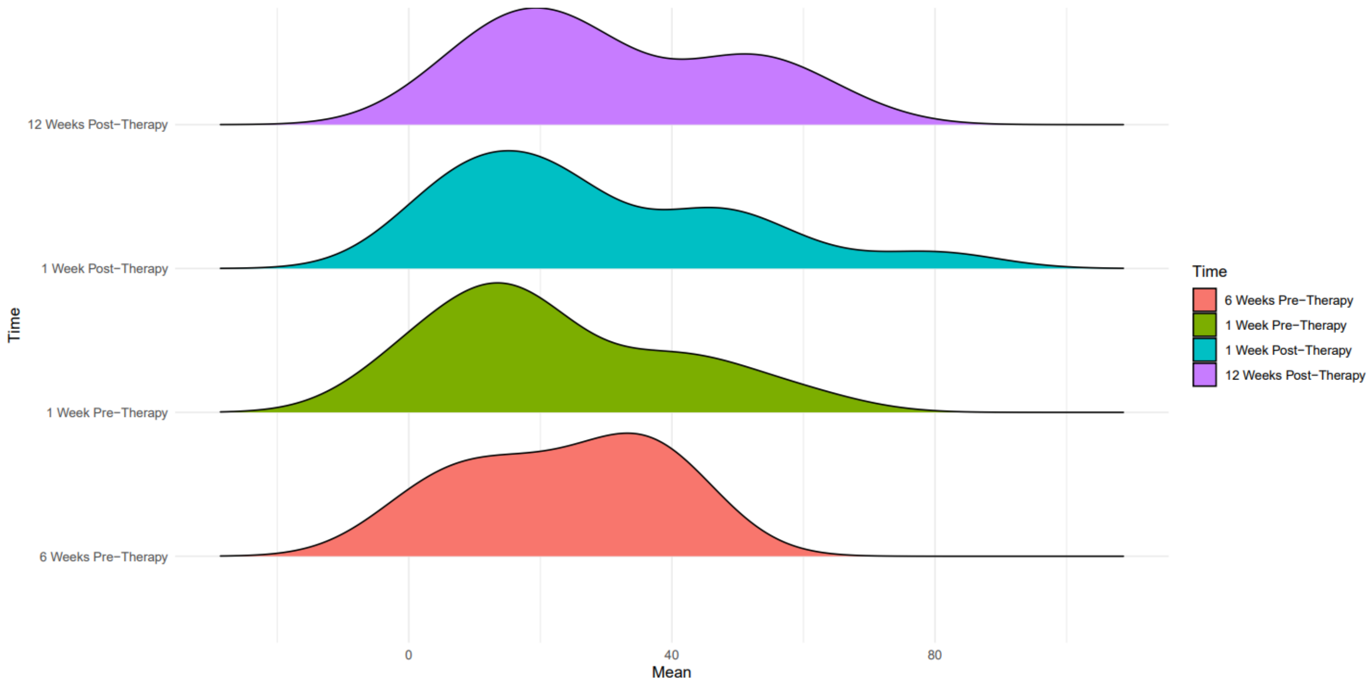

Figure 12 Ridgeline plot showing mean intelligibility distributions at each time point (Connected Speech Performance)

A small third ridge is evident 1 Week Post-Therapy, suggesting that a small number of children's mean intelligibility was much higher than others in the group. The distribution shown in the ridgeline plot indicates that improvement in intelligibility did occur within some children in the group, even though no statistically significant difference was found. The bimodal (and potential trimodal) distributions suggest there were potentially two or three groups of children separated by their intelligibility. These groups appeared to differ slightly from those in the SW data. The high intelligibility group was composed of eight children (P1, P2, P5, P7, P8, P10, P12, and P16), six who were in the high intelligibility group for SWs (P1, P2, P5, P7, P8, and P16) and two who were in the low intelligibility group for SWs (P10 and P12). The low intelligibility group was made up of children with lower CS intelligibility (P4, P6, P9, P11, P13, P14, and P15). All children in the low intelligibility group for CS were in the low intelligibility group for SWs also. When split into these groups, the new SD and SE fit better for most participants. However, P5's mean intelligibility remained well above the high intelligibility group. The SD for the high intelligibility group was very dispersed (Figure 13), indicating that not all within this group behaved similarly and that another group may have been present.

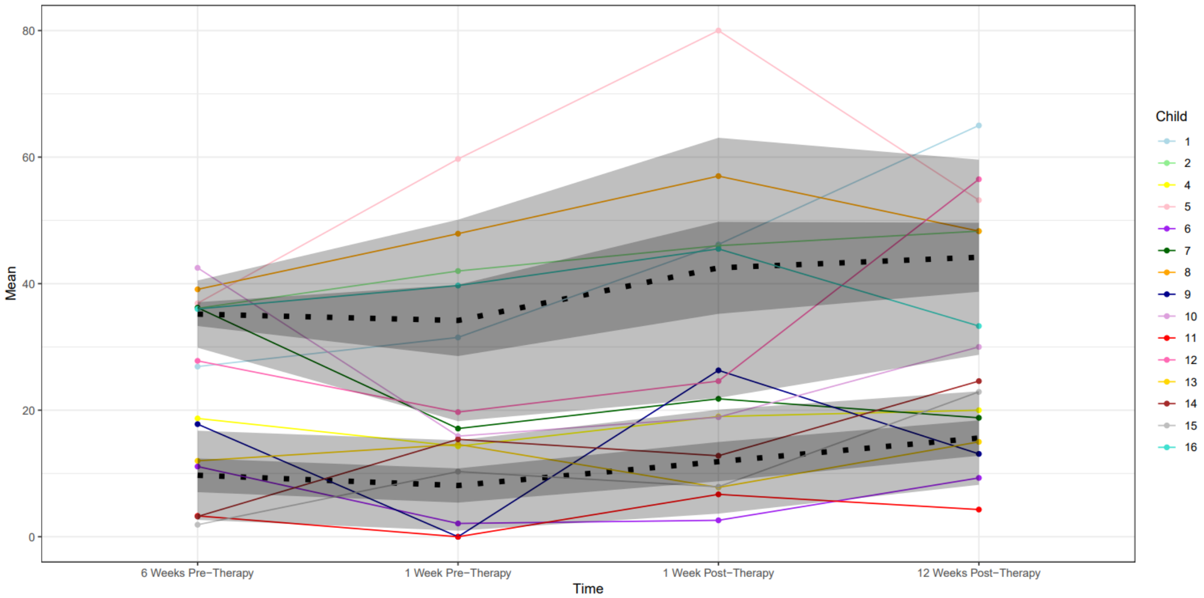

Figure 13 Line graph showing mean intelligibility, group mean, SD and SE across time for bimodal distribution (Connected Speech Performance)

When split into three groups of high (P5 and P8), mid (P1, P2, P7, P10, P12, and P16), and low (P4, P6, P9, P11, P13, P14, and P15) intelligibility the children were clearly separated by the SDs (see Figure 14). P1 and P2 were in between the high intelligibility and mid intelligibility group for CS performance intelligibility and could have been placed into either group. P7, P9, P10, and P12's CS performance intelligibility was unstable, with P7 and P12's performance at times aligning with the mid intelligibility group and at others with the low intelligibility group; similarly, P12's score at times aligned with the mid intelligibility group and others with the high intelligibility group, while P10's patterns intersected with all three groups. This highlights not only the significant variation in intelligibility across children (Estimate = 238.59, p = 0.01, 95% CI 109.28, 520.91), but also the variation within children across time (Estimate = 54.70; p = 0.003; 95% CI 28.19 to 106.15). The SD for the least intelligible children was less dispersed, indicating that they behaved in a similar way. The SDs were more dispersed for the high and mid intelligibility groups, particularly 1 Week Post-Therapy, suggesting that there were still potentially some differences in the way children within these groups behaved and responded to the therapy.

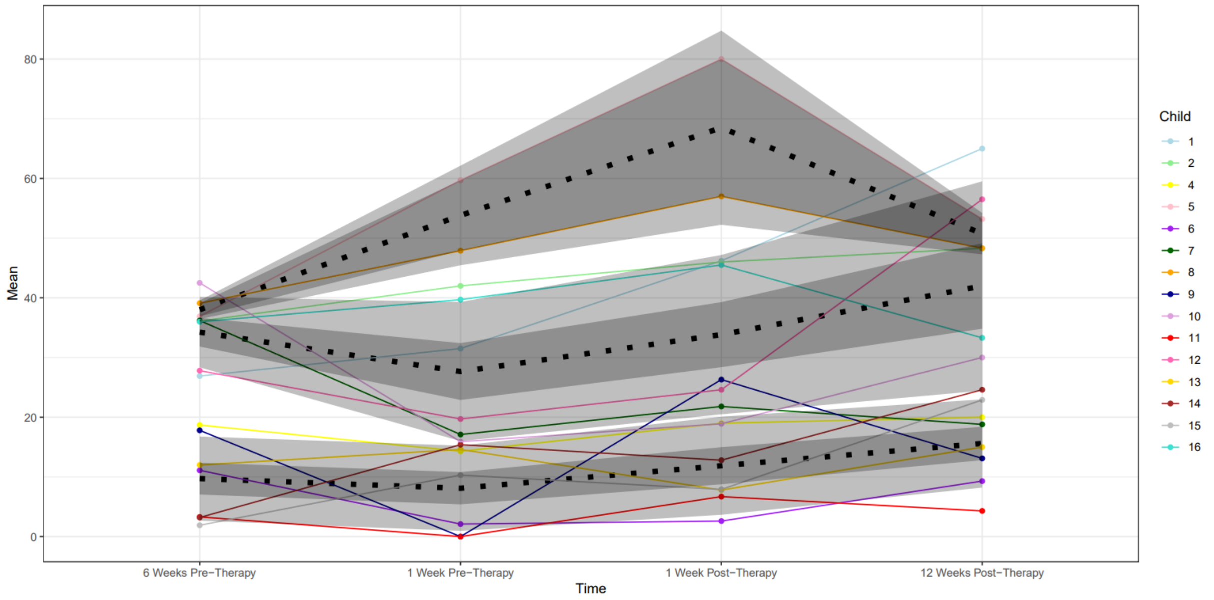

Figure 14 Line graph showing mean intelligibility, group mean, SD and SE across time for trimodal distribution (Connected Speech Performance)

5.6. Connected Speech Capacity

5.6.1. Distribution of Intelligibility Scores (CS Capacity)

Tests of homogeneity of variances indicated homogeneity of variance was met. Tests of normality showed that the pre-therapy data were normally distributed but the post-therapy data were not (Appendix I.1)**.** The QQ plots were slightly skewed (see Appendix I.2), but al ICC average measures showed good-to-excellent interrater reliability, ranging from 0.83 to 0.95, indicating likeliness of high agreement (see Appendix I.3), despite violations of normality.

The Shapiro-Wilk test showed that the range of listener scores data for each child were normally distributed at 1 Week Pre-Therapy (W(15) = 0.92, p = 0.16) and 1 Week Post-Therapy (W(15) = 0.88, p = 0.05) but not normally distributed 6 Weeks Pre-Therapy (W(15) = 0.83, p = 0.01) or 12 Weeks Post-Therapy (W(15) = 0.83, p = 0. 01). The non-parametric Friedman test indicated no statistically significant differences in the range of listener intelligibility scores for each child across the four timepoints (χ^2(3, N = 15) = 1.08, p = 0.78). The distribution of listener scores for each child at each timepoint can be seen in (see Appendix I.4).

High listener agreement of the CS capacity data enabled use of the mean intelligibility score for each child for analysis of intelligibility over time.

5.6.2. Change in Intelligibility Scores Across Time (CS Capacity)

The mean percentage intelligibility score and range of listener scores for each child at each timepoint is shown in Table 19.

Child	6 Weeks Pre % Mean Intell (Range)	1 Week Pre % Mean Intell (Range)	1 Week Post % Mean Intell (Range)	12 Weeks Post % Mean Intell (Range)
1	16.16 (24.20)	46.81 (917.00)	51.11 (20.00)	44.44 (50.00)
2	34.38 (12.50)	6.06 (9.10)	27.27 (33.30)	28.95 (15.80)
4	24.69 (3.70)	18.92 (13.50)	25.83 (15.00)	20.37 (11.10)
5	34.96 (39.00)	46.54 (11.30)	57.50 (45.00)	56.91 (29.30)
6	3.70 (11.10)	7.02 (21.10)	1.52 (4.50)	13.33 (5.00)
7	31.75 (4.80)	13.04 (13.00)	26.19 (7.10)	12.12 (18.20)
8	32.32 (42.00)	48.04 (5.90)	43.75 (28.10)	55.56 (58.30)
9	18.52 (8.30)	13.64 (9.10)	14.81 (11.10)	25.64 (23.10)
10	25.93 (11.10)	18.00 (12.00)	13.33 (1.00)	30.39 (2.90)
11	3.85 (7.70)	1.23 (3.70)	11.67 (10.00)	1.19 (3.60)
12	50.00 (27.30)	69.23 (30.80)	35.00 (20.00)	50.00 (15.60)
13	5.00 (0.00)	27.45 (11.80)	4.17 (6.30)	7.58 (18.20)
14	26.39 (4.20)	16.67 (8.30)	2.56 (3.80)	24.00 (20.00)
15	0.00 (0.00)	1.39 (4.20)	15.94 (30.40)	12.82 (3.80)
16	8.33 (5.00)	26.98 (23.80)	46.03 (4.80)	11.90 (3.60)
Group Mean	21.06	24.07	25.11	26.35

Table 19 Table Showing the Mean Intelligibility Ratings and Range of Listener Scores per Child per Timepoint for Connected Speech Capacity

The residuals of the CS capacity data were not normally distributed ($W(180) = 0.95$; $p < 0.001$) and the histogram and QQ plots were markedly skewed, therefore a linear regression could not be conducted. The raw mean intelligibility data were normally distributed at each timepoint ($p > 0.05$), and assumptions of homogeneity of variance and sphericity were met (see Appendix I.5). A repeated measures ANOVA found statistically significant differences in mean intelligibility of CS capacity across all timepoints, $F(1, 14) = 37.54$, $p < 0.001$, partial $\eta^2 = 0.73$. The partial eta squared suggests the effect size was large, with 73% of the variance in data attributed to overall mean scores. The test was very well powered to detect this effect (observed power = 0.99).

5.6.3. Exploring Grouping within the Data and Individual Differences (CS Capacity)

When analysing the CS capacity intelligibility as a group, it is clear that baseline intelligibility was not stable; some children's intelligibility increased between 6 Weeks

Pre- and 1 Week Pre-Therapy and some children's intelligibility decreased (Figure 15). This is also apparent between each timepoint. No difference across time was expected as there is no discernible pattern, with each child behaving differently at each timepoint, so no additional analyses were conducted.

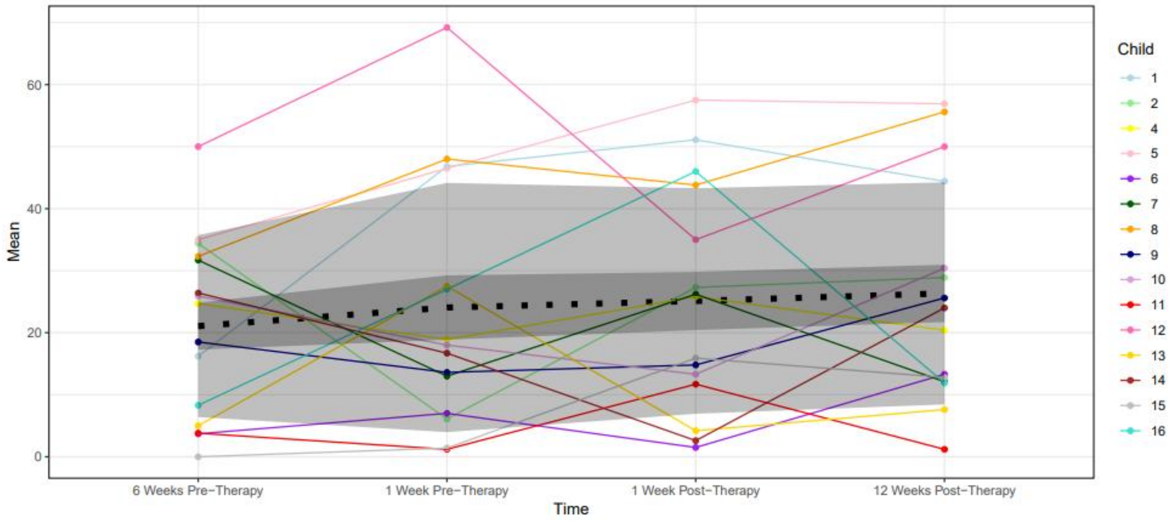

Figure 15 Line graph showing mean intelligibility, group mean, SD and SE across time (Connected Speech Capacity)

5.7. Summary of Connected Speech Percentage Words Correct

Children appeared to fall into three groups based on their CS performance intelligibility- (high intelligibility: P5 and P8; mid intelligibility: P1, P2, P7, P10, P12, and P16; and low intelligibility: P4, P6, P9, P11, P13, P14, and P15). However, the patterns of children in the mid intelligibility group appeared to vary, sometimes aligning with the other groups, indicating significant variation within and across children.

The statistically significant difference between 1 Week Pre- and 12 Weeks Post-Therapy indicates that the intervention had a positive effect on the children's CS performance intelligibility. Some children made clinically significant gains immediately after the intervention whereas others did not make any clinically significant gains until 12 Weeks Post-Therapy, indicating that the intervention had a delayed but medium-term effect on their intelligibility.

No pattern of effect of personalised intervention on intelligibility was evident in the CS capacity condition, with all children behaving differently to each other at each timepoint.

5.8. Summary of Percentage Words Correct

Statistically significant gains in intelligibility were made in the performance condition for both SWs and CS. The most improvement was seen 12 Weeks Post-Therapy, indicating effects of the personalised intervention were not immediate but medium-term. More children made clinically significant gains in SW performance (n = 7) compared to CS performance (n = 3) 12 Weeks Post-Therapy.

Children with higher baseline intelligibility appeared to make greater gains in SW intelligibility post-therapy, with only children in the high intelligibility group making clinically significant gains in both SW performance and capacity (P1, P2, and P8). Some children in the low intelligibility group did make clinically significant gains in SW performance post-therapy (P4, P10, P13, and P14), but did not in SW capacity.

Generally, children's baseline CS performance intelligibility was similar to their SW baseline intelligibility. P10 and P12 demonstrated higher baseline intelligibility in CS performance compared to SWs; thus, they were ranked mid intelligibility alongside P1, P2, P7, and P16 who were ranked high intelligibility for SWs. All other children were consistent in their intelligibility grouping for SW performance and capacity and CS performance (high: P5 and P8; low: P4, P6, P9, P11, P13, P14, and P15). For CS capacity, children's baseline intelligibility could not be categorised due to changes in intelligibility between 6 Weeks Pre- and 1 Week Pre-Therapy demonstrated by many children. Unlike in SWs, where children with higher intelligibility responded better to the intervention, there was no obvious pattern on how a child's baseline CS intelligibility contributed to their response to the intervention. Children from all three intelligibility groups made clinically significant gains 12 Weeks Post-Therapy. P1 and P12 (mid) made clinically significant gains in solely the CS performance condition, P5 (high) in CS capacity, and P15 (low) in both CS performance and capacity 12 Weeks Post-Therapy.

Children with profound speech disorders (i.e., P6 and P11) did not appear to benefit from the personalised intervention in terms of SW or CS intelligibility in either condition.

A summary of who made clinically significant gains in each condition can be seen in Table 20.

Child	Intell Group	SW Performance		SW Capacity		Intell Group	CS Performance		CS Capacity	
		1 Wk Pre vs. 1 Wk Post	*1 Wk Pre vs. 12 Wks Post*	*1 Wk Pre vs. 1 Wk Post*	*1 Wk Pre vs. 12 Wks Post*		*1 Wk Pre vs. 1 Wk Post*	*1 Wk Pre vs. 12 Wks Post*	*1 Wk Pre vs. 1 Wk Post*	*1 Wk Pre vs. 12 Wks Post*
1	High					Mid				
2	High					Mid				
4	Low					Low				
5	High					High				
6	Low					Low				
7	High					Mid				
8	High					High				
9	Low					Low				
10	Low					Mid				
11	Low					Low				
12	Low					Mid				
13	Low					Low				
14	Low					Low				
15	Low					Low				
16	High					Mid				

Note. Cells highlighted green indicate clinically significant changes in intelligibility, considering changes between intelligibility 6 Weeks Pre- and 1 Week Pre-Therapy.

Table 20 Table summarising children who made clinically significant gains in intelligibility

5.9. What Accounted for Change in Intelligibility?

5.9.1. Aim

To examine which predictor variables were associated with changes in intelligibility.

5.9.2. Hypotheses

It was predicted that due to increased intraoral pressure and increased time for accurate placement of articulators there would be increased correct identification of:

a) word initial (WI) singleton consonants;
b) word final (WF) singleton consonants;
c) WI consonant clusters;
d) WF consonant clusters;
e) polysyllabic words;
f) words appearing later in an utterance in connected speech

5.10. Assessing Predictor Significance

Before creating the models, the effects of WI and WF singleton consonants, WI and WF consonant clusters, syllable number and number of words in a phrase on words perceived correctly were examined to assess whether they had a significant effect on intelligibility for both SWs and CS and should be entered into a multivariable model.

The assumption of normality was met at all four timepoints for WI singleton consonants in SWs, but not at all four timepoints for WF singleton consonants in SWs or WI and WF singleton consonants in CS (see Appendix I.6).

5.10.1. Word Initial Consonants – Single Words

A repeated measures ANOVA indicated a significant main effect of timepoint on perceiving a WI consonant in SWs correctly ($F(1, 14) = 29.69$, $p < 0.01$, partial $\eta^2 = 0.58$).

The mean scores (6 Weeks Pre- = 20.97%, 1 Week Pre- = 23.07%, 1 Week Post- = 25.98%, and 12 Weeks Post-Therapy = 32.93%) showed consistent upward trajectory of scores over time, with the largest gains observed 12 Weeks Post-Therapy.

5.10.2. *Word Final Consonants – Single Words*

Results from the Friedman (χ^2 (3) = 9.88, p = 0.02) indicated statistically significant differences in the percentage of WF consonants in SWs perceived correctly across the four timepoints,.

There was an increase in mean ranks and mean scores overtime: 6 Weeks Pre- (rank = 1.93), 1 Week Pre- (rank = 2.30, 1 Week Post- (rank = 2.53), and 12 Weeks Pre-Therapy (rank = 3.23). This suggests improved performance in WF consonant production in SWs post-therapy. However, the increasing variability across time, as shown by the SDs, indicates some children may have made more gains than others.

5.10.3. *Syllable Count – Single Words*

A Chi-Square test revealed that at 1 Week Pre-, 1 Week Post-, and 12 Weeks Post-Therapy, there were statistically significant associations between number of syllables in a word and number of words perceived correctly for SWs. The association between the number of syllables and number of words correctly perceived 6 Weeks Pre-Therapy for SWs was close to statistical significance (see Table 22). At every timepoint, more polysyllabic words were perceived correctly compared to monosyllabic words. There was an increase in both the percentage of monosyllabic and polysyllabic words perceived correctly over time as shown in Figure 16 and Appendix J.1. As a significant effect of syllable count on SW intelligibility was found, it was included as a predictor variable in the SW GLMMs.

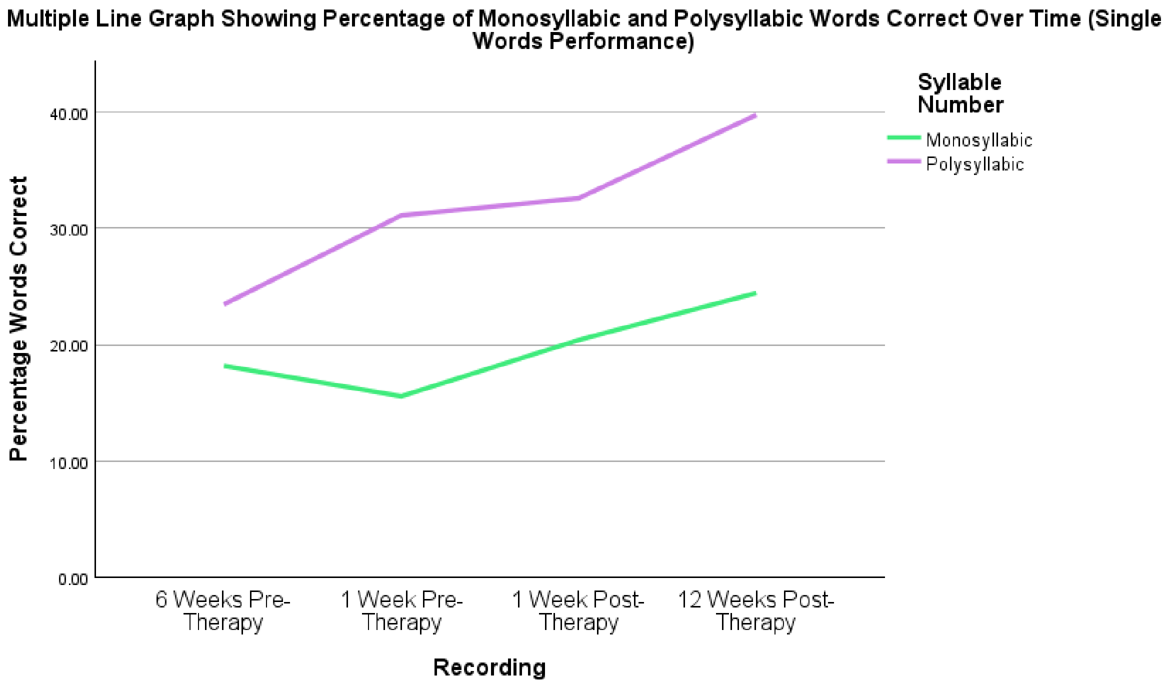

Figure 16 Line graph showing the percentage of monosyllabic and polysyllabic words perceived correctly at each timepoint (Single Words Performance)

5.10.4. Word Initial Consonants – Connected Speech

The Friedman test indicated statistically significant differences in WI consonants in CS perceived correctly across the four timepoints (χ^2 (3) = 15.24, p = 0.002).

There was an overall increase in WI consonants perceived correctly in CS, with the highest mean rank observed 12 Weeks Post-Therapy: 6 Weeks Pre- (rank = 2.07), 1 Week Pre- (rank, 1.67), 1 Week Post- (rank = 3.07), and 12 Weeks Post-Therapy (rank = 3.20). Improvements were sustained up to 12 Weeks Post-Therapy.

5.10.5. Word Final Consonants – Connected Speech

There was a significant difference in the percentage of WF consonants perceived correctly in CS over time (χ^2 (3) = 9.32, p = 0.03).

Perception by listeners improved significantly post-therapy, with substantial rise 1 Week Post-Therapy and sustained gains 12 Weeks Post-Therapy: 6 Weeks Pre- (rank = 2.30), 1 Week Pre- (rank = 1.77), 1 Week Post- (rank = 3.03), and 12 Weeks Post-Therapy (rank = 2.90). Again, the variability indicates some children may have responded better to therapy than others in terms of their production of WF consonants in CS.

As a significant effect of time was found on WI and WF consonants perceived correctly in both SWs and CS, they were included as predictor variables in the GLMMs.

5.10.6. Consonant Clusters – Connected Speech

There were too few observations of WI and WF consonant clusters produced in CS (Table 21), with some children not producing any (see Appendix M). Thus, no analyses were carried out on consonant clusters.

Timepoint	Number of Observations	
	WI Cluster	***WF Cluster***
6 Weeks Pre-Therapy	90	150
1 Week Pre-Therapy	102	165
1 Week Post-Therapy	39	176
12 Weeks Post-Therapy	151	142

Table 21 Number of Observations of Word Initial and Word Final Consonant Clusters at Each Timepoint

5.10.7. Syllable Count – Connected Speech

For CS, the Chi-Square found no statistically significant associations between number of syllables in a word and number of words perceived correctly at 1 Week Pre-, 1 Week Post-, or 12 Weeks Post-Therapy. The association between the number of syllables and number of words correctly perceived 6 Weeks Pre-Therapy for CS was statistically significant. As there was only an effect of syllable number on CS intelligibility 6 Weeks Pre-Therapy, syllable number was excluded as a predictor variable.

Timepoint	Single Words			Connected Speech		
	χ^2	*df*	*p*	χ^2	*df*	*p*
6 Weeks Pre-Therapy	3.80	1	0.051	4.45	1	0.04
1 Week Pre-Therapy	30.86	1	< 0.001	1.36	1	0.24
1 Week Post-Therapy	17.35	1	< 0.001	2.47	1	0.12
12 Weeks Post-Therapy	24.26	1	< 0.001	2.29	1	0.13

Table 22 Chi-Squared Test for Effect of Syllable on Perceiving a Word Correct in Single Words and Connected Speech (Performance)

5.10.8. Number of Words – Connected Speech

A logistic regression showed that number of words in a phrase was a significant predictor of perceiving a word correct 6 Weeks Pre-, 1 Week Pre-, and 12 Weeks Post-Therapy. The odds of perceiving a word correctly increased by 10.30%, 13%, and 6.5% respectively for every additional word in a phrase. At 1 Week Post-Therapy, the number of words in a phrase did not have a significant effect on the outcome (see Table 23). As some children did show improvement in CS intelligibility 12 Weeks Post-Therapy and number of words in a phrase was found to be a significant predictor of perceiving a word correct at this timepoint, it was included as a predictor in the GLMMs. The mean number of words produced in a phrase at each timepoint and the range in number of words produced can be found in Appendix J.2.

Timepoint	B (SE)	df	*p*	Exp(B)	95% CI Lower, Upper
6-Weeks Pre-Therapy	0.10 (0.02)	1	< 0.001	1.10	1.06, 1.15
1 Week Pre-Therapy	0.12 (0.02)	1	< 0.001	1.13	1.09, 1.17
1 Week Post-Therapy	0.04 (0.02)	1	0.15	1.04	0.99, 1.09
12 Weeks Post-Therapy	0.06 (0.03)	1	0.02	1.07	1.01, 1.12

Table 23 Logistic Regression Showing the Effect of Number of Words in a Phrase on Perceiving a Word Correct at Each Timepoint (Connected Speech Performance)

5.11. Predicting Single Word Perception

5.11.1. Words Containing Initial Singleton Consonants

Predictors	*AIC*	*B (SE)*	*p*	*Exp(B) (95% CI)*
6 Weeks Pre	1797.2	0.53 (0.55)	0.34	1.69 (0.58 to 4.93)
1 Week Pre [ref]		0 (0)	.	.
1 Week Post		0.06 (0.54)	0.91	1.06 (0.37 to 3.05)
12 Weeks Post		1.37 (0.52)**	0.009	3.92 (1.40 to 10.94)
WI Singleton Consonant		4.16 (0.20)***	<2e-06	64.10 (43.31 to 94.87)
Syllable Number [ref = mono]		1.08 (0.24)***	8.24e-06	2.93 (1.83 to 4.70)
Syllable*6 Weeks Pre		-0.21 (0.36)	0.55	0.81 (0.40 to 1.63)
Syllable*1 Week Post		0.25 (0.35)	0.47	1.29 (0.65 to 2.54)
Syllable*12 Weeks Post		-0.57 (0.33)	0.08	0.57 (0.30 to 1.08)

Note. [ref] = reference level;
*. = marginally significant (p-value < 0.1); * = significant (p-value < 0.05); ** = very significant (p-value < 0.01); *** = highly significant (p-value < 0.001)*

Table 24 Results from Optimum GLMM Investigating the Effect of Word Initial Singleton Consonant on the Outcome of Word Perceived Correctly (Single Words Performance)

For words with an initial singleton consonant the optimum regression model, which explained 62.3% of the variance in scores, contained the predictors of timepoint, word initial (WI) singleton consonant, syllable number, and the interaction between syllable number and timepoint. Findings from all models can be found in Appendix K.1. The optimum model revealed that the variables 12 Weeks Post-Therapy, WI singleton consonant, and syllable number had significant effects on the outcome of word perceived correctly. Table 24 shows higher odds of perceiving a word correct 12 Weeks Post-Therapy compared to the reference timepoint (1 Week Pre-Therapy). This corresponds to the findings from the full SW dataset and repeated measures ANOVA assessing the effect of perceiving a WI consonant correctly over time. The odds of perceiving a word correct were greater if the WI consonant was perceived correctly and if the word was polysyllabic.

The large positive estimate and odds ratio for the effect of WI consonant on the outcome was expected, as a word could only be perceived correctly if the WI consonant was correct. Therefore, this was not a finding of interest. The interaction between WI singleton consonant and timepoint needed to be addressed to see whether more WI consonants were perceived correctly post-therapy compared to pre-therapy. Adding this interaction to the model resulted in an error ("isSingular"), as the variance of the random effect timepoint:child was estimated as zero, due to the model being too complex relative to the data available. Therefore, it cannot be determined whether WI consonant production contributed to changes in overall SW intelligibility.

Although the interaction effect between syllable number and timepoint was not significant, the bar graphs in Figure 17 and Figure 18 suggest that the perception of WI singleton consonants improved in polysyllabic words 12 Weeks Post-Therapy but did not in monosyllabic words, as shown by the height of the 'word incorrect WI incorrect' bars. This corresponds with the findings from the full SW dataset, that polysyllabic words were more easily perceived and that the biggest improvement in SW intelligibility was found 12 Weeks Post- Therapy. It must be noted that fewer polysyllabic words (n = 315) were produced at each timepoint compared to monosyllabic words (n = 405) and therefore increases in percentage correct may have been magnified.

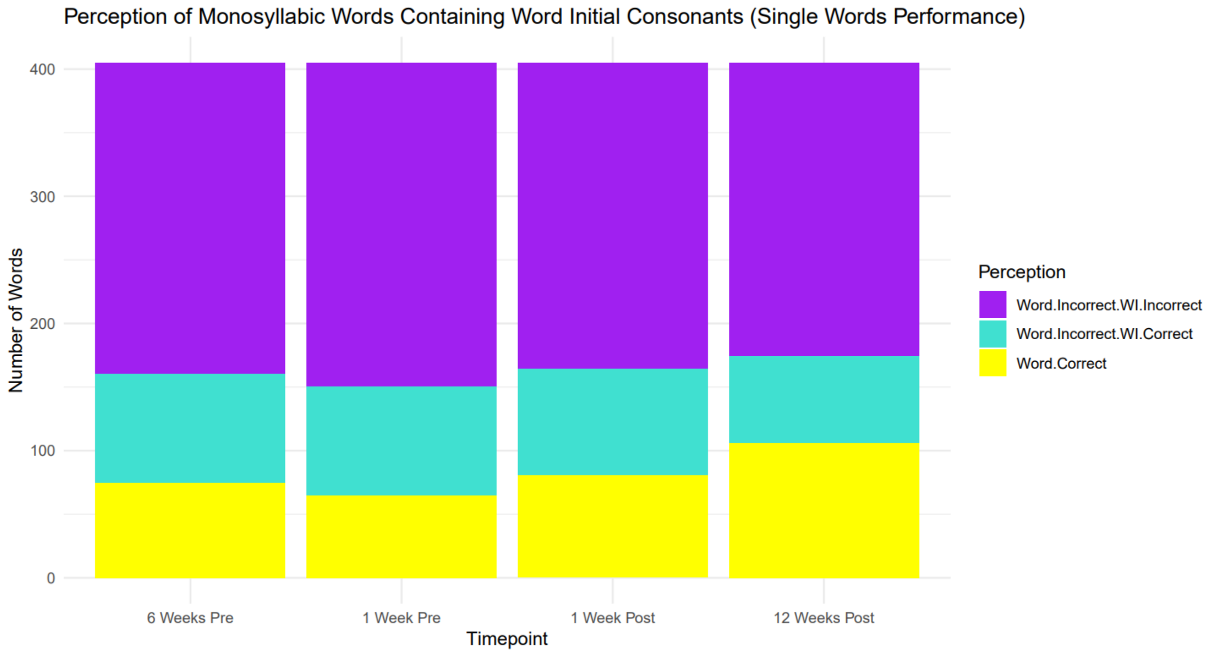

Figure 17 Stacked Bar Chart showing the Perception of Monosyllabic Words Containing Word Initial Singleton Consonants (Single Words Performance)

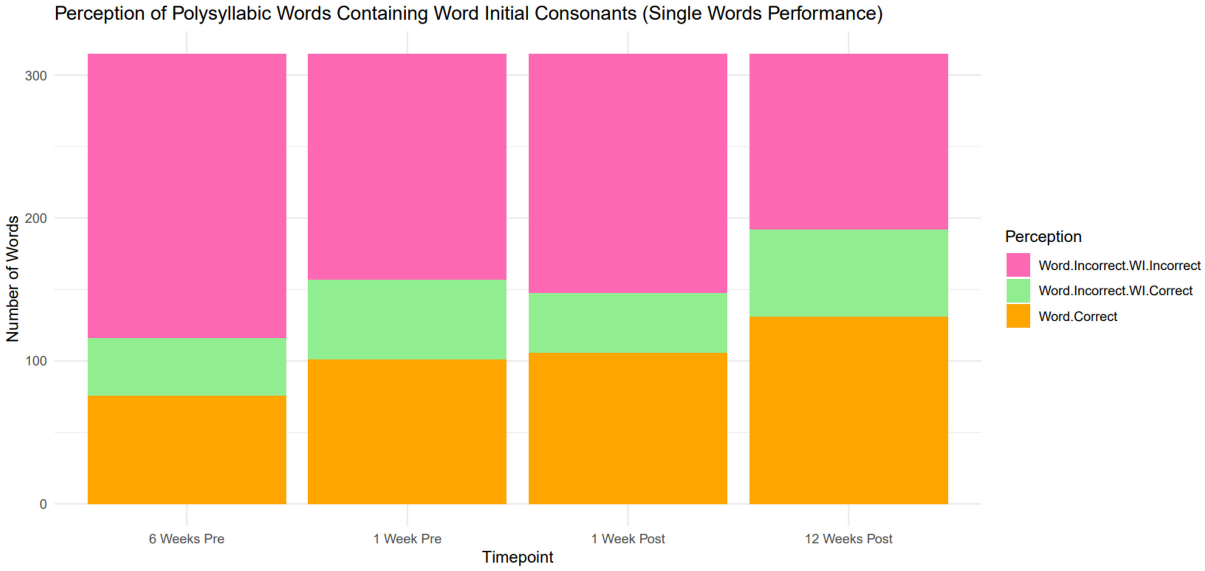

Figure 18 Stacked Bar Chart showing the Perception of Polysyllabic Words Containing Word Initial Singleton Consonants (Single Words Performance)

5.11.1.2. Exploring Individual Differences in Responses to Therapy

Child	Mean % Intell 6 Weeks Pre	Mean % Intell 1 Week Pre	Mean % Intell 1 Week Post	Mean % Intell 12 Weeks Post	Mean % Change 1 Week Post vs 1 Week Pre	Mean % Change 12 Weeks Post vs 1 Week Pre
1	37.50	47.90	66.70	70.80	18.80	22.90
2	37.50	31.30	47.90	60.40	16.60	29.10
4	20.80	16.70	29.20	27.10	12.50	10.40
5	52.10	39.60	50.00	50.00	10.40	10.40
6	2.10	4.20	2.10	6.30	-2.10	2.10
7	25.00	29.20	33.30	41.70	4.20	12.60
8	50.00	47.90	58.30	75.00	10.40	27.10
9	20.80	16.70	14.60	20.80	-2.10	4.10
10	10.40	12.50	16.70	18.80	4.20	6.30
11	2.10	6.30	0.00	6.30	-6.30	0.00
12	25.00	25.00	14.60	27.10	-10.40	2.10
13	8.30	10.40	6.30	20.80	-4.10	10.40
14	0.00	14.60	10.40	31.30	-4.20	16.70
15	4.20	8.30	10.40	4.20	2.10	-4.10
16	18.80	35.40	29.20	33.30	-6.20	-2.10
Group Mean	20.97	23.07	25.98	32.93		

Note. Green highlight shows clinically significant gains in intelligibility for WI singleton consonants.

Table 25 Mean Change in Percentage Intelligibility of Single Words (Performance) Containing Word Initial Singleton Consonants for Each Child

P1 and P2 made clinically significant gains in overall SW mean intelligibility as well as the intelligibility of words containing WI singleton consonants 1 Week Post-Therapy. Although an increase in intelligibility over 10% was observed in P4, P5, and

P8 from 1 Week Pre- to 1 Week Post-Therapy, their 1 Week Post-Therapy intelligibility was not at least 10% higher than their baseline intelligibility, thus it cannot be said that they made clinically significant gains in the intelligibility of SWs containing WI singleton consonants. At 12 Weeks Post-Therapy, P1, P2, P7, P8, P13, and P14 made clinically significant gains in the intelligibility of SWs containing WI singleton consonants. Those six children also made overall clinically significant gains in mean intelligibility. Despite P4 making clinically significant gains in overall SW intelligibility 12 Weeks Post-Therapy, his intelligibility of WI singleton consonants did not clinically improve. Increases in words containing WI singleton consonants generally followed the pattern found in the full SW data set, with the greatest improvement being seen 12 Weeks Post-Therapy.

To summarise, there was an overall increase in the number of WI consonants and polysyllabic words perceived correctly over time. The effects were not immediate but medium-term. However, no interaction effects were detected, and effects were not homogenous; thus, it cannot be concluded that WI consonants accounted for the change in overall SW intelligibility. There was greater variation between children (Variance = 0.77; SD = 0.88) in their likelihood of listeners perceiving a word containing a WI consonant correct compared to within children across timepoints (Variance = 0.01; SD = 0.09), with some children making gains and others not (Table 25).

5.11.2. *Word Final Singleton Consonants*

Predictors	*AIC*	*B (SE)*	*p*	*Exp(B) (95% CI)*
6 Weeks Pre	839.90	-0.50 (0.62)	0.43	0.61 (0.18 to 2.07)
1 Week Pre [ref]		0 (0)	.	.
1 Week Post		-0.20 (0.62)	0.75	0.82 (0.24 to 2.78)
12 Weeks Post		-16.27 (0.61)	0.61	8.60e-8 (1.45e-34 to 5.09e+19)
WF Singleton Consonant		3.71(0.46)***	1.45E-15	40.77 (16.40 to 101.36)
Syllable Number [ref = mono]		1.30 (0.19)***	1.36E-11	3.67 (2.52 to 5.35)
WF*6 Weeks Pre		0.19 (0.68)	0.78	1.21(0.32 to 4.60)
WF*1 Week Post		0.10 (0.67)	0.88	1.10 (0.30 to 4.13)
WF*12 Weeks Post		17.19 (31.45)	0.59	2.93e+07 (4.95e-20 to 1.74e+34)

Table 26 Table showing results from optimum GLMM for the effect of word final singleton consonant on the outcome of word perceived correctly (Single Words Performance)

The optimum model for intelligibility of words containing a WF consonant contained the predictors of timepoint, WF singleton consonant, syllable number, and the interaction between WF consonant and timepoint. It explained 93.5% of the variance in scores. Findings indicate that WF singleton consonant and syllable number had significant effects on the outcome (Table 26). The odds of perceiving a word correct were much higher if the WF consonant was correct and if the word was polysyllabic. Unlike with the WI singleton consonant dataset and full SW dataset, no timepoint had a significant effect on perceiving a word correct compared to 1 Week Pre-Therapy.

The significance of WF consonant on the outcome was not of interest as it was already known that WF had to be correct for the word to be perceived correctly. When the interaction between WF consonant and time was added as a variable to the model, no significant effect was found at any timepoint, suggesting that WF consonant production did not drive the change in overall SW intelligibility, despite a continuous increase in the percentage of WF consonants perceived correctly over time (see Section 5.10.2).

There was slight variation in the number of words containing WF singleton consonants across the two SW lists. Considerably more words were monosyllabic (6 Weeks Pre: n = 315, 1 Week Pre: n = 360, 1 Week Post: n = 318, and 12 Weeks Post-Therapy: n = 360) than polysyllabic (6 Weeks Pre: n = 180, 1 Week Pre: n =

135, 1 Week Post: n =177, and 12 Weeks Post-Therapy: n = 135). Although there was a significant effect of syllable on the outcome, the interaction effect between syllable number and timepoint was not significant (see Appendix K.2 for all models). This is likely due to not enough observations at each timepoint. Therefore, no further analysis on the effect of syllable number on correctly perceiving words containing WF consonants was made.

5.11.2.1. Exploring Individual Differences in Responses to Therapy

Child	Mean % Intell 6 Weeks Pre	Mean % Intell 1 Week Pre	Mean % Intell 1 Week Post	Mean % Intell 12 Weeks Post	Mean % Change 1 Week Post vs 1 Week Pre	Mean % Change 12 Weeks Post vs 1 Week Pre
1	21.20	63.60	63.60	69.70	0.00	6.10
2	30.30	18.20	30.30	51.50	12.10	33.30
4	3.00	15.20	12.10	12.10	-3.10	-3.10
5	33.30	33.30	30.30	51.50	-3.00	18.20
6	0.00	0.00	0.00	3.00	0.00	3.00
7	12.10	3.00	21.20	21.20	18.20	18.20
8	51.50	42.40	42.40	60.60	0.00	18.20
9	9.10	6.10	15.20	9.10	9.10	3.00
10	3.00	3.00	9.10	6.10	6.10	3.10
11	0.00	0.00	0.00	0.00	0.00	0.00
12	9.10	15.20	0.00	12.10	-15.20	-3.10
13	6.10	3.00	6.10	6.10	3.10	3.10
14	0.00	9.10	3.00	27.30	-6.10	18.20
15	0.00	3.00	6.10	0.00	3.10	-3.00
16	12.10	33.30	24.20	30.30	-9.10	-3.00
Group Mean	12.72	16.56	17.57	24.04		

Table 27 Mean Change in Intelligibility of Single Words (Performance) Containing Word Final Consonants for Each Child

No children made clinically significant gains 1 Week Post-Therapy and three children made clinically significant gains 12 Weeks Post-Therapy in the intelligibility of SWs containing WF consonants (Table 27). Again, this corresponds to the results of overall percentage words perceived correctly, with the greatest improvement made 12 Weeks Post-Therapy. P2 and P7 appeared to make clinically significant gains in WF singleton consonant production from 1 Week Pre- to 1 Week Post-Therapy, and P7 and P8 appeared to make clinically significant gains WF singleton consonant production from 1 Week Pre- to 12 Weeks Post-Therapy. However, the dip from 6 Weeks Pre- to 1 Week Pre-Therapy means clinically significant gains were not reached, despite all three of these children making clinically significant gains in overall SW intelligibility.

In summary, despite the percentage of WF consonants perceived correctly increasing over time, no significant interaction effect between WF consonant and timepoint suggests WF consonants did not account for change in SW intelligibility post-therapy. Polysyllabic words with WF consonants were easier to perceive than their counterpart monosyllabic words, however no significant effect was found between syllable and timepoint. There was greater variation between children (Variance = 1.15; SD = 1.07) in their likelihood of perceiving a word containing a WF consonant correct compared to within children across timepoints (Variance = 0.04; SD = 0.19), with some children making gains (Table 27) and others not.

5.12. Connected Speech

5.12.1. Word Initial Singleton Consonants

Predictors	*AIC*	*B (SE)*	*p*	*Exp(B) (95% CI)*
6 Weeks Pre-Therapy	1260.2	0.13 (0.31)	0.68	1.13 (0.62 to 2.07)
1 Week Pre-Therapy [ref]		0 (0)	.	.
1 Week Post-Therapy		0.42 (0.32)	0.18	1.53 (0.82 to 2.85)
12 Weeks Post-Therapy		0.40 (0.31)	0.20	1.49 (0.81 to 2.74)
WI Singleton Consonant		6.45 (0.31)***	<2e-16	633.49 (347.65 to 1154.43)

Table 28 Table showing results from optimum GLMM for the effect of word initial singleton consonant on the outcome of word perceived correctly (Connected Speech Performance)

The optimum model explained 76.0% of the variance in scores and contained the variables of timepoint and WI singleton consonant. This model's findings revealed that only WI consonant had a significant effect on the outcome (Table 28). The likelihood of perceiving a word correct when WI consonant was correct was much greater than if WI consonant was incorrect. As words cannot be perceived correctly if WI is incorrect, this was expected and therefore was not a finding of interest. No timepoint had a significant effect on the outcome and alternative models (see Appendix L.1) showed no significant difference in the interaction between WI consonant and timepoint at any timepoint. This corresponds with results from the full CS dataset, where no significant change in intelligibility as a group was found over time.

5.12.1.1. Exploring Individual Differences in Responses to Therapy

Child	Mean % Intell 6 Weeks Pre	Mean % Intell 1 Week Pre	Mean % Intell 1 Week Post	Mean % Intell 12 Weeks Post	Mean % Change 1 Week Post vs 1 Week Pre	Mean % Change 12 Weeks Post vs 1 Week Pre
1	24.60	31.90	46.80	61.90	14.90	30.00
2	40.30	45.80	47.90	49.40	2.10	3.60
4	20.00	11.50	16.70	24.40	5.20	12.90
5	35.70	57.70	63.90	58.80	6.20	1.10
6	13.30	0.00	3.70	13.90	3.70	13.90
7	35.40	12.00	24.60	0.00	12.60	-12.00
8	42.20	52.20	68.30	54.20	16.10	2.00
9	14.00	0.00	27.10	15.00	27.10	15.00
10	52.40	12.80	18.30	35.20	5.50	22.40
11	2.60	0.00	3.00	1.40	3.00	1.40
12	33.30	19.00	35.70	62.50	16.70	43.50
13	12.50	12.10	10.50	23.10	-1.60	11.00
14	4.20	15.70	10.50	22.20	-5.20	6.50
15	2.40	9.50	10.00	36.70	0.50	27.20
16	33.30	24.10	50.00	38.30	25.90	14.20
Group Mean	24.41	20.29	29.13	33.13		

Table 29 Mean Change in Percentage Intelligibility of Words Containing Word Initial Singleton Consonants for Each Child in Connected Speech (Performance)

Although no significant difference in the intelligibility of words containing WI consonants in CS was found for the group over time, some children did make clinically significant gains post-therapy (Table 29), which is in line with findings from the full CS dataset. P1 made clinically significant gains in both the mean intelligibility of CS overall and in the intelligibility of words containing WI consonants 1 Week Post-Therapy. P8, P9, and P16 did not make clinically significant gains in overall mean CS intelligibility 1 Week Post-Therapy but did in the intelligibility of words containing WI singleton consonants. All children who made clinically significant gains in overall mean CS intelligibility at 12 Weeks Post-Therapy (P1, P12, and P15), made clinically significant gains in the intelligibility of words in CS containing WI singleton consonants. P13 only made clinically significant gains in the intelligibility of words in CS which contained a WI consonant 12 Weeks Post-Therapy, and not gains overall.

To sum up, the optimum model (AIC = 1260.2) suggests that there was no significant interaction effect between WI correct and time for the group, although some children did make clinically significant gains in the intelligibility of words containing a WI singleton consonant post-therapy. The optimum model showed that there was slightly greater variation between children (Variance = 0.43; SD = 0.66) in their likelihood of perceiving a word correct compared to within children across timepoints (Variance = 0.29; SD = 0.54), which is in line with findings from the SW data.

5.12.2. Word Final Singleton Consonants

Predictors	*AIC*	*B (SE)*	*p*	*Exp(B) (95% CI)*
6 Weeks Pre-Therapy	938	0.39 (0.38)	0.31	1.47 (0.70 to 3.12)
1 Week Pre-Therapy [ref]		0 (0)	.	.
1 Week Post-Therapy		0.99 (0.39)*	0.01	2.70 (1.26 to 5.76)
12 Weeks Post-Therapy		0.59 (0.39)	0.13	1.81 (0.84 to 3.87)
WF Singleton Consonant		6.11 (0.26)***	<2e-16	448.25 (268.11 to 749.43)

Table 30 Table showing results from optimum GLMM for the effect of word final singleton consonant on the outcome of word perceived correctly (Single Words Performance)

The optimum model contained the predictor variables of timepoint and WF singleton consonant and explained 73.8% of the variance in scores. Results from this model showed that 1 Week Post-Therapy and WF singleton consonant had significant effects on the outcome. The odds of perceiving a word correct were greater if they were heard 1 Week Post-Therapy compared to 1 Week Pre-Therapy, which corresponds with results from the Friedman test (see Section 5.10.4), and if the WF consonant was perceived correctly (see Table 30). However, even though more words containing WF consonants were perceived correctly over time (see Table 29), fewer were produced at both post-therapy timepoints compared to 1 Week Pre-Therapy which may have magnified gains in intelligibility. Alternative models (see Appendix L.2) revealed no significant difference in the interaction between WF consonant and timepoint at any timepoint, indicating that WF consonant did not contribute to changes in CS intelligibility over time.

5.12.2.1. Exploring Individual Differences in Responses to Therapy

Child	Mean % Intell 6 Weeks Pre	Mean % Intell 1 Week Pre	Mean % Intell 1 Week Post	Mean % Intell 12 Weeks Post	Mean % Change 1 Week Post vs 1 Week Pre	Mean % Change 12 Weeks Post vs 1 Week Pre
1	30.30	33.30	37.90	71.80	4.6	38.5
2	37.30	43.30	44.40	44.40	1.1	1.1
4	22.20	7.40	26.20	21.20	18.8	13.8
5	31.40	57.80	83.30	50.00	25.5	-7.8
6	14.30	4.20	5.60	11.10	1.4	6.9
7	33.30	16.70	25.00	13.30	8.3	-3.4
8	34.70	42.70	70.60	44.40	27.9	1.7
9	15.80	0.00	27.30	15.60	27.3	15.6
10	37.80	13.30	17.80	31.30	4.5	18.0
11	4.20	0.00	8.30	5.90	8.3	5.9
12	27.50	21.20	22.20	55.60	1.0	34.4
13	19.00	25.00	7.70	12.80	-17.3	-12.2
14	0.00	18.30	11.90	29.20	-6.4	10.9
15	0.00	0.00	13.90	16.70	13.9	16.7
16	33.30	28.90	51.50	40.70	22.6	11.8
Group Mean	22.74	20.81	30.24	30.93		

Table 31 Mean Change in Percentage Intelligibility of Words Containing Word Final Singleton Consonants for Each Child in Connected Speech (Performance)

P5, P8, P9, P15, and P16 did not make clinically significant gains in *overall* CS intelligibility 1 Week Post-Therapy but did in the intelligibility of words containing WF singleton consonants, whereas P1 only made gains in *overall* CS intelligibility. At 12 Weeks Post-Therapy, P1, P12, P14, and P15 made clinically significant gains in the intelligibility of words in CS containing WF singleton consonants (see Table 31). P1, P12, and P15 also made *overall* clinically significant gains in mean CS intelligibility 12 Weeks Post-Therapy. Due to the decline in intelligibility for P4, P9, P10, and P16 from 6 Weeks Pre- to 1 Week Pre-Therapy, their gains at 12 Weeks Post-Therapy cannot be classified as clinically significant. Improvements were greater in intelligibility of WF consonants in CS than in *overall* mean CS intelligibility 1 Week and 12 Weeks Post-Therapy. Increases in words in CS containing WF consonant clusters did not follow the pattern found in the full CS data set.

To summarise, the optimum model for investigating correct perception of words containing WF singleton consonants in CS indicate that the main predictors of intelligibility were perceiving the word 1 Week Post-Therapy and perceiving WF consonant correct. The interaction effect of WF consonant with time was not significant. Findings indicate that the intervention had a positive and immediate effect on children's CS intelligibility, although effects were not maintained. Unlike with words containing WI singleton consonants in CS, variance associated with random effect of child (Variance = 0.34; SD = 0.59) was lower than the variance within child across time (Variance = 0.49; SD = 0.70) in terms of intelligibility of words containing WF singleton consonants in CS.

5.13. Summary of Predictors of Intelligibility

For SWs, the personalised intervention had a delayed but medium-term effect, with statistically significant improvements found 12 Weeks Post-Therapy. However, some children did make clinically significant gains immediately following the therapy and some children made no gains at either post-therapy timepoint. For CS, no statistically significant gains in intelligibility were found at either post-therapy timepoint. However, some children did make clinically significant gains from 1 Week Pre-Therapy to 1 Week Post- and 12 Weeks Post-Therapy.

For SWs, syllable number had a significant effect on perceiving words with WI and WF consonants correctly, with more polysyllabic words perceived correctly at each timepoint compared to monosyllabic words. However, as there was no significant interaction effect between syllable number and timepoint, it is unlikely that syllable number accounted for change in intelligibility post-therapy

The identification of WI and WF consonants improved over time for both SWs and CS, however no interaction effect between WI or WF with time was found in either condition, indicating that WI and WF consonants were not the driving force of change in intelligibility post-therapy. Perceiving a WI consonant correctly in SWs was more likely if it was perceived 12 Weeks Post-Therapy, which is in line with findings from the overall SW dataset. Perceiving a WF consonant correctly in CS was more likely if it was perceived 1 Week Post-Therapy, despite significant group gains occurring 12 Weeks Post-Therapy. The percentage of words containing WF consonants in SWs and words containing WI consonants in CS perceived correctly did not differ significantly over time, although some children did make clinically significant gains post-therapy.

The summary table below (Table 32) seems to indicate that children with lower baseline intelligibility made slightly more clinically significant gains in the predictor variables associated with CS compared to SWs. These improvements did not always correspond to clinically significant gains in overall CS intelligibility. For SWs, most children who demonstrated clinically significant gains in predictor variables made clinically significant gains in overall SW intelligibility.

There is no obvious relationship between children's cognition and receptive language and intelligibility. P8 and P14, who were reported by their parents/school as having no learning disability (LD) and working in line with their peers, both made clinically significant gains in their SW intelligibility but not in CS 12 Weeks Post-Therapy. P14 did make clinically significant gains in some CS predictor variables. Some children who had LDs and delayed receptive language made clinically significant gains in either SWs (P2, P4, and P7) or CS (P15). P1, P12, and P13, who were not reported as having a LD, but were working below age expectancy in school, also demonstrated clinically significant gains. P1 demonstrated clinically significant gains in both SWs and CS, P12 made clinically significant gains in CS, and P13 made clinically significant gains in SWs. P16, who also was reported as having no LD, but academically behind peers at school, made no clinically significant gains in intelligibility. The two children who had GDD (P9 and P11), and P6 who was the least intelligible and had a LD, made no improvements in intelligibility post-therapy. More severe LDs may contribute to less improvement following therapy. However, P6 and P9 did make improvements in some predictor variables in SWs and CS. There is no clear relationship between CP type (see Table 10) and intelligibility, given the small number of children in the sample, with children with both dyskinetic and spastic CP making clinically significant gains in overall intelligibility and in predictor variables.

Single Words										Connected Speech						
Child	Intell Group	Cog	Recept Lang	% Intell 1 Week Pre	% Intell 12 Weeks Post	WI	WF	Mono	Poly	Intell Group	% Intell 1 Week Pre	% Intell 12 Weeks Post	WI	WF	Mono	Poly
P8	High	Age approp.	Age approp.	50.00	70.00					High	47.92	48.28				
P5	High	LD ASD	Age approp.	43.33	56.67					High	59.72	53.15				
P1	High	Below av.	Delayed	51.67	70.00					Mid	31.48	65.00				
P16	High	Below av.	Delayed	38.33	31.67					Mid	39.68	33.33				
P2	High	Mod LD	Age approp.	30.00	55.00					Mid	42.03	48.33				
P7	High	Mod LD ADHD	Delayed	23.33	33.33					Mid	17.14	18.75				
P10	Low	LD	Delayed	10.00	15.00					Mid	15.87	30.00				
P12	Low	Below av.	Delayed	20.00	21.67					Mid	15.87	30.00				
P4	Low	Mod LD	Delayed	16.67	30.00					Low	14.29	20.00				
P9	Low	GDD	Delayed	15.00	25.00					Low	0.00	13.10				
P14	Low	Age approp.	Age approp.	15.00	28.33					Low	15.38	24.64				
P13	Low	Below av.	Delayed	10.00	20.00					Low	14.58	15.00				
P15	Low	LD	Delayed	6.67	3.33					Low	10.26	22.92				
P11	Low	GDD	Delayed	5.00	5.00					Low	0.00	4.30				
P6	Low	LD	Delayed	3.33	5.00					Low	2.08	9.26				

Note. Cells highlighted dark green indicate clinically significant gains in SWs and CS from full dataset. Cells highlighted light green indicate clinically significant gains in predictor variables.
Cog = Cognition; Recept Lang. = Receptive Language; Age approp. = Age appropriate; Below av. = below average

Table 32 Summary Table Showing Information on Children's Cognition and Receptive Language as well as Clinically Significant Gains in Overall Single Word and Connected Speech Intelligibility and Predictor Variables for Each Child 1 Week Pre-Therapy vs. 12 Weeks Post-Therapy

Chapter 6. Acoustic Results

6.1. Aim

To investigate whether personalised dysarthria therapy led to changes in the acoustic properties of phonemes, and whether these changes may have been associated with more target-like production.

6.2. Participants Individual Speech Characteristics

Child	Intell Group	Baseline Speech Characteristics	Therapeutic Goal	Vocal Cues	Expected Changes	Acoustic Findings
1	High	• Quiet and weak voice • Weak consonants • WF consonant deletion • Voicing errors • Fluctuating speech rate across phrases • Imprecise articulation	• Increase loudness • Maintain strong voice to end of utterances • Produce WF consonants • Maintain a steady speech rate across an utterance	• Strong (initially 'loud') • Strong to the end • Steady • Strong /s/ • Big mouth	• More frequent production of WF consonants (evidence on spectrogram/waveform) • Stronger WF consonants	• Improved phoneme accuracy • Reduced voicing errors
2	High	• Breathy, weak speech • Quiet voice • Loudness decay across a phrase • Weak consonants- fricatives & WFs • Prolonged vowels • Very quick speech rate • Imprecise articulation	• Increase loudness/stronger fricatives • Reduce speech rate • More precise articulation – clearer word boundaries • More accurate phoneme production	• Big mouth • Loud /s/ & /z/ • Steady • Loud /f/ & /v/	• Increased evidence of fricatives and WF consonants (on spectrogram/waveform) • Increased production accuracy	• Stronger WF production
5	High	• Excess loudness variation • WF consonant deletion • Weak bilabials, /f/ & /v/ • Hypernasality • Wet voice • Frequent breaths • Very fast rate • Imprecise articulation	• Produce WF consonants • Produce stronger bilabials and fricatives • Reduce speech rate • More precise articulation – clearer word boundaries	• Big mouth • Strong /f/ & /v/ • Strong to the end • Steady • Strong /p/, /b/, & /m/	• More evidence of WF consonants, bilabials, /f/ and /v/ • Stronger WF consonants, bilabials, /f/ and /v/	• More accurate phoneme production
7	High	• Loudness decay across longer utterances • Voicing errors • WF consonant deletion • Cluster reduction • Vowel errors	• Maintain a strong signal across an utterance • Reduce speech rate • Produce all syllables • Produce all WF consonants	• Big mouth • Steady • Strong to the end • Strong /s/ & /z/ • Strong clusters	• Stronger WF consonants and clusters • More evidence of WF consonants and clusters • More precise articulation	• More accurate phoneme production

Child	Intell Group	Baseline Speech Characteristics	Therapeutic Goal	Vocal Cues	Expected Changes	Acoustic Findings
		• Weak consonants- /s/, /z/ and WFs • Syllable omission • Very quick speech rate • Imprecise articulation	• Produce all phonemes in a cluster • Improved vowel accuracy			
8	High	• Breathy and weak • Loudness decay across longer utterances • Weak consonant production (/s/ and /l/) • Weak clusters • Wet and hoarse quality • Imprecise articulation • Vowel errors • Voicing errors • Fluctuating speech rate	• Maintain a strong signal across an utterance • Stronger consonant production • Use a steadier speech rate	• Nice and easy • Strong to the end • Steady • Strong clusters • Strong /s/ & /l/	• Stronger consonant and clusters production • More evidence of WF consonants and clusters • More precise articulation	• Less accurate phoneme production
16	High	• Breathy • Strained quality • Weak phoneme production • Cluster reduction • Voicing errors • Hypernasality • Imprecise articulation • Fluctuating speech rate across longer utterances	• Maintain a strong signal across an utterance • Stronger consonant production • Use a steadier speech rate	• Strong • Strong /s/ & /ʃ/ • Steady • Strong /p/ & /b/ • Strong /ʤ/	• More evidence of consonant production • Stronger consonants	• No change in production accuracy
4	Low	• Stammer • Harsh onsets • Excessive loudness variation • Harsh onsets • Loudness decay across longer utterances	• Reduce loudness and harsh onsets • Maintain a strong signal across an utterance • Produce WF consonants and consonant clusters	• Big mouth • Strong to the end • Nice and easy • Steady • Soft (instead of Nice and easy)	• Stronger consonant and clusters production • More evidence of WF consonants and clusters • More precise articulation	• More accurate phoneme production

Child	Intell Group	Baseline Speech Characteristics	Therapeutic Goal	Vocal Cues	Expected Changes	Acoustic Findings
		• Hesitations • Hoarse and creaky • WF consonant deletion • Cluster reduction • Vowel errors • Imprecise articulation • Fluctuating speech rate	• Reduce rushing across utterances • More precise articulation			
6	Low	• Excessive loudness variation • Breathy • Hoarse and creaky • Weak consonant production • Imprecise articulation • WF consonant deletion • Cluster reduction • Very fast speech rate	• Reduce loudness and harsh onsets • Reduce hoarseness and creakiness • Maintain a strong signal across an utterance • Produce WF consonants • Reduce speech rate	• Strong to the end • Nice and easy • Steady	• More evidence of WF consonants • More precise articulation	• Increased WF consonant production • Articulation errors
9	Low	• Loudness decay in longer utterances • Fast speech rate • Syllable omission • Imprecise articulation • Cluster reduction • Weak WF consonants/WF consonant deletion • WM consonant deletion	• Produce all consonants • Stronger consonant production • Improved production accuracy • Reduce speech rate	• Strong • Steady • Strong /p/, /b/, /f/, & /v/ • Slow on long words	• Evidence of all consonants • Stronger consonant production • More precise articulation	• Improved consonant cluster accuracy • Articulation errors
10	Low	• Quiet, weak, and breathy speech • Hoarse and creaky • Wet voice • Imprecise articulation • WF and WF consonant deletion	• Increase loudness • Produce all consonants (especially WF consonants and clusters) • Improve production accuracy • Reduce speech rate	• Strong • Steady • Loud (instead of Strong) • Slow (instead of Slow)	• Evidence of all consonants • Strong WF consonants	• Some improvement in phoneme production accuracy • Creaky voice

Child	Intell Group	Baseline Speech Characteristics	Therapeutic Goal	Vocal Cues	Expected Changes	Acoustic Findings
		• Cluster reduction • Very fast rate		• Strong to the end • Strong /s/ • Strong clusters		
11	Low	• Quiet speech • Breathy • Imprecise articulation • No plosives • Omitting fricatives • WF consonant deletion • Very fast speech rate in longer utterances	• Increase loudness • Reduce speeding up across longer utterances • Produce WF consonants • Produce fricatives in all word positions	• Strong • Strong /f/ & /v/ • Steady • Strong /s/	• Evidence of WF consonants • Evidence of fricatives	• No change in consonant accuracy
12	Low	• Quiet speech • Breathy voice • Wet voice • Imprecise articulation • Weak articulation • WF consonant deletion • Cluster reduction • Increased rate across polysyllabic words • Fluctuating rate in longer utterances	• Increase loudness • Maintain a strong signal across an utterance • Produce WF consonants • Produce stronger fricatives • Reduce speech rate	• Strong • Steady • Strong to the end • Strong /s/ • Strong /f/ • Strong /v/	• Evidence of WF consonants • Evidence of fricatives	• Evidence of WF consonant production • No fricatives produced
13	Low	• Quiet speech • Breathy • Imprecise articulation • Cluster reduction • Consonant deletion • Weak consonants (particularly /s/) • Fluctuating speech rate	• Increase loudness • Produce stronger consonants • More precise articulation • Reduce speech rate	• Strong • Steady • Strong /s/ • Strong clusters	• Evidence of consonants • Stronger consonant production	• No change in production accuracy
14	Low	• Very quiet • Breathy and wet voice • Weak consonants	• Increase loudness • Produce stronger consonants	• Loud • Slow	• Evidence of all consonants • Stronger consonant production	• Some improvement in phoneme production accuracy

Child	Intell Group	Baseline Speech Characteristics	Therapeutic Goal	Vocal Cues	Expected Changes	Acoustic Findings
		• Hyponasality • Cluster reduction • Fast and fluctuating speech rate	• Reduce speech rate	• Strong /s/, /p/, /b/, & /m/ • Big mouth		
15	Low	• Very quiet • Breathy • Weak consonants Imprecise articulation • Fluctuating speech rate	• Increase loudness • Produce stronger consonants • More precise articulation • Reduce speech rate	• Loud • Steady • Steady on long words • Big mouth • Loud & steady to the end	• Evidence of all consonants • Stronger consonant production • More precise articulation •	• Some improvement in phoneme production accuracy

Note. Cells highlighted dark green represent children who made clinically significant gains in SW performance intelligibility from 1 Week Pre- to 12 Weeks Post-Therapy.

Table 33 Table Showing Each Child's Therapy Goals, Vocal Cues, and Expected Changes and Acoustic Findings from Five Single Words 12 Weeks Post-Therapy in Relation to their Individual Speech Characteristics

6.3. Strengths of Children's Speech

While therapy primarily targeted the deficits in children's speech, the children demonstrated strengths within their speech production that supported their communication. The pre-therapy transcriptions (see Table 34) show that most children produced accurate nasals and approximants, and only a few displayed vowel errors. Additionally, many children demonstrated a strong speech signal at the beginning of SWs, with WI consonants produced more accurately and frequently than WF consonants.

Although therapy targeted areas of difficulty, therapy sessions incorporated phonemes, words, and phrases where the children already exhibited strengths, to foster their confidence and morale. Acoustic analysis focused mainly on areas of difficulty that were directly targeted in the intervention.

Child	Intelligibility Group	Target Word	Phonetic Transcription 1 Week Pre	Phonetic Transcription 12 Weeks Post
1	High	bin	mbɛndʰ	bɪn
1	High	feather	hɛdə	fɛdə
1	High	log	lɒgʰ	lɒg
1	High	pond	bɒnd	pɒnd
1	High	waiter	weɪ.də	ʋeɪtə
2	High	bin	bɪn͉	bɪn
2	High	feather	fɛðə	fɛʋə
2	High	log	wɒgʰ	lɒg͉
2	High	pond	pɒnd̥ʰ	pɒnd
2	High	waiter	weɪʔə	weɪtə
5	High	bin	bɪn͉	bɪn(ə)
5	High	feather	f̚↓ɛðə	fɛð̪͆ə
5	High	log	lɒk	lɒg
5	High	pond	pʰɒnd	kɒnd
5	High	waiter	weɪtə	waɪtə
7	High	bin	bin	bin
7	High	feather	waʊwə	βəwə
7	High	log	ɹɒd	lɒt
7	High	pond	pɒnd	pɒnd͉
7	High	waiter	weɪʔə	we̹ɪ̹ʔə
8	High	bin	bɪn	bin
8	High	feather	fɛðə	βəwə
8	High	log	lɒg̥	lɒt
8	High	pond	pɒⁿnd̥͉	pɒnd͉

Child	Intelligibility Group	Target Word	Phonetic Transcription 1 Week Pre	Phonetic Transcription 12 Weeks Post
8	High	waiter	weɪtə	we̹ɪ̹ʔə
16	High	bin	ʔɪn	ʔɪn
16	High	feather	f̹əvə̰	f̹ˡɛvə
16	High	log	nɒʔʱ	nɒʔʱ
16	High	pond	kh͢ɒnd	hɒnd
16	High	waiter	weɪtə	weɪtɑ
4	Low	bin	bɪn	bin
4	Low	feather	f.fɛvə	fɛvə
4	Low	log	n̺ɒk	l͢ðe.ɒg
4	Low	pond	pɒnd̥ʰ	pɒŋd̥ʰ
4	Low	waiter	eɪtə	ə.eɪtə
6	Low	bin	mbw͢əɪ	bə.əʊtʰ
6	Low	feather	mbɛ.ʔ̰ə	βɛ.ʔə.d
6	Low	log	lɒ	lɒtʰ
6	Low	pond	mβɒ	ɸ̬ɒŋkʲ
6	Low	waiter	weɪ.ʔ̰ə	βw͢eɪʔə̰ʊ̰.tˡʰ
9	Low	bin	gɪŋ	gɪŋ
9	Low	feather	k̩ⁿʱəgə	fŋ̊gɛ.gə
9	Low	log	nɒg	nɒg
9	Low	pond	kʰɒŋg̊ʰ	kʱɒnd̥
9	Low	waiter	w̺̰eɪʔ̰ə	hə.weɪʔə
10	Low	bin	dɪn	dɪ̰n
10	Low	feather	dɛdɑ	d̰ɛ̰ð̰ə̰
10	Low	log	lɒd̺ʰ	lɒ̰d̺
10	Low	pond	pɒnʱ	dɒnʱ
10	Low	waiter	weɪʔ̰ə	weɪʔ̰ə̰
11	Low	bin	ɪn	ɪn
11	Low	feather	ʔɛʋə	ʔɛʋə
11	Low	log	bɒ̰ʔ	ð̼ɒ
11	Low	pond	ɒ̰n	ɒm̺
11	Low	waiter	ʊɹw͢eɪʔ̰ə̰	meɪʔə
12	Low	bin	bɪn	bɪn
12	Low	feather	kʱɛʔ̰ʔ̰ə	p͢ʱjɛ̰ʔ̰ə
12	Low	log	ʊɒ	uwɒd̥
12	Low	pond	pɒnd̥	pɒnd̥
12	Low	waiter	wḛɪ̰ʔ̰ə	weɪʔ.ʔə
13	Low	bin	βɪn	ɓβ͢ɪn
13	Low	feather	fˡɛvə	fˡɛvə
13	Low	log	lɒg	lɒg̊
13	Low	pond	pɒnd	pɒnd̥
13	Low	waiter	ʋeɪʔʔ ə̰	ɓβ͢eɪʔ.tə

Child	Intelligibility Group	Target Word	Phonetic Transcription 1 Week Pre	Phonetic Transcription 12 Weeks Post
14	Low	bin	bɪn̪̰	bɪn̙
14	Low	feather	fəvə	fɪvə̰
14	Low	log	lɒg̙ʱ	lɒŋʱ
14	Low	pond	pɒ.əʊʱ	hɒŋg̊ⁿ
14	Low	waiter	weɪʔ̰ʔ̰ə	weɪʔ̰ʔ̰ə̰
15	Low	bin	gɪn̙	bɪŋ̙
15	Low	feather	ɹɛʔ̰ə̰	gɛɣə
15	Low	log	ʔɪ.ɒ	jʱɒ
15	Low	pond	hɒn	q̣ʱɒŋ̙
15	Low	waiter	weɪʔ̰ə̰	weɪʔ̙ə

Table 34 Table Showing Each Child's Phonetic Transcriptions 1 Week Pre- and 12 Weeks Post-Therapy

6.4. Acoustic Changes in Response to Vocal Cues

The acoustic changes which occurred following the personalised intervention are discussed below in response to the children's vocal cues. The cues 'steady to the end' (given to P15) and 'slow' (given to P10 and P14) are not discussed as these were only used to help the children reduce their speech rate in CS. The children's vocal cues and speech characteristics are described in Table 33. The logic model below highlights the speech characteristics which were targeted in therapy, what vocal cues were used, and what changes were expected in relation to the mechanisms of change (Figure 19).

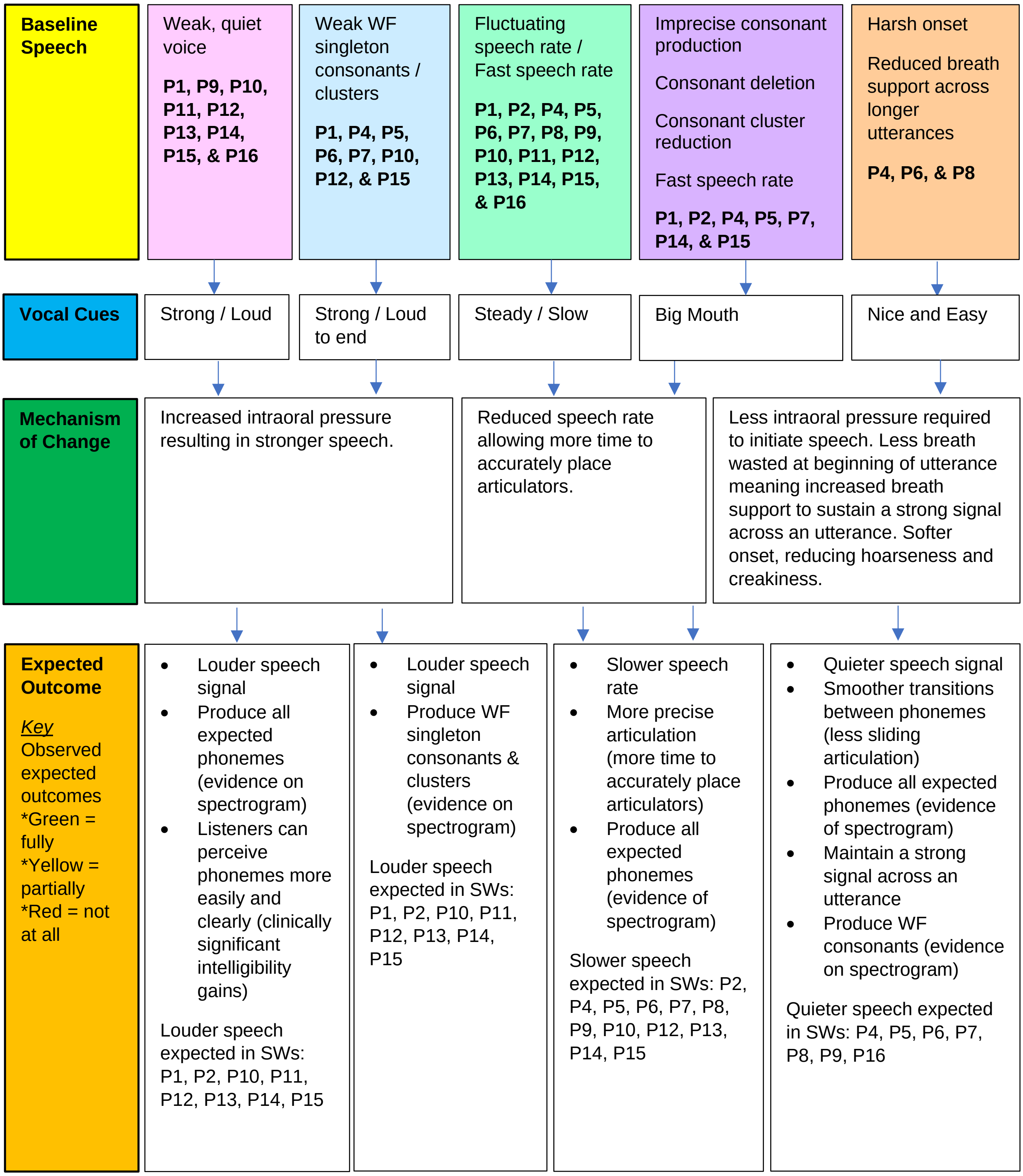

Figure 19 Logic Model Describing the Mechanisms of Change and Expected Speech Changes in Relation to the Children's Baseline Speech Characteristics and Vocal Cues

6.4.1. Strong/Loud

The following children were given the cue “strong/loud” during the intervention: P1, P9, P10, P11, P12, P13, P14, P15, and P16. These children presented with weak, quiet and/or breathy speech pre-therapy.

Three of the nine children who were given the vocal cue “strong/loud” made clinically significant gains in SW intelligibility overall- P1, P13, and P14 (see Table 35).

Table 35 shows that four children who received the cue “strong/”oud” (P12, P13, P14, and P15) produced more plosive bursts 12 Weeks Post-Therapy compared to 1 Week Pre-Therapy. As plosives require strong intraoral pressure to produce, increases in the number of plosives produced suggests that they were using their strong/loud cue post-therapy.

A WM plosive burst was observed in P13’s 12 Weeks Post-Therapy production of *‘waiter’*, whereas no burst was evident 1 Week Pre-Therapy where they replaced the WM /t/ with a glottal stop (see Table 34). The burst suggests stronger production of the phoneme post-therapy, indicating use of their vocal cue.

When looking at the transcriptions (see Table 34), some of these children who demonstrated weak phoneme production pre-therapy produced stronger articulated consonants post-therapy, including P10 and P15. However, neither of these children made clinically significant gains in SW intelligibility overall.

Child	Intell Group	Weekly Vocal Cues						Clin Sig. Gains	WI Bursts Present	WM Bursts Present	WF Bursts Present
		1	2	3	4	5	6				
P1	High	Loud -> Strong	Strong to end; Steady; Strong /s/			Big mouth					
P8	High	Nice & easy; Strong to end	Steady; Strong clusters	Strong /s/, /l/							
P5	High	Big mouth; Strong /f/, /v/	Strong to end	Steady		Strong /p/, /b/, /m/					
P16	High	Strong; Strong /s/, /ʃ/	Steady	Strong /p/, /b/	Strong /ʤ/						
P2	High	Big mouth; Loud /s/, /z/	Steady	Loud /f/, /v/							
P7	High	Big mouth	Steady	Strong to end; Strong /s/, /z/	Strong clusters						
P12	Low	Strong; Steady	Strong to end	Strong /s/	Strong /f/	Strong /v/					
P4	Low	Big mouth; Strong to end		Nice & Easy	Steady	Nice & easy -> Soft					
P9	Low	Strong; Steady	Strong /p/, /b/, /f/, /v/		Slow on long words						
P14	Low	Loud	Slow	Strong /s/, /p/, /b/, /m/	Big mouth						
P10	Low	Strong & Steady	Strong & Steady -> Loud & Slow	Strong to end; Strong /s/		Strong clusters					
P13	Low	Strong; Steady	Strong /s/	Strong clusters							
P15	Low	Loud	Steady	Steady on long words; Big mouth		Loud & steady to end					
P11	Low	Strong	Strong /f/, /v/; Steady		Strong /s/						
P6	Low	Strong to end; Nice & easy		Steady							

Table 35 Table Showing Children Who Produced More Plosives in Different Word Positions 12 Weeks Post-Therapy Compared to 1 Week Pre-Therapy

6.4.2. Strong/Loud to the end

The cue “strong/loud to the end” was provided to P1, P4, P5, P6, P7, P10, P12, and P15 to address difficulties in maintaining a strong speech signal across utterances or consistently producing WF consonants. Table 35 shows that P6, P12, and P15 produced more WF plosives post-therapy. The spectrograms below provide visual evidence of P12 producing a WF consonant 12 Weeks Post-Therapy, which she did not realise 1 Week Pre-Therapy (Figure 20 and Figure 21). However, despite increased production of WF plosives suggesting that P6, P12, and P15 were employing the cue “strong/loud to the end”, they did not make clinically significant gains overall in SWs (see Table 35).

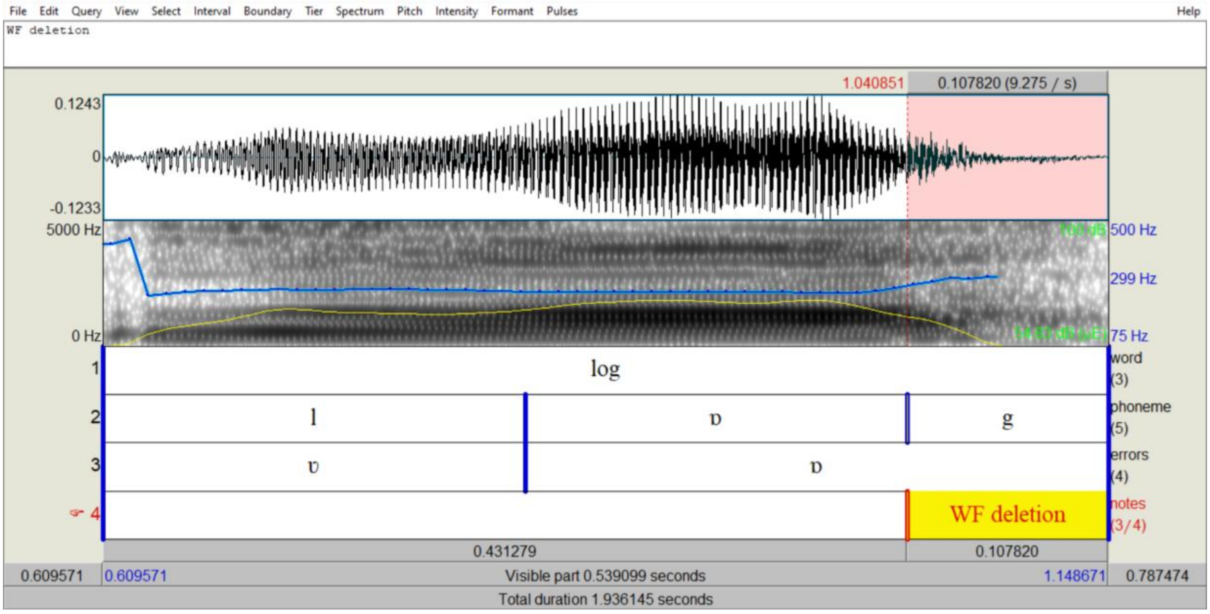

Figure 20 Spectrogram and Waveform of P12's Production of ‘log' 1 Week Pre-Therapy

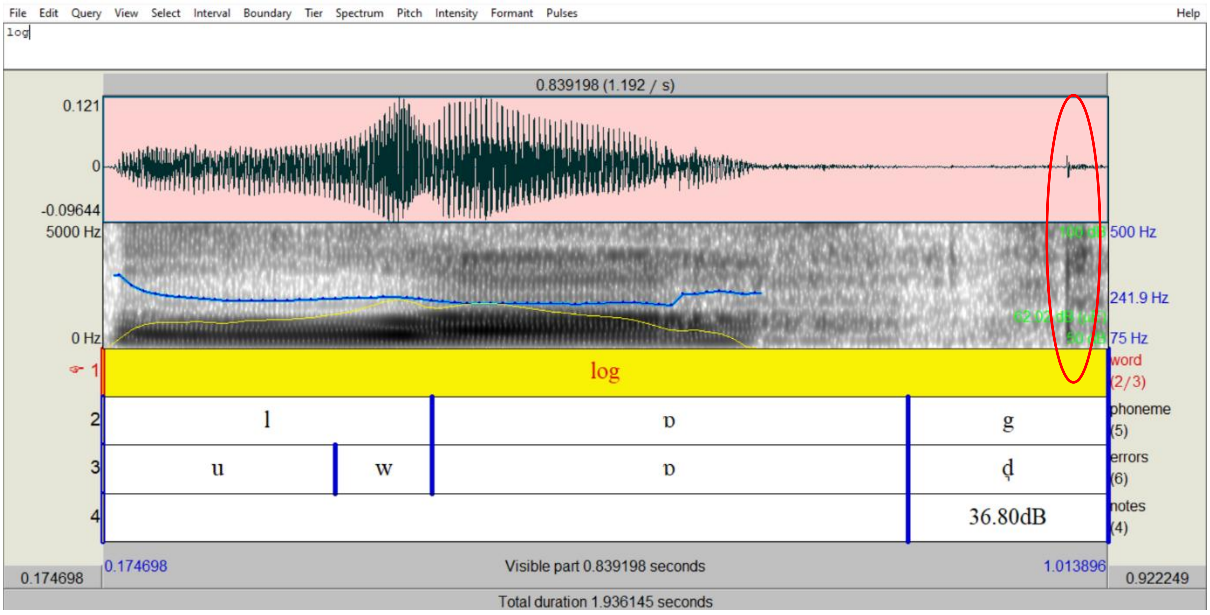

Figure 21 Spectrogram and Waveform of P12's Production of ‘log’ 12 Weeks Post-Therapy

Phonetic transcriptions (see Table 34) indicated improvements in WF phoneme production among several children receiving this cue. For instance, at 1 Week Pre-Therapy, P5 and P15 weakly articulated WF consonants in ‘bin’ and ‘log’ respectively but demonstrated stronger articulation 12 Weeks Post-Therapy. Notably, P5 appeared to respond to the cue “strong to the end”, demonstrated by her transitioning from a voiceless to voiced WF plosive in ‘*log*’ post-therapy. Voiced sounds, which generally have greater energy and are louder than voiceless sounds (Gordon, 2002), likely demanded stronger articulation. Furthermore, more energy would have been required to produce the longer vowel which preceded the voiced consonant. Additionally, P6 who frequently omitted WF consonants pre-therapy, began producing them post-therapy, albeit with occasional inaccuracies, as seen in ‘*feather*’ and ‘*waiter*’. He successfully produced two WF consonants with the correct MoA in ‘pond’ post-therapy, compared to none pre-therapy. Conversely, P4 and P7 showed no improvement in WF consonants in SWs, likely due to their ability to sustain a strong voice in shorter utterances but weakening across longer ones.

P5 was given the cue ‘strong to the end’ instead of solely “strong/loud” as her habitual speaking volume was loud, and at times excessively loud. However, this loud speech signal was not always sustained to the ends of utterances, but if given the cue ‘strong/loud’ it would result in shouting, which is detrimental to vocal hygiene. She appeared to respond better to ‘strong to the end’, with her managing to produce strong WF consonants (see Table 34).

6.4.3. Steady

All children, except P14, received the cue “steady” to manage fast or fluctuating speech rates, which were primarily observed in CS, but occasionally in polysyllabic words and less frequently monosyllabic words. Due to his young age (5 years), P14 responded better to the simpler cue ‘slow’ instead of ‘steady. Fast speech often led to imprecise articulation, and phoneme or syllable omissions.

Analysis of polysyllabic words revealed no consistent pattern linking the "steady" cue to improved intelligibility. For example, no substantial acoustic changes were noted except for P6, whose addition of an incorrect WF consonant reduced accuracy. Children with inaccurate pre-therapy productions often continued to struggle post-therapy.

For monosyllabic words, improvements were evident in WF singleton consonant production, such as P4 and P6's enhanced production of ‘*log*’ (see Figure 22 and Figure 23). Production accuracy improved slightly 12 Weeks Post-Therapy for some children who had the cue “steady”. For example, P1 accurately produced the WI /f/ in *‘feather’* and P14 produced a WF cluster, which he omitted 1 Week Pre-Therapy, in the word *‘pond’* 12 Weeks Post-Therapy.

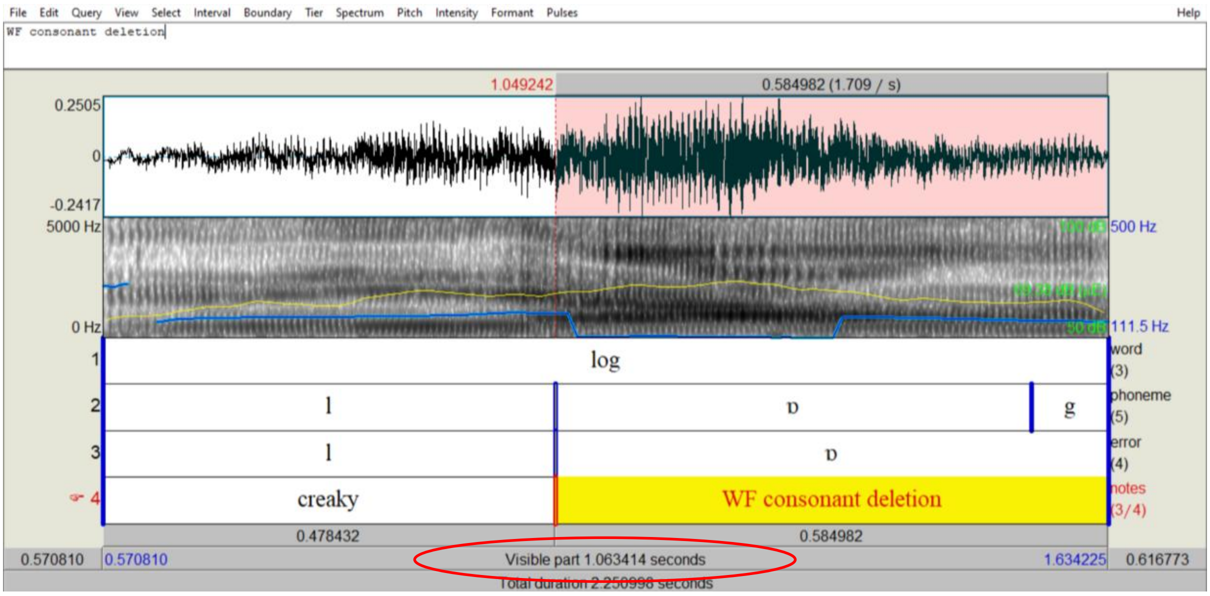

Figure 22 Spectrogram and Waveform of P6's Production of 'log' 1 Week Pre-Therapy

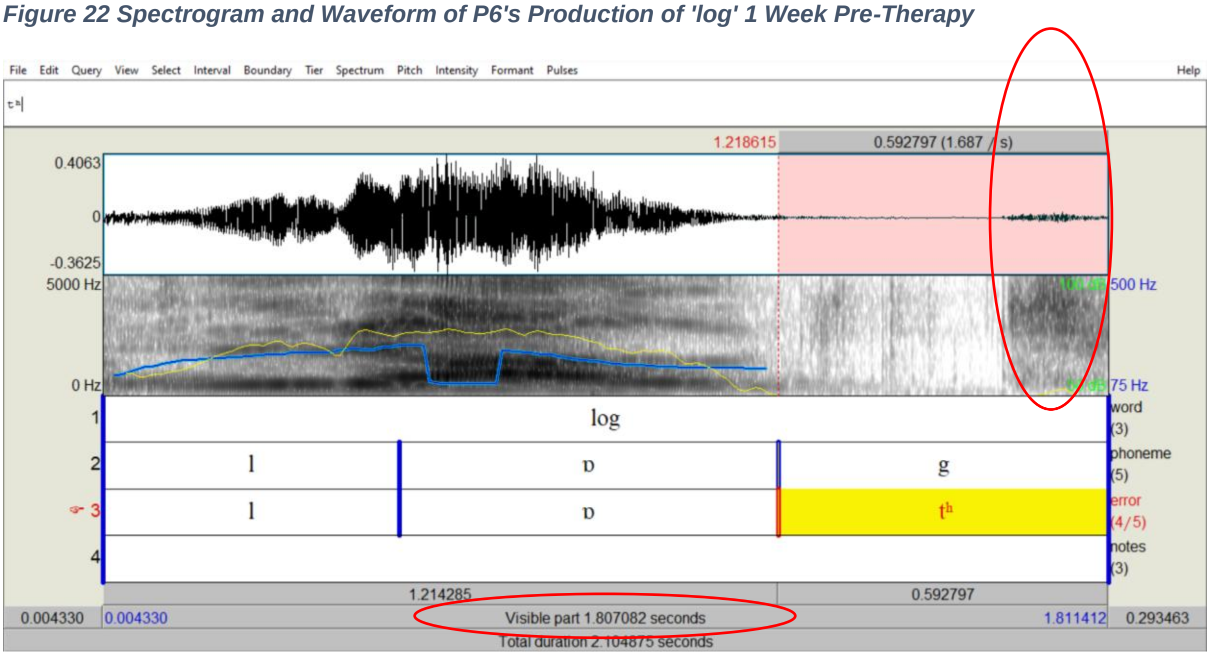

Figure 23 Spectrogram and Waveform of P6's Production of 'log' 12 Weeks Post-Therapy

These gains may reflect the children’s ability to slow their articulators while maintaining a steady speech rate, allowing more precise articulation and accurate consonant placement. Enhanced clarity in SWs may not have transferred as effectively to CS, where maintaining a steady rate posed greater challenges for most children, so would be useful to look at in future research.

6.4.4. Big Mouth

The cue "big mouth" was used to encourage hyperarticulation, aiming to improve consonant and vowel accuracy, and support a slower speech rate. This cue was provided to P1, P2, P4, P5, P7, P14, and P15.

Post-therapy, 'big mouth' appeared to contribute to several articulation improvements. For example, P1 correctly produced the WI /b/ and vowel in *'bin'* and resolved voicing errors previously observed in *'pond'* and *'waiter'.* Although these changes could also be in response to the cue 'strong' or a combination of both cues. Similarly, P2, P4, and P7 accurately articulated the WI consonant in *'log'*, though P4 added a fricative following the approximant. P7 and P15 corrected MoA errors in *'feather'* and *'log',* respectively, while P14 successfully produced a consonant cluster at the end of *'pond'*, which had been omitted pre-therapy. These changes likely reflect the children having more time to position their articulators accurately. 'Big mouth' may have contributed to over-articulation in some cases, leading to vowel distortions. For instance, P4, P5 and P14 exaggerated vowel targets, resulting in errors post-therapy. An example is shown below (Figure 24 and Figure 25), where P4 elongated the vowel in *'bin'* resulted in it being perceived as 'bean'.

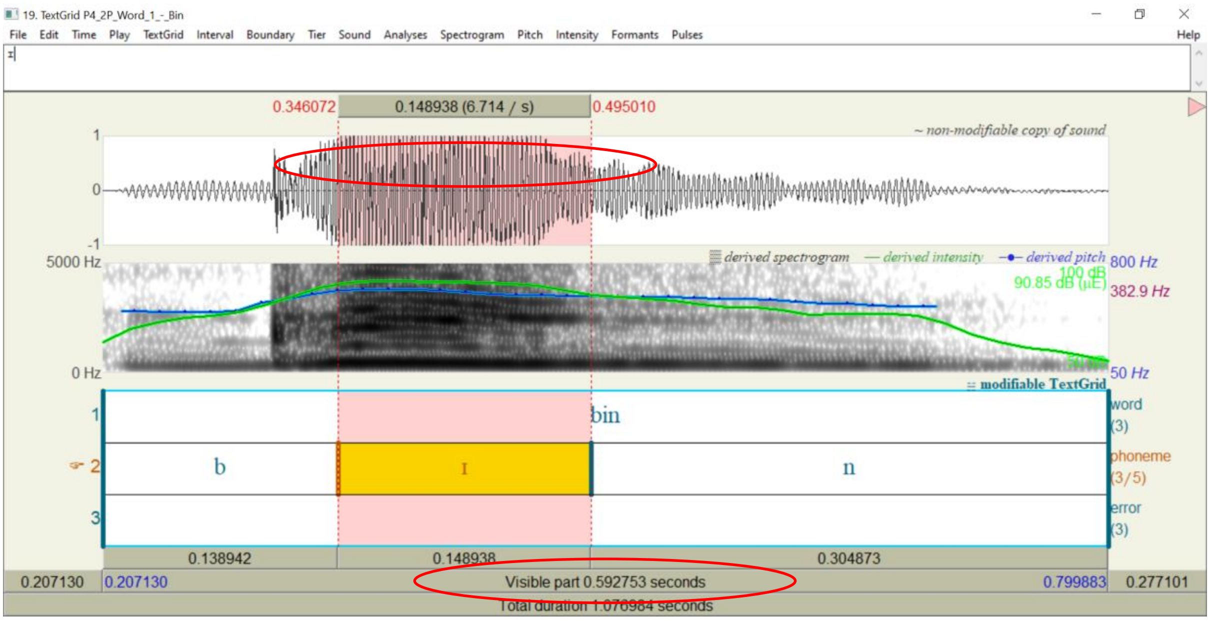

Figure 24 Spectrogram and Waveform of P4's Production of 'bin' 1 Week Pre-Therapy

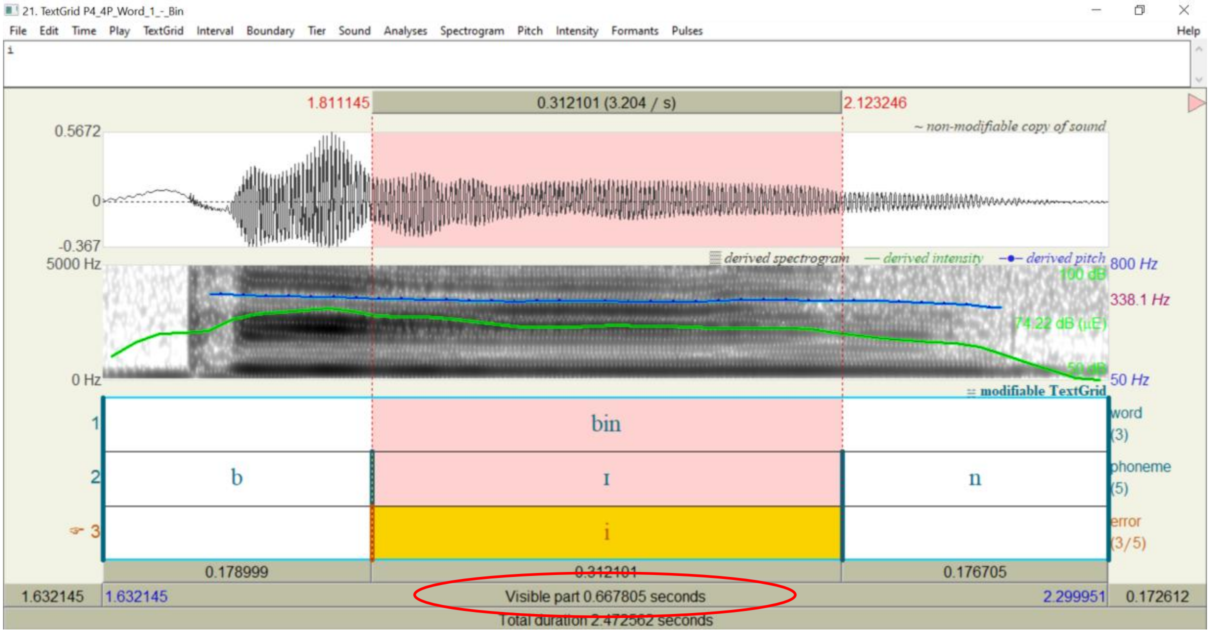

Figure 25 Spectrogram and Waveform of P4's Production of 'bin' 12 Weeks Post-Therapy

6.4.5. Nice and Easy/Soft

The cue "nice and easy/soft" was given to P4, P6, and P8 to prevent excessive loudness at the beginning of utterances, resulting in reduced breath over the rest of the utterance to sustain a strong speech signal, and to reduce any harsh or creaky vocal qualities. It was also used with P4 to help control his stammer.

"Nice and easy" appeared to reduce the prominence of P4's stammer, enabling him to hit targets first time, e.g., the WI /f/ in *'feather'* (see Figure 26 and Figure 27). It also enabled him to attempt the sound /w/ which he typically avoided pre-therapy, as seen in his production of *'waiter'* (see Table 34).

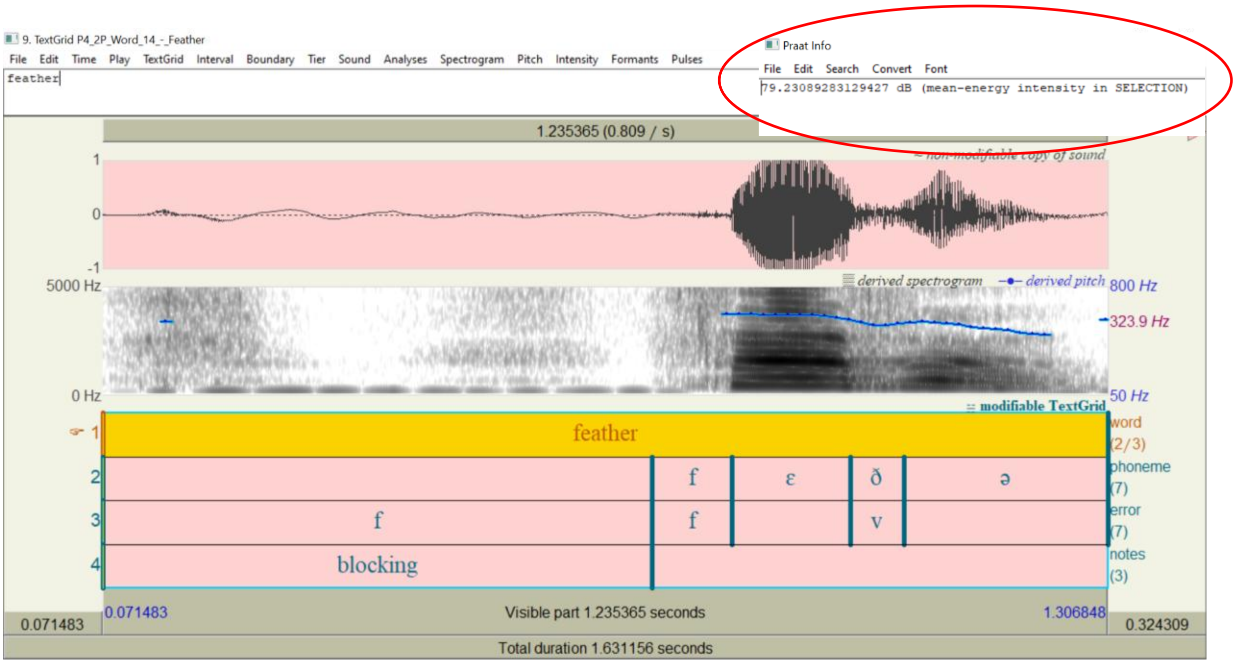

Figure 26 Spectrogram and Waveform of P4's Production of 'feather' 1 Week Pre-Therapy

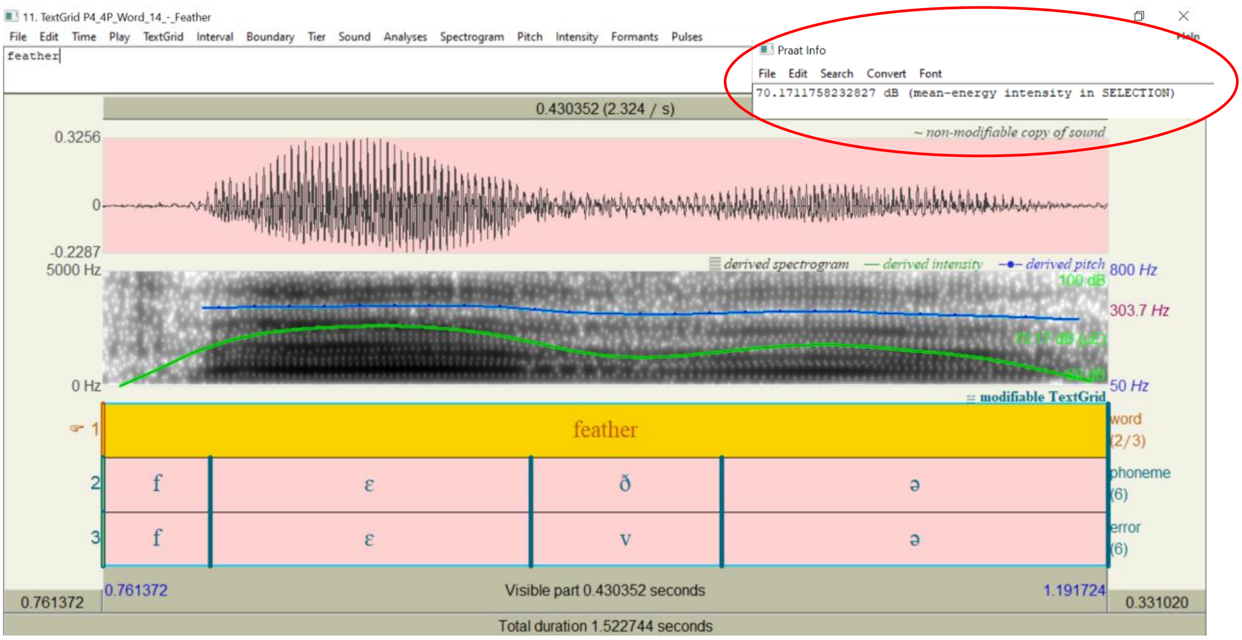

Figure 27 Spectrogram and Waveform of P4's Production of 'feather' 12 Weeks Post-Therapy

P6 improved precision in articulating WI target consonants following the intervention, avoiding transitions from one WI consonant to another (e.g., in *'bin'*, *'feather',* and *'pond'*). However, sliding articulation was present in his post-therapy production of *'waiter'*. "Nice and easy" may have contributed to these changes as it may have resulted in more control of his articulators, enabling him to place his articulators on one consonant only. Not using up all his breath support at the beginning of the utterance because of this cue may have also led to his ability to produce WF consonants post-therapy.

Although P8 continued to make articulation errors post-therapy (see Table 34), he did make clinically significant gains in overall SW intelligibility.

6.4.6. Exploratory Acoustics

Some of the children received very specific vocal cues to help with difficulties on individual speech sounds and characteristics. Specific phonemes were only targeted if children were stimulable to produce these phonemes, i.e., had the capacity to produce the sounds. These vocal cues are discussed below, where applicable to the SW data available.

6.4.6.1. Strong/Loud on Fricatives

Two thirds of the children (P2, P5, P7, P8, P9, P10, P11, P12, P13, and P16) were given cues to address the accuracy and strength of fricative production, specifically /f/, /v/, /s/, /z/, and /ʃ/. The fricatives /v/, /s/, /z/, and /ʃ/ were not present in any of the target words, thus the impact of therapy on these phonemes could not be explored. P2, P5, P9, P11, and P12 all worked on producing a strong /f/.

The phonetic transcriptions show that P2 produced an accurate /f/ both pre- and post-therapy. P5's production of /f/ was not audibly released and was proceeded with an ingressive airflow 1 Week Pre-Therapy. At 12 Weeks Post-Therapy she produced a strong, precise /f/, indicating that she may have been employing her cue. P9 did not produce an accurate /f/ pre- or post-therapy, but her post-therapy production was closer to target, with the bilabial fricative [fŋ̊]. P12's PoA of her post-therapy production was closer to the target /f/, moving from a velar plosive to a bilabial plosive.

P11 had great difficulty with producing consonants, particularly plosives which he often released as a glottal. His speech was stimulable for the phonemes /f/ and /s/ and it was judged important to work on improving the production and increasing the frequency of these phonemes to enhance his intelligibility, given the omission of other consonants. Transcription shows that he released /f/ as a glottal stop both pre- and post-therapy, indicating that he might have still been relying on his vocal cues to employ a strong voice and perhaps may have needed more time for his skills to generalise beyond therapy sessions.

6.4.6.2. Strong Approximants

P8 was given the cue ‘strong /l/’ to enhance the accuracy of his productions, as sometimes they were perceived as [j] or [w] in CS. His WI /l/ in *‘log’* was perceived correctly both pre- and post-therapy, due to his strong signal in SWs. Analysis of /l/ in his CS may offer more information on the reduction of precision in longer utterances.

6.4.6.3. Strong on Bilabials

P5, P9, P14, and P16 all had difficulty producing strong bilabial plosives (/p/ and /b/), due to the strength and coordination required for full lip closure. P5 and P14 also struggled to produce a strong bilabial nasal /m/. As /m/ was not a target in any of the SWs under acoustic analysis, improvement of the accuracy of this phoneme production could not be explored.

P5 and P14 produced a strong WI /b/ both pre- and post-therapy. Their accuracy of /p/ was reduced 12 Weeks Post-Therapy, with P5 realising it as the velar plosive [k] and P14 realising it as the glottal fricative [h] (see Figure 28 and Figure 29). P9 and P16 did not produce /b/ or /p/ accurately pre- or post-therapy (see Table 34). P14 was the only child with a vocal cue targeting bilabials who made clinically significant gains in overall SW intelligibility.

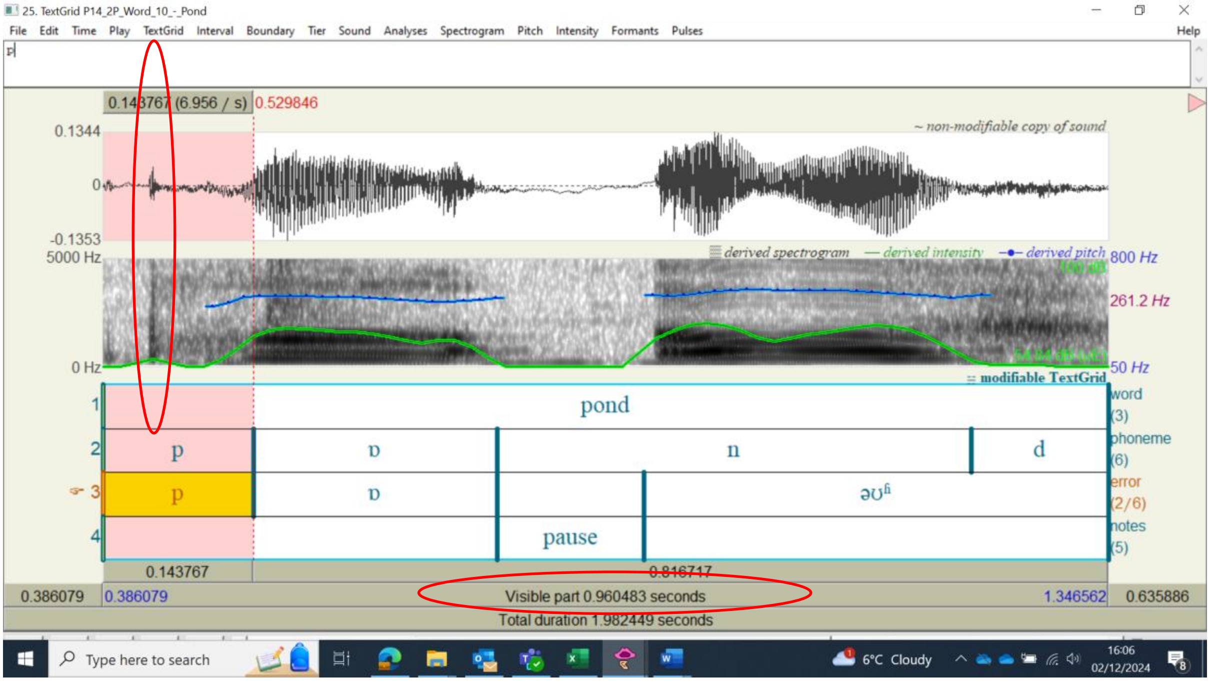

Figure 28 Spectrogram and Waveform of P14's Production of 'pond' 1 Week Pre-Therapy

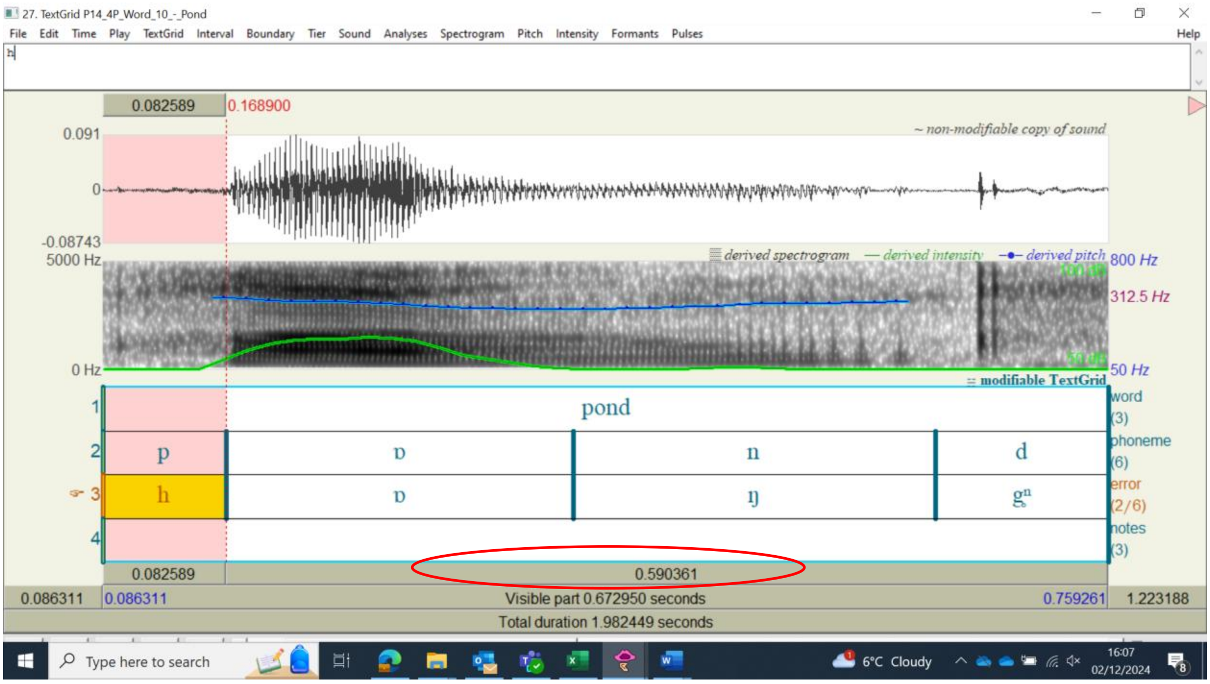

Figure 29 Spectrogram and Waveform of P14's Production of 'pond' 12 Weeks Post-Therapy

6.4.6.4. Strong on Consonant Clusters

Consonant clusters were targeted in P7, P8, P10, and P13's therapy. Exploration of the transcriptions showed no substantial change post-therapy in any of the children's WF consonant cluster production in the word *'pond'* (see Table 34). This could be potentially due to the cue being introduced too late for some children, for example P7 was only introduced to the cue in week 4 and P10 in week 5 (Table 35). More consonant clusters both in SWs and CS would need to be examined.

6.4.6.5. Steady/Slow on Long Words

Due to a tendency to rush over polysyllabic words, P9 and P15 were given the cue "slow/steady on long words" (polysyllables). The lack of improvement in articulation precision of *'feather'* and *'waiter'* for both children indicates they may have needed more practice and reinforcement of this cue (see Figure 30, Figure 31, Figure 32, Figure 33 and Table 34).

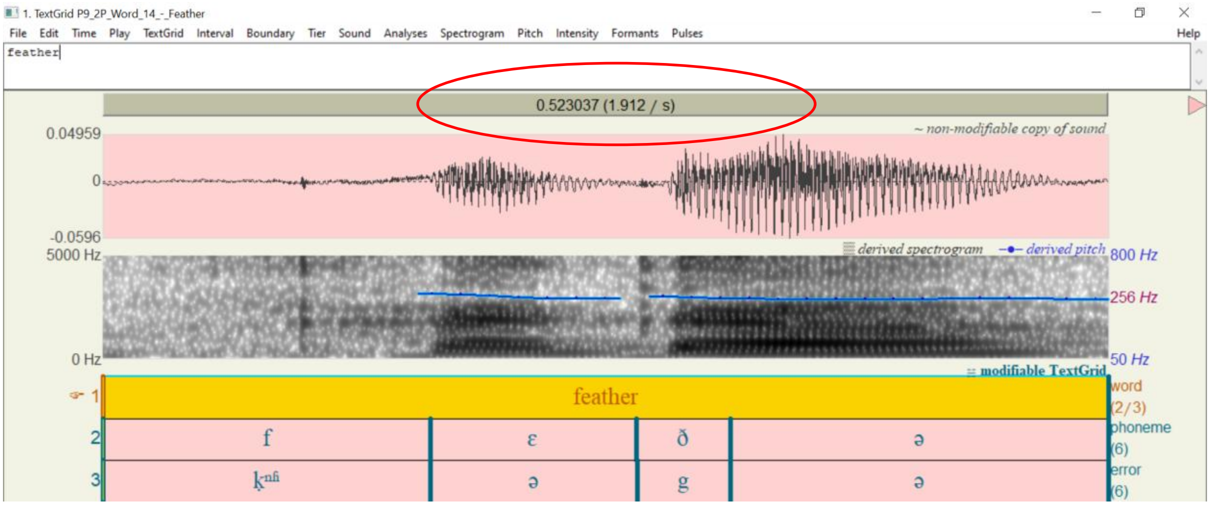

Figure 30 Spectrogram and Waveform of P9's Production of 'feather' 1 Week Pre-Therapy

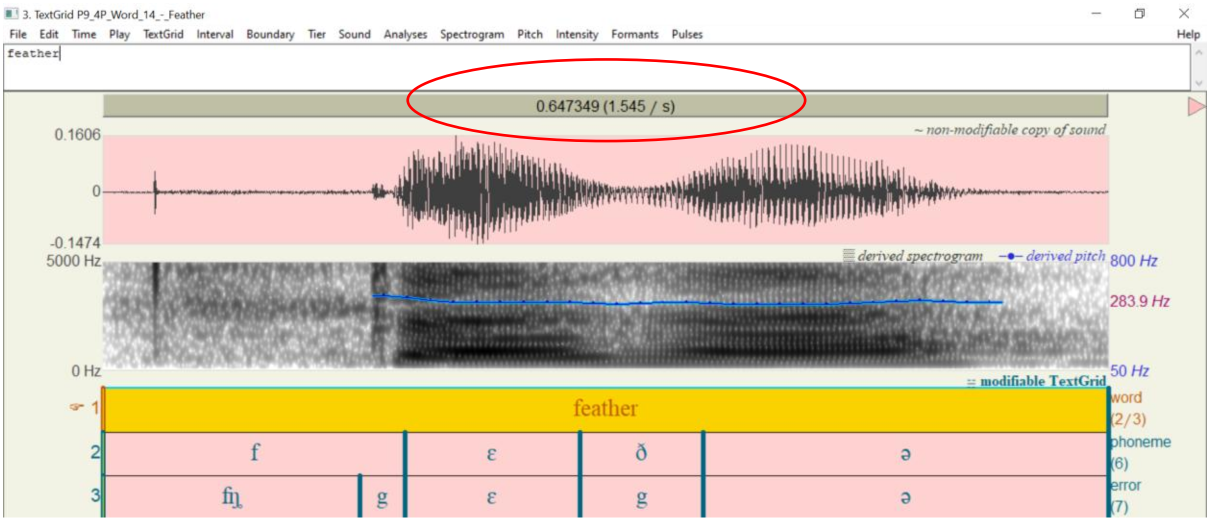

Figure 31 Spectrogram and Waveform of P9's Production of 'feather' 12 Weeks Post-Therapy

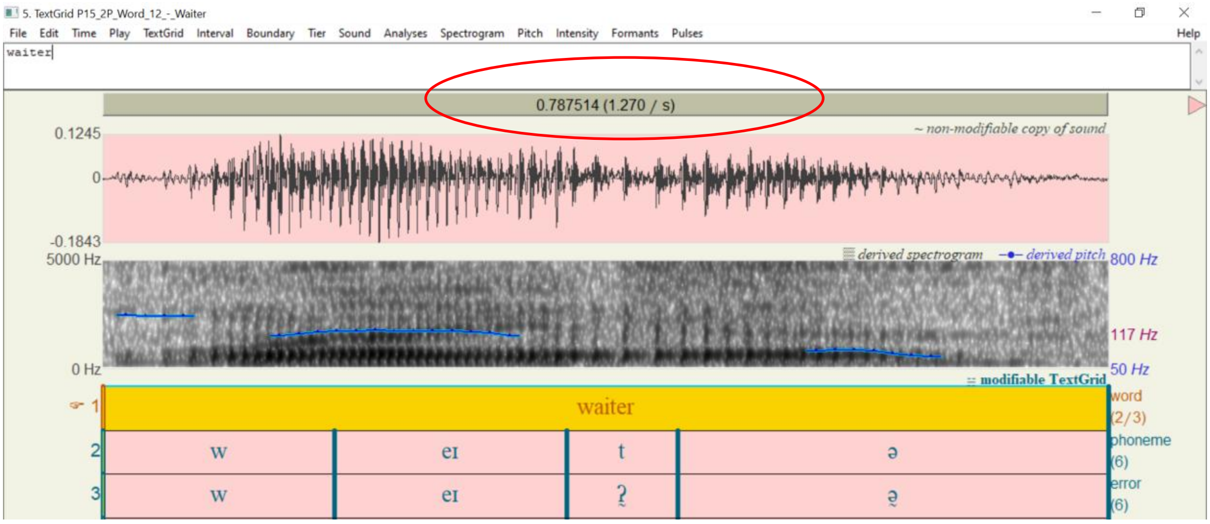

Figure 32 Spectrogram and Waveform of P15's Production of 'waiter' 1 Week Pre-Therapy

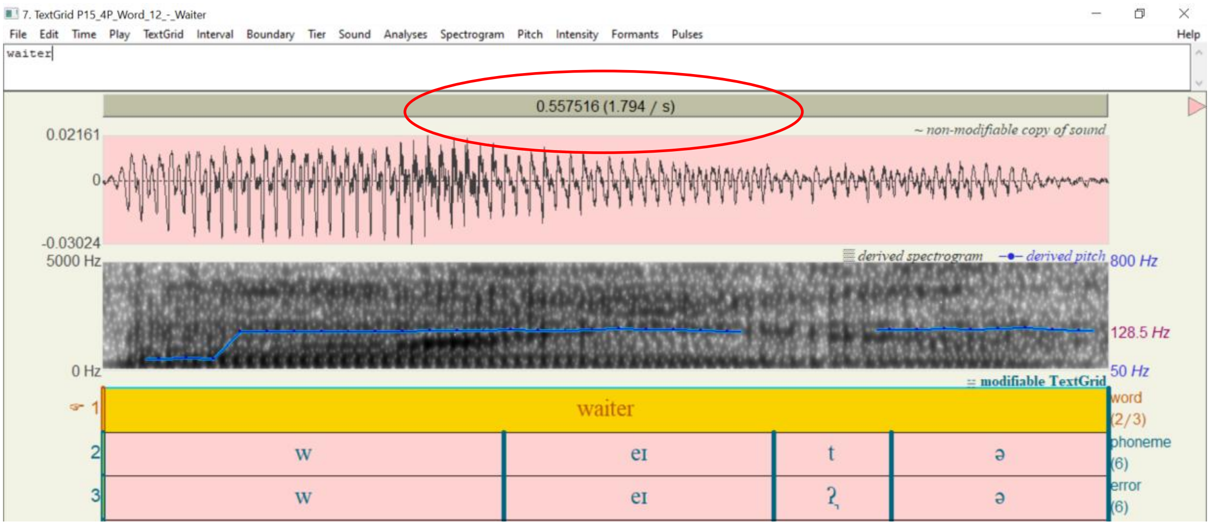

Figure 33 Spectrogram and Waveform of P15's Production of 'waiter' 12 Weeks Post-Therapy

6.5. Summary

All children exhibited visible acoustic changes on the spectrogram in the SWs analysed, with many moving closer to the target sounds. However, there was no obvious relationship between changes in acoustic profiling and the vocal cues trialled. Some children achieved expected outcomes, such as an increase in the number of WF consonants perceived following the cue “strong/loud to the end”. Other children exhibited unexpected changes, such as less accurate plosive production after having a specific cue targeting plosives, or showed no change at all.

Chapter 7. Reflection on the Process, Acceptability, and Feasibility of the Online Personalised Intervention

7.1. Introduction to Chapter 7

This chapter reflects on the process and acceptability of delivering personalised dysarthria intervention online. It discusses the advantages and limitations of the online intervention, addressing the logistics of conducting the intervention remotely while children are at school and collecting weekly speech samples to tailor the intervention. It then discusses the feedback provided by the participants, their teaching assistants (TAs) and parents regarding the intervention, and my clinical reflections. Finally, the chapter considers the feasibility of using acoustic analysis to inform weekly intervention.

7.2. Advantages of the Online Personalised Intervention

The feasibility of delivering the Speech Systems Approach online has already been investigated and results suggested that parents and participants found the online provision of the therapy feasible and acceptable (Pennington *et al.*, 2019). Online delivery of the personalised intervention had its advantages which are described below.

7.2.1. No Travel Time for Families

Online intervention eliminated the need for families to travel, requiring only up to 40 minutes from a participant's day to attend a therapy session. The absence of travel between schools allowed for more efficient scheduling, enabling me to see more children each day by moving seamlessly from one session to the next via Microsoft Teams. The approach also significantly reduced fuel expenses, which is especially valuable during a cost-of-living crisis.

7.2.2. Supporting Generalisation

Familiar adults, such as TAs and parents, attended the sessions and became familiar with the child's vocal cues. While TAs and parents were not specifically instructed to reinforce the cues outside of therapy, many enquired about ways to support their child's speech between sessions. Information about the cues, including their purpose, the aspects of speech they address, and when to use them, was provided to parents and TAs. Both parents and TAs reported prompting children to use the cues outside of therapy. Some TAs also integrated the vocal cues into the child's school targets. The use of vocal cues outside of therapy should facilitate the generalisation of skills in everyday settings.

7.3. Disadvantages of the Online Personalised Intervention

7.3.1. Internet Stability

Occasional internet instability disrupted sessions, leading to shortened or rescheduled sessions. P11 and P14 required one therapy session to be rescheduled due to the school internet being down for a full day. Internet connection was lost during one of P6, P9, P10, and P13's sessions, and during four of P11's sessions. The internet loss ranged from multiple brief losses of a few seconds to more prolonged durations up to 10 minutes. However, online delivery made rescheduling sessions less disruptive since no time was wasted travelling to appointments and there was no need to reorganise travel to attend rescheduled appointments. Only three sessions needed to be rescheduled in total.

7.3.2. Audio and Video Issues

Being able to hear and see the children clearly was essential for assessing their speech accurately and responding to their speech during therapy. Audio was only lost in six of the 254 therapy sessions delivered (range: 0-2 per child). Audio loss in this instance refers to periods of silence where the children could not hear me speak or I could not hear them speak, despite visual evidence that someone was talking. Disruptions ranged from brief interruptions of a few seconds to issues lasting up 10 minutes. Audio disruption made it difficult to assess children's speech. This led to a reliance on the child's self-report, where they would evaluate their own performance, e.g. whether they maintained vocal intensity throughout an utterance. While some children (mostly older – above 16 years) were able to state whether they used their target voice throughout the utterance or correct imprecise productions (P1, P5, P7, P8), younger children (P2, P13, P14 and P16) or those with more severe learning disabilities (P4, P6, P9, P10, P11, P12, and P15) were less reliable in their self-assessments, reporting that they were unsure if they used their target voice. Those supervising were asked to confirm use of vocal cues because they were aware of the difference between the child's usual speech and their speech when they applied their vocal cue(s), and I monitored articulation accuracy via video cues.

Video issues, i.e., a frozen or black video feed, impacted my ability to observe articulatory movements, especially when the audio was disrupted, and to assess whether children were employing the vocal cue ‘big mouth’. Loss of video occurred in six sessions (range: 0-2 per child), with disruptions ranging from 5 minutes to the full 40-minute session. Restarting the computer usually resolved video issues, though this was not always practical mid-session. The MS ‘PowerPoint Live’ feature also resolved video difficulties but displayed the slides in a shared window rather than full screen. The smaller display sometimes made it difficult for children to see therapy resources.

7.3.3. Distractions and Engagement

Background noise in school settings occasionally distracted children, drawing their attention away from the therapy tasks. Without being physically present, it was sometimes challenging to re-engage the children and redirect their focus to the screen. A quiet space for children to complete therapy sessions was available in most schools. However, P2’s school was open plan and background noise was frequently picked up in the computer audio and in the recordings. P2 resorted to wearing headphones during the therapy sessions. This reduced the background noise I could hear, helping me home in on her speech, and aided P2’s concentration as she could not hear the noise around her. However, her TA could not hear me as a result. This caused some delays in the session as P2 would have to swap headphones when I needed support from or had a question for her TA.

Additionally, during therapy tasks some children directed their speech toward their assistant rather than the computer screen, limiting my ability to fully observe and support their speech production. I frequently reminded the children to look at the screen and asked them to repeat what was said if it was not directly at me initially. I also asked the TAs to remind the children to speak directly to me. A further approach which worked well was having the TA sit quietly behind the child and asking them to only get involved in the therapy when I asked for support. This reduced the children’s reliance on and urge to speak to their TA.

7.3.4. Creating Engaging Therapy Resources

Personalising therapy activities based on a child’s interests helps to ensure engagement and maintain attention in a session. Creating engaging online therapy activities posed challenges, especially without the physical resources like board games and picture cards often used in face-to-face therapy. I enhanced interactivity using PowerPoint, incorporating animated visuals and themed backgrounds to maintain engagement.

To manage the workload of three weekly sessions per child, I developed a versatile set of adaptable activities. Universal activities included tasks like picture description using composite images, picture sequencing, and "Spot the Difference" games. These activities were designed to elicit connected speech, encompassing a wide range of phonemes, and facilitating the identification of specific speech deficits. For more targeted interventions, activities such as "Use Me in a Sentence" and "Odd One Out" were customised with vocabulary that focused on specific phonemes each child needed to improve. This personalisation ensured that each session was directly aligned with the individual speech goals of the participants. Additionally, interactive games like "Guess Who?" and "20 Questions" were adapted to incorporate topics related to each child's personal interests—such as favourite characters, TV shows, sports, or music.

Regular feedback from children and assistants about the activities used in therapy sessions informed iterative adjustments, refining activities to suit each child's preferences and needs. This personalised and flexible approach successfully fostered a supportive online therapy environment, sustaining motivation and promoting meaningful progress in each child's therapy block.

7.4. Acceptability of the Online Intervention

Acceptability refers to whether the study design, procedures, and intervention is appropriate from the perspective of the participant (Ayala and Elder, 2011). According to the Theoretical Framework of Acceptability V2 (Sekhon, Cartwright and Francis, 2017), seven component constructs are involved. These include (1) Affective Attitude; (2) Burden; (3) Ethicality; (4) Intervention Coherence; (5) Opportunity Costs; (6) Perceived Effectiveness; and (7) Self-efficacy. While a formal acceptability review was not conducted, feedback was collected from participants, TAs, SLTs, and parents/carers, which informed the evaluation of these constructs.

Most participants received the intervention at school/college, although P1, P8, and P15 children received the intervention at home. Schools were eager to participate, recognising the intervention as a valuable opportunity for their students.

7.4.1. Affective Attitude

Affective attitude refers to how the children felt about participating in the intervention. Most children appeared to have a positive attitude towards the intervention. This was indicated through their behaviours, such as smiling and laughing at the activities, actively participating in sessions, and giving positive post-therapy feedback.

Thirteen children actively engaged in the therapy tasks and reported that they found the activities fun; for example, P5 said she looked forward to the sessions and enjoyed using Disney lyrics to practise her target voice, and P7 said he found the Only Fools and Horses video description tasks funny.

Some participants found parts of the therapy challenging. P13 often experienced fatigue during sessions, occasionally asking to finish the session after 20 minutes. P16 reported finding certain tasks difficult, especially those targeting phonemes she struggled with, which sometimes resulted in frustration and feeling upset. Despite these challenges, both participants assented to continuing the therapy and provided positive feedback after completing the sessions. TAs and parents were engaged and reported that children were practicing the vocal cues in everyday settings, further indicating a positive attitude towards the intervention.

Following the six-week therapy block, children were asked ‘did you enjoy the therapy?’ and all children said each yes, although one child did report that she found it difficult. Children were also asked ‘how has your speech changed?’ and the answers received included, ‘I have slowed down’, ‘more people understand me’, and ‘my speech is clearer’.

7.4.2. Burden

Burden has been defined as “the perceived amount of effort that is required to participate in an intervention” (Sekhon, Cartwright and Francis, 2017).

Conducting sessions online relieved the physical and logistical burdens of traveling, making therapy more accessible and less stressful for families. Telehealth has been favoured by families of children with motor disorders, with reduced travel time being reported as one of the most important benefits (Ballantyne *et al.*, 2019; Edirippulige *et al.*, 2016).

Parental involvement was limited to providing informed consent, completing the pre- and post-therapy questionnaires, a brief phone call to discuss their child's medical history pre-therapy, and a phone call or email following therapy to discuss their child’s progress and provide advice how to support their child’s speech using the vocal cues from therapy. Results from the questionnaires can be found in Table 10 and Table 36 in Section 7.4.6.

Parents were able to contact me throughout the study if they had any queries. For those children who completed the intervention at home, their parents were also required to supervise each session and encouraged to use vocal cues at home to support generalisation and maintenance of skills.

Therapy sessions were scheduled to minimise disruption to school activities. Efforts were made to avoid scheduling sessions after physical activities and therapy sessions were kept to a maximum of 40 minutes to avoid participant fatigue. However, therapy sessions held during school hours still posed a considerable burden on schools, as staff needed to be released from classroom duties to supervise the sessions, limiting their availability for other responsibilities.

7.4.3. Ethicality

Ethicality refers to the adherence to moral principles and guidelines to ensure the integrity, fairness, and respect for participants, data, and the research process. The study received ethical approval from the HRA, and all appropriate measures were taken to ensure participant safety, including parental consent and child assent, insurance, GDPR compliance, and confidentiality. Ethical considerations were maintained throughout the intervention block. For instance, assent was obtained at the start of each session to confirm that children were willing to participate. If a child appeared distressed or tired during sessions therapy sessions were terminated early or rescheduled. This happened in five instances: three sessions for P13 and two for P6.

7.4.4. *Intervention Coherence*

Intervention coherence has been defined as "the extent to which the participant understands the intervention, and how the intervention works" (Sekhon, Cartwright and Francis, 2017). The intervention's intensity allowed participants to become familiar with their vocal cues and begin to use them independently. Awareness and understanding of the cues were assessed by asking children at the beginning of each session to name their vocal cues. By the third session of using a particular cue, children were able to recall it. TAs and parents reported reinforcing the cues outside of therapy sessions, highlighting their awareness of the vocal cues and how the children's target voice should sound. For the most part, this resulted in children using their vocal cues when prompted. However, one family noted that their child became frustrated when prompted to use the cues at home.

7.4.5. *Opportunity Costs*

Opportunity costs refer to the benefits, profits, or values that must be much be sacrificed to participate in the intervention. Schools were already equipped with computers, and they were provided with audio recorders, so no additional costs were incurred by schools or participants. The online nature of the intervention reduced travel costs, as the children's sessions took place whilst they were in school or at home. My travel costs were minimal, with only two in-person assessments at 6 Week Pre- and 12 Weeks Post-Therapy. Most children's sessions took place during the school hours, though P1, P8, and P15 received therapy at home, outside of school hours. Since sessions were held during the school day, opportunity costs arose due to the need for a TA to supervise, taking them away from other duties. Additionally, children missed some class time. However, the online format allowed children to remain in class longer, as no travel was required for the sessions. Furthermore, session schedules were coordinated with school staff in advance to avoid conflicts with important lessons or activities, such as physiotherapy.

7.4.6. *Perceived Effectiveness*

Perceived effectiveness is a subjective evaluation about an individual's view on the success or impact of an intervention. Participants reflected positively on their speech at the end of the intervention. For example, P5, P9, P10, P12, P13, P15 and P16 expressed that they felt others could understand them better, while P5, P7, P8, and

P16 noted improvements in the clarity of their speech. Teachers, TAs, and SLTs also noticed positive changes in the children's speech. For instance, P7's SLT shared that people find him easier to understand and P6's TA said she noticed an improvement in his speech and that his teacher found his speech stronger and clearer. There did not appear to be a difference in outcomes for children who completed the therapy at home compared to at school.

Parent responses to the follow-up ICS questionnaires, which provides data on parent/carer perceptions of their child's intelligibility in different contexts when speaking with various listeners, indicated progress in some of the children's speech (Table 36). The follow-up ICS was completed by parents/carers after the six-week therapy block and included three supplementary questions which were not part of the pre-therapy ICS. The supplementary questions were:

1. Has your child's speech changed since the start of therapy?
2. How has your child's speech changed?
3. What difference has this made?

Although some children's ICS scores remained unchanged or even declined, most parental feedback reported positive speech changes. The declines or lack of score changes may stem from parents not recalling their initial scores from the baseline assessment. Seven parents did not respond to follow-up contact despite two reminders, resulting in missing ICS scores and answers.

Child	Baseline ICS	Follow-up ICS	Q1	Q2	Q3	Additional Reports	Preference for in-person therapy
P1	28/35	-	-	-	-	Mum thought P1's speech intelligibility decreased 12 Weeks Post-Therapy.	-
P2	19/35	25/35	Yes.	Can produce WF consonants. Can make all sounds except /s/.	Gained confidence. Willing to talk to more people. Makes interacting easier. Does not need to repeat herself. Speaking on FaceTime.	Mum said less familiar communication partners noticed a difference. P2 thought her speech improved after therapy.	-
P4	25/35	24/35	Yes.	Slower and clearer speech. Calmer whilst speaking. Less stuttering before WI consonants.	The difference made during therapy was not sustained post-therapy. P4 remembers the therapy but less sure about what he learnt.	P4 said the therapy helped his speech. Mum reported that therapy on a more regular basis would benefit P4.	-
P5	19/35	20/35	Yes.	Clearer and slower speech. Takes time to pronounce her words. Still struggling with WI consonants.	Improved confidence. Uses her cues independently. She is more aware of how her speech sounds.	P5 thought her speech was clearer post-therapy and that people understood her better.	-
P6	21/35	23/35	Yes.	Calmer whilst talking. Clearer speech. Taking his time which helps his articulation. Understood more.	Can communicate his needs easier than before. Easier to meet his needs.	TA reported that teachers found P6's speech stronger and clearer. TA noticed improvement in his speech. She included his vocal cues in school targets.	No.

Child	Baseline ICS	Follow-up ICS	Q1	Q2	Q3	Additional Reports	Preference for in-person therapy
P7	22/35	25/35	Yes.	Slower and clearer speech. Less frustrated when not understood. Uses cues when he cannot be understood.	Increased confidence. Independently made phone calls and placed orders in restaurants and bars. Understood more.	P7 enjoyed the therapy. He reported clearer speech and said people understood him quicker post-therapy. His SLT reported that people found him easier to understand. She said another block of therapy would cement his learning and in-person could further enhance his speech.	Yes.
P8	Parent: 25/35 P8: 29/35	- -	-	-	-	P8 thought therapy improved the clarity and precision of his speech. He said people thought his speech was clearer and slower during the therapy. He thought his intelligibility declined at the follow-up. His support team at the charity he attends noticed a difference, reporting that he tried more and was self-monitoring his speech.	Yes.
P9	29/35	-	-	-	-	P9 said therapy helped her speech and that people understood her better due to her strong and steady speech. P9's TA noted a positive change and said she was more willing to answer in class.	No.
P10	19/35	-	-	-	-	P10 enjoyed the therapy. He said it helped him slow his speech and that people understood him better. His TA said he used his cues in class and began speaking to other children at playtime.	Yes.
P11	20/35	20/35	No.	Attempts WI phonemes, often repeating /h/ to indicate a WI phoneme	No difference	-	-
P12	22/35	-	-	-	-	P12 said people understood her better. She said she was unsure how to use her cues independently. Mum	Yes.

Child	Baseline ICS	Follow-up ICS	Q1	Q2	Q3	Additional Reports	Preference for in-person therapy
						and TA did not notice change in her speech and said she was unable to generalise strategies outside of therapy.	
P13	24/35	24/35	Yes.	Clearer speech. Can talk for longer without tiring.	Uses his speech more. Goes into more detail when speaking.	P13 said people understood him better and he knew how to make his speech clearer post-therapy. His teacher and TA noticed a positive change in his speech during therapy and thought the therapy greatly supported him. They noticed declines when he was not receiving therapy. His TA said he needed reminded to use his cues outside of therapy.	Yes.
P14	25/35	-	-	-	-	-	-
P15	22/35	21/35	Yes and no.	Clearer speech through slowing down.	Understands the importance of using his cues and is fully on board.	P15 said that he enjoyed the therapy. He thought his speech was slower and people understood him better. Dad reported that it is an ongoing process, with change not expected in 6 weeks. He reported the importance of educating communication partners.	Yes.
P16	22/35	-	-	-	-	P16 said people understood her more post-therapy, especially her younger sister. She reported her speech to be clearer due to her using loud and steady speech.	Yes.
Note. '-' = missing information. Cells highlighted green indicate an increase in ICS scores.							

Table 36 Parent ICS Ratings and Answers to Supplementary Questions at the Baseline and Follow-up Assessments

7.4.7. Self-efficacy

Self-efficacy is defined as a person's confidence in their capability to perform a behaviour. Over time, most participants appeared to gain confidence in using their vocal cues. This was demonstrated by their increased independence in employing the cues, reduced reliance on prompts from the TAs and myself, and spontaneous use of vocal cues outside of therapy tasks, such as during everyday conversations at the beginning of sessions. While some participants required more prompts than others, overall, self-efficacy improved as they became more consistent in using their target voices.

7.4.8. Summary of Acceptability of the Online Personalised Intervention

Overall, the personalised intervention seemed to be well-accepted by participants, school staff, and parents/carers. Schools were supportive, facilitating therapy sessions, and providing necessary resources and parents/carers were generally responsive. The number of sessions attended ranged from 14 to 18 (median = 17) (see Table 12 for full details**).**

The online format was generally accepted, although there was preference for face-to-face delivery by most children, with children reporting that this would have allowed for more engaging use of physical resources (Table 36). Although some children's ICS scores remained unchanged or even declined, most parental feedback reported positive speech changes. The declines or lack of score changes may stem from parents not recalling their initial scores from the baseline assessment. Seven parents did not respond to follow-up contact despite two reminders, resulting in missing ICS scores and answers.

None of the participants refused to have their speech recorded, and no issues were reported with the number of recordings required.

7.5. Participant Reflections and Feedback

The intervention was highly regarded by participants, schools, and families, garnering positive feedback on the impact of the intervention, not only on the children's speech, but on their confidence, independence, and educational attainment.

P7 was excited to share his first experience ordering a takeaway pizza independently over the phone, stating that he used his cues and was understood. P2 shared that she began talking to her grandparents over FaceTime and that she thought they understood her better because she used her cues. Several other children also reported that they were understood more by others following the therapy, e.g., P16 said that her younger sister was able to understand her better at home. P6's dad reported that his son was able to communicate his needs better after therapy, P13's TA said his reading out loud in class had improved, and P15 achieved student of the week for using his vocal cues in school.

Some feedback was not as positive. For example, P1's mum reported that her child's speech deteriorated at the 12 Weeks Post-Therapy follow-up assessment, compared to her speech during and immediately post-therapy, and that she was looking for private SLT to support her speech. P8 self-reported that his speech intelligibility had also declined at the follow-up assessment and asked to be reminded of his cues. However, both participants demonstrated clinically significant gains in intelligibility 12 Weeks Post-Therapy, indicating that the personalised intervention did have a positive impact on their speech intelligibility.

Some TAs integrated vocal cues into the children's school targets. It was evident which children had been consistently using their cues following the intervention as they were able to recall their vocal cues at the follow-up assessment and employ them, despite some needing a few prompts. P14 could not remember receiving the therapy at the follow-up assessment, and consequently forgot his cues. P14 was the youngest participant, only 5 years of age, and this could have played a part in him forgetting about the therapy. Furthermore, his follow-up assessment occurred after the summer break. As he was receiving the intervention in school, it is likely that Mum was not aware of his vocal cues and thus he was not practising and generalising his skills outside of therapy. Mum was unable to be contacted following the therapy block due to personal challenges at home.

Many children reported that they enjoyed the therapy and found therapy tasks based around their hobbies and interests. Using topics which were of interest to the children helped keep them engaged and promoted use of CS. For example, P13 found the therapy challenging and, if the topic was not of interest, he would often answer using only one or two words and fatigue after 20 minutes, requesting to end the session. When therapy tasks were based around Newcastle United Football Club his utterance length increased, he initiated conversation, and would complete the full 40-minute therapy sessions.

A limitation arose with P13's follow-up assessment due to a change in his medication during the 12 weeks leading up it. The new medication improved his oral muscle movement, altering his articulatory control, range, and speed of motion. As a result, the sensory feedback associated with using his cues felt different. Imprecise articulation was a prominent characteristic of P13's speech, and during therapy, his limited oro-motor ability made the 'big mouth' cue unsuitable. With his increased oro-motor capabilities, it is likely that 'big mouth' could now be a more appropriate cue, potentially enhancing his speech intelligibility and enabling gains in CS performance that were not achieved during the study. This improvement might also reduce the physical demands of therapy for him, leading to less fatigue during sessions.

7.6. Feasibility of Weekly Acoustic Analysis to Inform Intervention

Weekly acoustic analysis aimed to inform the personalisation of the intervention. It was expected that acoustic analysis would reveal speech characteristics and covert changes not easily perceived by ear, such as changes in intensity or evidence of consonant production. This would allow the therapy to be adjusted to target these characteristics, and the acoustic data could help objectively track the children's responses to therapy and specific vocal cues.

Analysis could only proceed if school staff supervising the sessions set up and use the audio recorder correctly, captured clear speech samples, and transferred recordings promptly by sending them via File-Drop directly after the session. Given the time-intensive nature of acoustic analysis, limits were set to measure only the mean intensity and duration of five single words (SWs) and three phrases for all participants, with exploratory measures tailored to individual speech characteristics taken for individual children. Exploratory measures involved acoustic profiling of particular phonemes individuals found difficult, e.g., looking for evidence of a WF consonant if WF consonant deletion was a characteristic of a child's speech pre-therapy.

However, weekly acoustic analysis quickly proved impractical. Despite managing to collect all six recordings for each child over the therapy block, delays in the transfer of recordings made it unfeasible to analyse data in time to inform the next week's therapy sessions. Delays were caused by GDPR restrictions in schools banning access to File-Drop, family commitments, school routines, and occasional technical difficulties.

Recording protocols required precise adherence to ensure reliability, including maintaining a standardised microphone-to-mouth distance and minimising background noise. This proved challenging; participants' involuntary movements, busy school environments, and different people supervising, contributed to inconsistent recording conditions. Unavoidable background noise affected 23 out of 210 recordings from nine children. This noise interfered with listener transcription for perceptual analysis and compromised the accuracy of certain acoustic measures, such as intensity and spectrogram analyses, which made it more challenging to perform detailed acoustic profiling. However, the presence of background noise provided a realistic context, reflecting typical everyday speech settings.

Initially, the acoustic analysis workload of 2–3 hours per child was manageable, especially when only one child's therapy block was active. However, as recruitment increased and multiple therapy blocks overlapped, the time required for acoustic analysis expanded to up to 21 hours weekly. With 20–30 minutes of planning per session, this cumulative workload quickly became unmanageable alongside other commitments (see Table 37), shifting the study's approach to rely on perceptual analysis for planning and using acoustic analysis for retrospective validation.

Task	Time Taken
Planning Therapy	~3 hours (7 children; 20-30 minutes per child)
Delivering Therapy & Case Notes	~21 hours (7 children; 40-minute therapy sessions; 15-minutes on case notes)
Acoustic Analysis	~21 hours (7 children; 3 hours per child)
Hours remaining of 37.5 hour working week:	-7.5 hours

Table 37 Table showing time taken to complete tasks for maximum number of children on case load (based on 37.5 hour working week)

The online nature of the intervention meant that delays in receiving recordings were difficult to avoid. Future studies should explore whether in-person sessions, where researchers can directly record and manage files, would allow for more feasible weekly acoustic analysis. However, in settings like the NHS with high caseloads, automated acoustic analysis may be essential for larger-scale feasibility.

Recent research has begun exploring the potential of automated analysis for disordered speech (Shahin, Zafar and Ahmed, 2019). However, the vast diversity of speech disorders and their varying severities, combined with the limited availability of disordered speech corpora, means that speech analysis tools are not yet reliable enough for clinical use.

Chapter 8. Discussion

8.1. Overview of the Discussion Chapter

This primary purpose of this PhD was to examine how personalised speech and language therapy influences the intelligibility of children with CP and dysarthria, from both perceptual and acoustic perspectives. It also aimed to assess the feasibility of gathering acoustic measures during therapy to inform the intervention. This final chapter summarises the study's findings, situating them in the context of findings from other studies, highlights the strengths and limitations, and considers the clinical implications, along with suggestions for future research.

8.2. Summary of Findings

8.2.1. Does personalised speech and language therapy improve the intelligibility of children with CP and dysarthria?

Before answering this question, the key findings on the subgroups of participants that emerged from the study at baseline and their CP characteristics are summarised.

Visual analysis of the SW data revealed two distinct groups based on baseline intelligibility – high and low. Six children (P1, P2, P5, P7, P8, and P16) were categorised as having high intelligibility, while nine children (P4, P6, P9, P10, P11, P12, P13, P14, and P15) were classified as low intelligibility in SWs. A similar pattern was observed in CS, though the children appeared to separate into three groups – high, mid, and low intelligibility. This finding that children's SW and CS intelligibility were relatively similar corresponds to previous research indicating a significant correlation between word and sentence intelligibility for speakers with dysarthria (Sussman and Tjaden, 2012). P5 and P8 performed significantly better in CS than others in the high intelligibility SW group and remained in the high intelligibility group for CS. In contrast, P1, P2, P7, and P16 were reclassified into the mid intelligibility group for CS. P10 and P12, initially grouped as low intelligibility for SWs, were reclassified into the mid intelligibility group for CS due to their comparatively higher baseline intelligibility. Children categorised as low intelligibility in CS (P4, P6, P9, P11, P13, P14, and P15) exhibited the lowest baseline performance in both SW and CS tasks. This observation is consistent with Hustad's (2007) findings, which reported no difference between SW or CS intelligibility in children with profound dysarthria.

In CS, word identification can be affected by recognition of other words within the phrase. If listeners identify other words, they can make educated guesses about unclear segments using world and linguistic knowledge in their top-down processing. When speech is less intelligible, listeners depend more on top-down working memory processes to understand what has been said (Zekveld, Heslenfeld, Festen and Schoonhoven, 2006; Pichora-Fuller, Schneider and Daneman, 1995). Those who listened to P10 and P12's CS may have used contextual cues from the words they did understand to complete the rest of the phrase, which they would not have been able to do in the SWs. Use of these contextual cues to understand P10 and P12 may explain why they were classified in the mid baseline intelligibility for CS but low baseline intelligibility for SWs. Some listeners may have been unable to use semantic and syntactic cues in identifying words spoken by children with lower intelligibility, as they likely struggled to understand enough words to graph the context of the speech, explaining why children who were in the low intelligibility group for SWs remained in that group for CS.

No obvious relationship was observed between participants' response to therapy and their individual characteristics. Although participants' ages ranged from 5 to 18 years, there was no apparent link between age and therapy response — younger children did not consistently show poorer outcomes than older children, a finding also found by Pennington et al., (2013). There was a mixture of CP type across the intelligibility groups. Four children with higher intelligibility and three children with lower intelligibility had dyskinetic CP. Spastic CP was diagnosed in one child in the high intelligibility group and in six children in the low intelligibility group. P5, who was in the high intelligibility group, had a diagnosis of Worster-Drought Syndrome. No distinct speech patterns appeared to be specifically linked to CP type. Speech characteristics such as rapid or fluctuating speech rate, loudness decay, excessive loudness variation, breathiness, and weak consonant production were observed across children with various types of CP. These findings are consistent with previous studies reporting an overlap in speech characteristics in children with spastic and dyskinetic CP, attributed to the developmental nature of motor speech disorders

(Nordberg, Miniscalco, Lohmander and Himmelmann, 2013; Byrne, 1959; Pennington, 2012). Although it is slightly surprising that most children with high baseline intelligibility had dyskinetic CP, given the fact speakers with spastic CP have been found to have more accurate speech production (Clarke and Hoops, 1980), no clear pattern was expected between CP type and dysarthria severity as the differences in the speech production accuracy between spastic and dyskinetic CP have frequently not been statistically significant (Byrne, 1959; Irwin, 1972). Poorer speech accuracy demonstrated by the children in this study with spastic CP may be due to them having severe motor disorders, with most children presenting with bilateral spastic CP (see Table 10). There is variation in the speech accuracy of children with spastic CP, with children with unilateral spastic CP having higher speech accuracy than those with bilateral spastic CP (Nordberg, Miniscalco, Lohmander and Himmelmann, 2013; Liégeois and Morgan, 2012).

Although there was no definitive pattern linking CP type to speech intelligibility, the severity of motor impairment may have influenced intelligibility levels. Children with higher baseline intelligibility generally exhibited less severe motor impairments compared to those with lower intelligibility. For instance, while P2 and P8 were classified at levels V and IV, respectively, on the GMFCS, they demonstrated relatively better fine motor skills, ranking at level II on the MACS. In contrast, over half of the children in the lower intelligibility group were ranked at GMFCS levels IV or V and MACS levels III or IV. This aligns with prior studies indicating a correlation between dysarthria severity and motor dysfunction severity as classified by the GMFCS and MACS (Soriano and Hustad, 2021; Sigurdardottir and Vik, 2011; Coleman, Weir, Ware and Boyd, 2013).

There was no clear relationship between cognition and speech intelligibility. P8 and P14 were the only children whose parents reported that they had no cognitive impairment. P14's school reported that his learning and understanding was in line with his peers. P8 was in the high intelligibility group for both SWs and CS whereas P14 was in the low intelligibility group for both SWs and CS. All other children in the study experienced cognitive delays or impairments, such as learning delays, learning disabilities, or global developmental delays (see Table 10). These findings are consistent with research suggesting that the presence of a speech disorder is independent of cognitive ability in children with CP, and that there is no correlation between speech production accuracy and cognition (Mei *et al.*, 2020b). Other studies propose a potential relationship between cognition and speech intelligibility (Soriano and Hustad, 2021). The high prevalence of cognitive difficulties among participants was not unexpected, as they affect approximately 50% of individuals with CP (Novak, Hines, Goldsmith and Barclay, 2012; Vitrikas, Dalton and Breish, 2020).

The results of the present study suggest that personalised SLT can improve the intelligibility of children with CP and dysarthria. Group results showed statistically significant improvements in the performance intelligibility of SWs and CS 12 Weeks Post-Therapy, suggesting that personalised intervention had a medium-term impact on the intelligibility of children with CP and dysarthria. These findings correspond with previous research that has reported gains in both SW and CS intelligibility (Pennington *et al.*, 2013; Pennington, Miller, Robson and Steen, 2010). No statistically significant group improvements were observed immediately following the therapy, although some children did make clinically significant gains 1 Week Post-Therapy. Not all children who made clinically significant gains in intelligibility immediately following the intervention maintained improvements 12 Weeks Post-Therapy.

Previous research has not examined the stability in baseline intelligibility for children with CP and dysarthria. This study found that some children had unstable baseline intelligibility, with their scores either increasing or decreasing by >10% from 6 Weeks Pre- to 1 Week Pre-Therapy, especially in the capacity conditions. No statistically significant group difference in SW and CS capacity intelligibility might be because some children had a stable baseline, whilst some decreased and some increased from 6 Weeks Pre- to 1 Week Pre-Therapy.

Similar to findings from Pennington et al. (2023), there was no consistent relationship between improvement in SW and CS intelligibility in this study. Clinically significant gains in one condition did not always correspond to gains in the other, regardless of the child's baseline intelligibility level (i.e., high, mid, or low). For instance, P1, classified as having high SW intelligibility but mid CS intelligibility, made clinically significant gains in both conditions 12 Weeks Post-Therapy. In contrast, P2 and P7, who also had high SW but mid CS intelligibility, showed clinically significant improvements only in SWs. P13 and P14, with low intelligibility in both conditions, made significant gains solely in SWs, whereas P15, also with low intelligibility in both conditions, demonstrated significant gains only in CS.

A greater number of children achieved clinically significant gains in SWs compared to CS 12 Weeks Post-Therapy. This contrasts with the findings of Pennington et al. (2010), who reported that a greater number of older children with CP made clinically significant gains in CS compared to SWs 6 Weeks Post-Therapy, and Pennington et al. (2013), who found an equal number of younger children with CP achieving clinically significant gains in both SWs and CS 12 Weeks Post-Therapy, when rated by unfamiliar listeners. The difference in this current study's results compared to Pennington et al.'s could be due to the greater severity of intelligibility limitations experienced by the children in this study. Children with higher baseline intelligibility scores benefited more from the intervention than those with very low baseline intelligibility (e.g., P6 and P11). It may have been challenging for the children with severe or profound dysarthria, who scored at or near 0% intelligibility pre-therapy, to demonstrate noticeable gains due to them encountering floor effects (Pennington *et al.*, 2013; Pennington, Miller, Robson and Steen, 2010). No noticeable gains may have been due to the therapy being too complex for the children's insufficient volitional oro-motor control or the transcription task being too complex for listeners to reliably detect subtle changes in their speech. Research has suggested that orthographic transcription often misses subtle improvements in intelligibility among individuals with very severe/profound dysarthria, and that a multiple-choice task may be a more sensitive method for assessing intelligibility in this group (Yorkston and Beukelman, 1978; Yorkston and Beukelman, 1981). The progress of P6 and P11 (and possibly P14 and P15) may have been obscured due to the constraints associated with orthographic transcriptions, leading to an underestimation of therapeutic effectiveness for these individuals.

One constraint was the absence of visual cues in the listener transcription task, as it relied solely on auditory information. Previous research has shown that children with CP and severe dysarthria tend to perform better when the listener is presented with an auditory-visual task compared to auditory-only (Hustad and Cahill, 2003a), suggesting that integrating visual cues may enhance the intelligibility of children with very low baseline intelligibility. Other studies observed that only speakers with moderate dysarthria (not severe) demonstrated higher scores when listeners were presented with auditory-visual information compared to auditory-only (Hunter, Pring and Martin, 1991). It is worth noting that intelligibility ratings in the latter study were subjective, rather than objective scores derived from transcription tasks. Furthermore, there is a possibility that less intelligible children in this study made improvements in comprehensibility, which were not captured because the study exclusively measured intelligibility. Research indicates that comprehensibility scores often exceed intelligibility scores for speakers with moderate and severe dysarthria (Hustad, 2008).

8.2.2. What accounts for changes in intelligibility of children with CP and dysarthria?

I predicted that gains in intelligibility would be associated with greater identification of WI and WF singleton consonants and polysyllabic words in SWs and WI and WF singleton consonants and words produced in longer phrases in CS. These predictions were based on the therapy mechanisms of action – improved respiratory control and phonatory effort and slower rate of speech facilitating precise articulation, and findings from previous research (Pennington *et al.*, 2023).

Within the SW data, the perception of WI singleton consonants, WF singleton consonants, and polysyllabic words all significantly improved over time, with the largest gains observed 12 Weeks Post-Therapy, corresponding with findings from the full SW dataset. More children made clinically significant gains in WI singleton consonants than WF singleton consonants. No single predictor variable or combination of predictors accounted for the improvement in children's *overall* SW intelligibility given no interaction effect between any variable and timepoint.

The intelligibility of both WI and WF singleton consonants in CS also significantly improved over time. The greatest gains in WI consonants perceived correctly were observed 1 Week Post-Therapy and improvements appeared to be sustained 12 Weeks Post-Therapy. Similarly, WF consonants showed an increase in intelligibility 1 Week Post-Therapy, with a slight additional improvement by 12 Weeks Post-Therapy. Changes in intelligibility of WI and WF singleton consonants could be due to some children making large gains in these predictor variables. However, as some children made no improvements in these predictor variables, and other children's intelligibility decreased, no interaction effects were detected. Children with higher baseline intelligibility tended to achieve greater intelligibility gains compared to those with very low baseline intelligibility, some of whom showed no improvement.

Previous research has also identified clinically significant improvements in the intelligibility of polysyllabic words within SW contexts (Pennington *et al.*, 2023). It is possible that more polysyllabic words were perceived correctly given the fact that they are more predictable than monosyllabic words, which are more easily confusable especially when even small articulatory errors are made (Haley and Martin, 2011). In contrast, for CS, no significant differences over time were observed in the number of monosyllabic and polysyllabic words perceived correctly, a finding consistent with Pennington et al.'s (2023) results. This lack of statistical improvement might be attributed to imprecise articulation, which can make it challenging for listeners to identify syllable endings and word boundaries. Research by Klein and Liu-Shea (2009) highlights that children often delete sounds at word boundaries in CS due to the high segmental and suprasegmental demands. Specifically, syllable-final and WF consonants in CS are particularly prone to deletion among children with speech sound disorders. Furthermore, it has been noted that while children with dysarthria may not exhibit reduced loudness in SWs, vocal decay may be observed in CS (Iuzzini-Seigel, Allison and Stoeckel, 2022). This raises the possibility that reduced intensity could also account for the lack of significant differences in the perception of monosyllabic versus polysyllabic words in CS. Although intensity measures in CS were not analysed in this study, it is possible that phonemes were being articulated, but the sound signal lacked sufficient strength for listeners to perceive phonemes toward the ends of polysyllabic words. This aligns with the logic model (Figure 19) discussed in Chapter 6. Acoustic Results, which emphasises the importance of sustaining a loud or strong signal throughout an utterance to enhance listener perception of phonemes and syllables.

Syllable final and WF consonant deletions, combined with the speech errors already observed in SWs, may account for fewer children making clinically significant gains in CS compared to SWs. Consonant deletions between words in CS can lead to sound changes through assimilation, an issue which does not affect SW production. Additionally, children in this study sometimes over emphasised phonemes when using their cues or produced phonemes they struggled with in isolation rather than blending them into the word, as seen in some SW transcriptions (see Table 34). These exaggerated phonemes may have been misperceived by listeners as separate syllables or words in CS. This misperception aligns with findings that lexical stress within words (e.g., distinguishing **’per**mit from per**'mit**) and across utterances helps listeners identify syllable and word boundaries (Lowit *et al.*, 2018; Mattys and Samuel, 1997).

The number of words in a phrase did not significantly influence whether a word was perceived correctly. This differs from other research which found the intelligibility of mid-length sentences (four to six words) to be greater than short sentences (two to three words) and long sentences (seven words) in children with CP (Darling-White and Jaeger, 2023; Allison and Hustad, 2014; Hustad, Schueler, Schultz and DuHadway, 2012). The heterogeneity of the speech characteristics and intelligibility of children in this current study may have accounted for the overall lack of effect of number of words in a phrase on intelligibility. Additionally, the method of elicitation may have accounted for the lack of effect of number of words. The TOCS+ was used by Allison and Hustad (2014) and Hustad et al., (2012), so the children had a model and the length of utterances were individually capped. In this current study, children were not given a model and they could produce phrases of any length, resulting in lots of variation both within and across children at each timepoint.

Like with SWs, the intelligibility of both WI and WF singleton consonants in CS significantly improved over time. The greatest gains in WI consonants perceived correctly were observed 1 Week Post-Therapy and improvements appeared to be sustained 12 Weeks Post-Therapy. Similarly, WF consonants showed an increase in intelligibility 1 Week Post-Therapy, with a slight additional improvement by 12 Weeks Post-Therapy. Changes in intelligibility of WI and WF singleton consonants could be due to some children making large gains in these predictor variables. The two most intelligible and two least intelligible children showed no improvement in the perception of WI or WF consonants in CS. Clinically significant gains were only made by children classified as having mid or low CS intelligibility. This could be due to floor or ceiling effects experienced by those with milder and more severe dysarthria (Pennington *et al.*, 2013).

Repeated measures analyses are particularly sensitive to within-subject changes, even when these changes are subtle (Field, 2024); thus, those large changes in intelligibility by some children may explain the significant effects of the predictors observed in ANOVA tests (see Sections 5.10 and 5.11)**.** In contrast, binary logistic regression requires a stronger and more consistent pattern of change across subjects for effects to reach statistical significance. The small sample size and high variability in how children improved on the predictor variables may have weakened the overall signal, making the increases insufficient to yield a statistically significant interaction effect in the regression model. The high variability in children's improvement on the predictor variables may explain why no interaction effects were observed, despite measurable increases in the predictor variables over time. Detecting such effects would require a larger sample, and fully powered dataset, which was not feasible given the small sample size of 15 children.

Previous research has reported improvements in WI and WF consonant production following therapy in both SWs and CS, but with improvement in consonant recognition within CS being less pronounced (Pennington *et al.*, 2023). The findings from this study align with these observations, showing that more children achieved clinically significant improvements in identification of WI consonants in SWs compared to CS. There was little difference in the number of children who made clinically significant gains in the identification of WF consonants in SWs compared to CS, with three showing gains in SWs and four in CS. A relationship was noted between correct identification of WI and WF consonants in SWs and clinically significant improvements in *overall* SW intelligibility. In contrast, WI and WF consonant identification in CS did not consistently result in clinically significant gains in *overall* CS intelligibility (see Table 32). For SWs, fewer children achieved clinically significant gains in the perception of WF consonants compared to WI consonants, consistent with previous findings (Pennington *et al.*, 2023).

From visual comparisons of tabulated changes, children with lower baseline intelligibility appeared to make slightly more clinically significant gains in the predictor variables in CS than SWs, however these improvements did not always correspond to clinically significant gains in *overall* CS intelligibility. For example, P13 and P14 made clinically significant improvements 12 Weeks Post-Therapy in WI and WF consonant intelligibility respectively but no clinically significant gains in *overall* CS.

This indicates that positive changes have occurred in their speech but are not yet sufficient to lead to *overall* gains in CS intelligibility, i.e., gains in phoneme recognition but not word recognition. This aligns with findings from Platt et al., (1980) who found speakers with dysarthria to have better phoneme scores (78%) than intelligibility scores (50%). Although, Platt et al.'s (1980) finding may be due to the phonemes being transcribed by a trained phonetician and the individual words being transcribed by naïve listeners. For SWs, most children who demonstrated clinically significant gains in predictor variables made clinically significant gains in *overall* SW intelligibility. This suggests a relationship between articulatory errors and SW speech intelligibility, which aligns with findings from previous research (Whitehill, 2002; Whitehill and Chun, 2012); however, Whitehill's research investigates intelligibility in speakers with cleft palate and not CP. No changes in *overall* CS intelligibility may be due to higher demands on the oromotor system for CS compared to SWs.

Consonant clusters in WI and WF positions were excluded from the analysis due to the low frequency of observations in both the SW and CS data. Similarly, previous research on dysarthria intervention for children with CP (Pennington *et al.*, 2023) also reported a limited number of words containing WI and WF consonant clusters, despite having a larger sample size (n = 42). Observations from the CS data suggests that children with CP and dysarthria tend to produce few consonant clusters in their typical speech. This may reflect avoidance behaviour (Ingram, 1989; Ferguson and Farwell, 1975) likely due to the high motor demands involved in rapid and precise coordination of multiple articulatory movements. The low number of observations in the SW data suggests limitations in words selected to undergo analysis. The effect of consonant clusters on speech intelligibility should be examined in future research.

8.2.3. Effect of Acoustic Features on Intelligibility

Group analysis could not be completed due to children having different baseline speech characteristics and vocal cues (see Table 33), and conclusions drawn from observed changes are speculative.

Analysis of the phonetic transcriptions revealed that most children who achieved clinically significant gains produced phonemes that were generally closer to the target productions. This suggests that articulation may serve as a strong predictor of intelligibility. These findings align with previous research, which identifies articulation as the most significant predictor of intelligibility (De Bodt, Huici and Van De Heyning, 2002; Lee, Hustad and Weismer, 2014).

Due to the restricted set of acoustic data available, it was difficult to assess which (if any) vocal cues were associated with particular acoustic changes and whether acoustic changes accounted for increases in intelligibility. No one cue can be identified as accounting for the changes as measures were not taken directly after each cue was introduced. Expected changes related to vocal cues, such as stronger articulation or production of WF consonants, did occur across children in the group, however, it cannot be concluded that these changes were because of a specific vocal cue. Some vocal cues target similar mechanisms, thus can cause similar changes in speech. For example, ‘big mouth’ and ‘strong’ can result in more precise articulation. Furthermore, children were given a combination of vocal cues. Therefore, determining which cues were responsible for certain changes proved difficult, especially given the inconsistent acoustic changes across children. It is likely that a combination of cues together led to changes in both acoustic and perceptual speech characteristics. As vocal cues were introduced in different orders across the six-week therapy block, there is the chance that some were added too late for any acoustic (or perceptual) changes to be observed. For example, P10’s cue “strong on consonant clusters” which was hoped to improve the accuracy of consonant cluster production was not introduced until week 5 of therapy. Had this been introduced earlier it may have resulted in improved consonant cluster accuracy.

8.3. Process and Feasibility of the Intervention

The sample size, while relatively small, was determined by practical constraints, including the number of children that could be treated within a school term, given the intensive nature of the therapy, and the need to align therapy and data collection with school holidays. It was comparable to sample sizes used in similar studies (Pennington *et al.*, 2013; Pennington, Miller, Robson and Steen, 2010; Pennington *et al.*, 2019). Additionally, the sample size was constrained by the time taken to obtain HRA ethical approval and the extensive time required to analyse the substantial amount of data. The children recruited for this study were similar to those in previous research, representing a range of gender, age, CP types, and communication and motor skill levels, although some children in this current study presented with more severe dysarthria than previous dysarthria intervention research (Pennington, Miller, Robson and Steen, 2010; Pennington *et al.*, 2013).

Most schools were able to support the online intervention, allocating time for staff to supervise sessions and recognising the therapy's value for the children's care and education. Schools generally had the necessary facilities and equipment, and substitute staff were often available when the usual TA was unavailable.

The primary challenges in delivering the online intervention were associated with technology used, such as audio and visual issues or internet connectivity problems. These disruptions affected therapy sessions by making it difficult to hear children's speech production and evaluate their use of vocal cues and caused children to focus on therapy tasks. Such issues occasionally led to session rescheduling, which was challenging due to the children's busy school schedules and the need to manage other therapy sessions. Internet connectivity issues, commonly reported in studies utilising online therapy (Pennington *et al.*, 2019; Grogan-Johnson *et al.*, 2013), were generally brief and resolvable in this study as well. Some research has noted instances where sessions could not proceed at all due to a lack of internet connection (Fairweather, Lincoln and Ramsden, 2016), a problem that would not arise in face-to-face therapy. In the event of last-minute rescheduling or cancellation of therapy sessions (e.g., due to child sickness or staff shortages), the online format ensured no time was spent on travel, making these disruptions less impactful compared to in-person appointments. Research has found that when technical preconditions are met, online healthcare within the NHS is safe and popular with both patients and staff (Shaw *et al.*, 2018). However, Shaw and colleagues (2018) reported online consultations to work best when clinicians and patients know and trust each other; thus, the in-person screening/baseline assessment may have contributed to the children's willingness to engage in the online intervention in this current study.

While most TAs and parents were able to record and transfer speech samples without issue, one school's GDPR policy blocked the use of the File Drop-off site, requiring manual collection of the recorder each week. This added burden required time away from other duties. Additionally, TAs often faced delays in transferring recordings as they had to prioritise classroom responsibilities after therapy sessions. These delays rendered weekly acoustic analysis unfeasible.

To improve the feasibility of weekly acoustic analysis and reduce the workload on session supervisors, it may be beneficial for the TA or parent to remain on the call after recording sessions to facilitate immediate transfer of recordings. Using features like screen sharing to demonstrate how to use the site and providing verbal instructions could simplify the process, ensuring recordings are submitted promptly on the same day. This adjustment would provide more time for acoustic analysis.

Although conducting acoustic analysis during therapy could offer valuable insights into covert changes in children's speech and the influence of vocal cues on acoustic properties and intelligibility, implementing such an approach in real-world clinical settings would be challenging. The large caseloads and time constraints faced by NHS clinicians make it unlikely that acoustic analysis could routinely inform intervention in practice.

8.4. Reflections and Participant Feedback

From clinical reflection, the personalised therapy appeared to be widely accepted by participants, schools, and families. This judgement was drawn from observations of the children's behaviours, engagement, and motivation during therapy sessions, as well as positive feedback provided from participants, families, and school staff. Similar findings have been reported in other research on SLT for children with CP, where children were found to enjoy the therapy, and parents expressed that they valued the therapy (Pennington, Rauch, Smith and Brittain, 2020; Pennington *et al.*, 2019). Much of the enjoyment and engagement observed during the intervention stemmed from the use of personalised therapy tasks that incorporated the children's areas of interest, a factor that was also highlighted by Pennington et al. (2020) as being particularly valued.

The therapy seemed to improve some children's confidence, as evidenced by their increased independence in communicating over the phone, initiating conversations more frequently, and speaking with a wider range of people. Similar reports of improved confidence, self-esteem, and more successful social interactions in children with CP and dysarthria following intensive SLT have been documented (Pennington, Rauch, Smith and Brittain, 2020; Pennington *et al.*, 2013). The increased social interaction and communicative participation is a crucial outcome for the children, as it can potentially lead to greater independence and an improved quality of life — factors that are often limited in children with CP and dysarthria (Fauconnier *et al.*, 2009; Colver *et al.*, 2015). Improvements in reading performance and other school awards, such as 'student of the week', reported by school staff, are also highly positive outcomes of the intervention, especially considering that dysarthria can significantly impact children's educational attainment (Mei *et al.*, 2015; Kuschmann, Schölderle and Haas, 2023). Another encouraging outcome was that some TAs reported integrating vocal cues into the children's school targets. This addresses a need previously identified by parents in research by Pennington et al. (2013), where they emphasised the importance of training teachers to implement vocal cues trained during therapy.

Self-reports and parent reports of noticeable improvements in children's speech (e.g., clearer, louder, and slower speech) and increased understanding by unfamiliar listeners following therapy noted in this study have also been observed in other studies on SLT for children with CP and dysarthria (Fox and Boliek, 2012; Pennington *et al.*, 2013; Pennington, Parker, Kelly and Miller, 2016). Not all feedback from children and parents in this study was as positive, with some reports indicating little to no noticeable improvement in speech post-therapy or a reduction in intelligibility at the follow-up assessment. Similar findings have been reported in other studies on SLT for children with CP and dysarthria, where participants either saw no change in their perception of their speech disorder (Marchant, McAuliffe and Huckabee, 2008; Pennington, Rauch, Smith and Brittain, 2020) or experienced changes that were not thought to be maintained at follow-up (Fox and Boliek, 2012). These findings highlight the variability in responses to therapy, likely due to the heterogeneous nature of dysarthria in children with CP.

Careful planning of the assessment and therapy schedules was implemented to avoid (where possible) long school holidays, such as the six-week summer break, falling between therapy sessions and follow-up assessments — particularly for children receiving school-based therapy. This was to reduce the chances of children losing skills due to limited practice at home during extended breaks. Unfortunately, due to recruitment delays, this was unavoidable for P14. P14 did not recall his vocal cues at the 12 Week Post-Therapy follow-up. This may be because practise was disrupted due to his follow-up assessment occurring after the six-week summer break. P14's Mum was unable to be contacted during and after therapy due to other commitments, thus was unaware of P14's cues to implement them at home. Additionally, it may explain why P14 did not achieve clinically significant gains in CS intelligibility at the follow-up assessment. While meticulous scheduling may address this issue, it is not practical in real-world clinical settings due to large caseloads, long waiting lists, and other logistical constraints.

Another important clinical observation involved P13, whose post-therapy progress was influenced by changes in medication. While P13 actively attempted to use his vocal cues in the follow-up assessment, altered sensory feedback from improved oro-motor movement may have impacted his ability to make clinically significant gains in CS intelligibility. P13 might benefit from another therapy block, focusing on either new cues or extended practice of the initial targets, to accommodate the sensory changes caused by improved motor function. This suggests that when medication changes are anticipated to affect motor function during an intervention block, delaying therapy may be advisable until the effects of the medication stabilise. Similar exclusion criteria have been implemented in other research on motor performance in children with CP (Law *et al.*, 2011). The change in medication for P13 was unplanned and therefore this criterion could not be operationalised in this study. In clinical practice, delaying therapy is not always feasible. Children with motor disorders often require ongoing adjustments to medication dosage or type due to factors such as body weight changes or side effects (Reilly, Liuzzo and Blackmer, 2020), and these adjustments cannot always be predicted. For P13, improved oro-motor control may reduce fatigue experienced in future therapy, allowing for greater participation and engagement, and potentially leading to more meaningful gains.

8.5. Strengths of the Study

8.5.1. Procedure

8.5.1.1. Development of Single Word Lists

The development of the phonetically balanced SW lists provides future researchers and clinicians with a valuable tool for assessing intelligibility across a diverse range of participants and patients in various contexts. These word lists include a broad spectrum of phonemes in different positions within words, incorporating both those that are easier for children with CP and dysarthria to produce, as well as those that are more challenging. This approach allows for the evaluation of a wide array of articulatory processes whilst minimising discouragement by avoiding phonemes participants can easily produce. Since the word lists included only 20 words to assess SW intelligibility, children were able to produce all the words in no more than five minutes, with some producing all 20 words in under one minute. This allowed more time to focus on therapy delivery, as recording sessions did reduce some therapy time. Pennington et al. (2019) reported that using 20 words to estimate intelligibility produced results comparable to assessments with 50 words. In this study, variability was observed in listeners' intelligibility ratings between 6 Weeks Pre-Therapy and 1 Week Pre-Therapy. This variability was inconsistent across children: some scored at least 10% higher at 6 Weeks Pre- compared to 1 Week Pre-Therapy, others showed the opposite trend, and some achieved the same scores at both timepoints. Contrary to Pennington et al.'s findings, using only 20 words may not have been sufficient to reliably estimate intelligibility for the children in this study. Other factors may have contributed to this variability, such as variations in children's motivation and attention during each recording session, more severe speech impairments experiences by the children in this study, or differences between the two word lists – one list of words might have been easier for a child to produce or may have contained words more familiar to a listener, easing perception.

8.5.1.2. Online Intervention

Implementing this personalised dysarthria intervention remotely has shown to be feasible and was well accepted by schools and families, with an average completion rate of 16.9 out of 18 sessions among the children. Some children missed therapy sessions due to illnesses, medical appointments, staff shortages, and family commitments. While most missed sessions were rearranged, this was not always feasible due to prolonged absences lasting a full working week (experienced by P10, P12, and P13), other obligations, or scheduling conflicts caused by multiple therapy sessions on my timetable. Missed therapy sessions may have reduced the effects of therapy. Most children who missed sessions did not make any clinically significant gains in intelligibility. Those children who had a week between therapy sessions due to prolonged absence from school (P10, P12, and P13) required prompting of their vocal cues when they returned. Intelligibility gains may have been greater if they had not have had to relearn their vocal cues in the middle of the therapy block.

Several children expressed a preference for face-to-face therapy, stating that in-person sessions would have allowed for more engaging use of physical resources. Additionally, direct interaction would have facilitated clearer hearing and visibility of their speech productions, enhancing perception. Previous research indicates that face-to-face delivery of SLT has been effective (Pennington, Miller, Robson and Steen, 2010; Pennington *et al.*, 2013).

8.5.1.3. Personalisation

This study enabled refinement of the SSA through personalising vocal cues to target individual speech deficits. Personalisation allowed different cues to be trialled throughout the therapy block for each child. If a child did not respond well to a particular cue, it could be replaced with another cue or reintroduced later. Cue names were adapted to help children understand them and use them correctly. For example, the youngest participant (P14) did not understand the cue ‘steady’, so it was changed to ‘slow’. P1 struggled with the cue ‘loud’ as it led her to shout, negatively affecting her vocal hygiene; so, her cue was modified to ‘strong’. In contrast, P10 preferred the cue ‘loud’.

Children progressed through the hierarchy of tasks at different rates. For instance, children with higher baseline intelligibility advanced to phrases and CS much quicker than those with lower baseline intelligibility. As the perceptual results show, these children generally had more intelligible SW productions pre-therapy and therefore it was not surprising that they could advance on to CS quicker. Therapy targets moved from universal target words to target words based on children’s interests (which contained target phonemes and syllable count where possible) to keep children with low baseline intelligibility motivated when producing SWs and two- to three-word phrases. Moving images were used instead of static pictures to help with engagement. This method also encouraged the use of CS as they could name the picture and then go on to describe what was happening in the moving image, e.g., *“Spiderman is swinging”*.

The activities used to address words, phrases, connected speech and other speech difficulties were tailored to the children’s interests and targeted specific phonemes they struggled with. This individualised approach ensured that children were motivated to work on areas of difficulty while avoiding unnecessary focus on speech sounds or dysarthria characteristics that were not relevant to them, making therapy more efficient.

8.6. Limitations of the Study

8.6.1. Procedure

8.6.1.1. Screening

No additional screening tests were undertaken to rule out co-occurring phonological disorders. If children in this study had other phonological disorders, e.g., CAS, alongside their dysarthria then the personalised dysarthria intervention may not have been appropriate or they may need additional intervention, such as ReST, to make any intelligibility gains. This should be considered in future research.

8.6.1.2. Single Word Lists

The SW word lists (see Table 7) were designed to be as phonetically balanced as possible. Each list included a set number of words with word initial (WI) and word final (WF) singleton consonants representing various manners of articulation, as well as WI and WF consonant clusters, and both monosyllabic and polysyllabic words. Despite efforts to create phonetic balance, differences in vowels and specific phonemes within the lists contributed to pre-disposed variability, impacting comparison of acoustic profiling across time. For example, word two in Word List 1 ‘face’ has a naturally longer vowel than word two in Word List 2 ‘fish’.

8.6.1.3. Recording Quality and Standardisation

There were several challenges related to the quality of the recordings, which affected both listener transcription and the ability to take accurate acoustic measurements. Background noise interfered with some speech signals, obscuring softer speech and weak phoneme productions. Coupled with disordered speech, this made it difficult for some listeners to accurately perceive what the children were saying. Additionally, background noise was visible in the spectrograms and waveforms, likely influencing the recorded intensity values and diminishing the reliability of these measures. Although it was recommended that sessions be conducted in quiet environments, this was not always feasible due to limitations in available school rooms and the busy nature of home environments. These limitations mirror the realities of real-world practice, where similar challenges are likely to arise in clinical environments.

Furthermore, as highlighted in Section 8.2.3, the online nature of the intervention meant that standardisation of the recording process made by the TA or parent could not be closely monitored. Consequently, some speech samples may have inaccurately reflected the children's intensity, either overestimating or underestimating it. In-person recordings taken by the researcher, like in Pennington et al.'s (2019) study, would allow strict following of the recording protocol. An ideal recording protocol has been developed to produce the highest quality recordings appropriate for acoustic analysis (Vogel and Morgan, 2009). However, the ideal recording protocol involves the use of a stand-alone hard disc recorder, an independent mixer to attenuate the incoming signal, and a high-quality microphone in a sound attenuated room. Following this protocol is not feasible when research is being carried out in schools, due to the resources available.

8.6.1.4. Speech Samples

The children's recordings were segmented into individual single words (SWs) and phrases for the orthographic transcription task for several reasons. First, this process ensured that any extraneous speech, such as fillers or general conversation—which could contain sensitive information—was excluded from playback to the listeners. Additionally, not all phrases produced during the video description task were intended for transcription. Segmenting the recordings allowed those meeting the criteria outlined in the study protocol to be isolated. Finally, breaking the recordings into individual words and phrases enabled listeners to hear each item in isolation, allowing them as much time as needed to complete their transcriptions accurately. Parsing CS recordings into separate utterance sound files has also employed in research assessing the validity of the TOCS+ sentence intelligibility measure for children with CP and dysarthria (Hodge and Gotzke, 2014a).

Selecting appropriate cut points for CS phrases was challenging, as phrases were chosen based on semantic content and breath groups. Dysfluencies were removed from the beginning of phrases. Phrases with dysfluencies in the middle were excluded from analysis as they could not be omitted. For children like P4, who had a stammer, this approach posed additional difficulties since dysfluencies occurred throughout most of their CS. Removing dysfluencies at the start of phrases sometimes resulted in the truncation of word beginnings, further impacting intelligibility. To address this, any dysfluencies that led to partial phoneme omission were retained in the samples. Dysfluencies transcribed by listeners were ignored in analysis. Including speech characteristics such as P4's stammer in listener samples was essential, as it is a characteristic that affects his intelligibility and reflects his typical speech patterns.

Another challenge in selecting CS samples was the variation in utterance length. The children produced sentences of different lengths in response to the video clips. Some of these longer utterances could not be shortened without losing meaning or unintentionally cutting phonemes due to fast speech rate. For listeners transcribing longer utterances, the task was more cognitively demanding, requiring a stronger working memory capacity. According to Miller (1956), people typically recall between five and nine items in short-term memory. One way to address this issue could be to standardise the utterances, aiming for sentences of five to nine words. This approach might not reflect the natural speech patterns of some children, possibly affecting the representativeness of the intelligibility assessment. Moreover, asking children to produce standardised sentences would introduce additional demands, like reading or recalling and repeating specific phrases. Previous research has used spontaneous speech as a method to elicit CS (Pennington *et al.*, 2023) but limited the duration of the speech samples to 60 seconds. This resulted in a range of one to eleven words produced per phrase. In the current study, phrases were as long as 16 words in length. Limiting the duration of the CS sample may have reduced the number of words in an utterance, easing the demands required by the listener. However, this could have resulted in phrases being cut inappropriately so that they no longer made grammatical sense.

8.6.1.5. Listener Speech Sample Allocation

As only two distinct word lists were used, listeners encountered the same SW list at least twice, with some listeners hearing the same list three times by chance. This familiarity with the target words could have influenced their transcriptions, potentially resulting in an increased number of correctly perceived SWs — or fewer if target words were initially misperceived — compared to a scenario where they heard three different word lists. To mitigate this bias, listeners were randomly assigned three speech samples from three different children to prevent familiarisation with any individual child's speech characteristics. Similar methods have been used in other research to prevent learning effects of listeners (Platt, Andrews, Young and Quinn, 1980; Pennington *et al.*, 2013; Pennington, Miller, Robson and Steen, 2010).

Previous studies have used the CSIM to elicit SWs (Pennington *et al.*, 2013; Pennington, Miller, Robson and Steen, 2010). The CSIM has 200 lists reducing listener familiarity of the vocabulary tested but not all feature contrasts (e.g., a voiced vs voiceless alveolar plosive) are represented in a list. Furthermore, listeners are given a list of 12 phonetically similar words to the target to choose from. This may force listeners to select a word they did not perceive, consequently impacting the precision of estimates of sound identification, an issue that does not occur in orthographic transcription tasks.

8.6.2. Analyses

8.6.2.1. Orthographic Transcriptions

Several challenges emerged during the analysis of listener transcriptions. The difficulties identified during the transcription analysis were noted and this led to the development of a detailed protocol to standardise decision-making (see Appendix D.1). This protocol was informed by literature on measuring intelligibility as well as personal clinical reasoning. For instance, some phrases contained repeated words, such as "And then he tried to hit hit the pinata but but he but he couldn't." Where possible, phrases which featured repetitions were avoided, but this was not always possible given the other constraints on selecting phrases and if a child only produced phrases with repetitions. Not all listeners documented repetitions, resulting in a lower percentage of correctly perceived words during analysis, even though the overall meaning of the sentence was understood. This suggests that clearer instructions might have been necessary, such as specifying, "Write down all the words you hear, including any repeated words." While comprehensibility could be considered to acknowledge when the child's meaning is understood, the focus of this study was on speech intelligibility. Therefore, words that were omitted or transcribed incorrectly were marked as incorrect.

Another issue arose when listeners transcribed phonetically similar words that did not match the intended targets. For example, the target phrase “go in to” was misheard as “going to.” Additionally, listeners were instructed to mark an 'X' in their CS transcriptions when they heard a word but could not identify it. Not all listeners utilised the ‘X’, possibly because they did not hear the word or mistakenly perceived two monosyllabic words as a single polysyllabic word or because they forgot to use it or did not follow the instruction. This inconsistency made it challenging to align the transcribed words with the target phrases accurately. Consequently, this may have introduced inaccuracies into the CS percentage intelligibility scores due to some degree of guesswork in matching transcriptions to target phrases. This challenge was also experienced by Pennington et al. (2023) and could explain why fewer children made clinically significant gains in CS compared to SWs.

8.6.2.2. Acoustic Analysis

The limited availability of data restricted the scope of the acoustic analysis, preventing definitive conclusions about the therapy's impact on acoustic speech characteristics and their relationship with speech intelligibility. Because the words selected for acoustic analysis were predetermined, they did not encompass all the speech features targeted during therapy for each child, so observable changes were not always anticipated. Furthermore, changes may have occurred in targeted sounds in other words which were not analysed. The possibility of detecting potential covert changes undetectable by ear, which have been documented in other research (Pennington *et al.*, 2023), was also limited.

The use of spontaneous speech introduced numerous challenges for acoustically analysing CS. Variability in factors such as phrase length and phoneme compositions at different time points made it particularly difficult to compare the acoustic properties of speech pre- and post-therapy. This variability highlighted the complexity of conducting detailed acoustic analysis in a naturalistic context. However, eliciting CS through spontaneous speech has been reported to be the most ecologically valid method (Pennington *et al.*, 2023) and therefore findings may be more generalisable to children’s speech in real life, unlike findings from studies using repetition to elicit CS (Hustad, 2007).

8.7. Clinical Implications

The findings of the current study could help clinicians to make informed decisions about the SLT children with CP and dysarthria should receive. The NICE guidelines for managing CP in under 25s (NICE, 2017) recommend tailoring care to each individual's needs and providing personalised training in communication approaches to those involved in the care of a child with CP. They also recommend offering interventions to improve speech intelligibility to children with CP who have a motor speech disorder, use speech as their primary means of communication, and can engage with the intervention.

Results from this small study suggest that therapy was effective at improving intelligibility in children with CP and moderate-severe dysarthria but not in children with CP and profound dysarthria. Receiving personalised dysarthria therapy as part of a care plan may be beneficial for children with CP and mild, moderate, and moderate-severe dysarthria. However, more research should be conducted to establish the dosage required for each cue to allow acquisition and maintenance of new speech behaviours. Before implementing personalised dysarthria intervention in practice, the most efficient therapy needs to be developed so children can maximise their intelligibility as quickly as possible and not have to receive regular therapy throughout their childhood.

Positive speech changes were mainly reported by parents, SLTs, and TAs who were frequently prompting the children to use their vocal cues outside of therapy. Thus, incorporating vocal cues into school and home routines, by training familiar communication partners on how to implement vocal cues, may also enhance motor learning opportunities and help children generalise their speech skills.

Interventions should be customised not only to address each child’s unique speech characteristics and vocal cues but also to include therapy tasks based on their interests. This approach fosters motivation and engagement and promotes speech production. SLTs should assess children’s awareness of their vocal cues and their understanding of how to use them effectively. Allowing children to choose the names for their cues may enhance their ability to apply them. Difficulty in understanding or using cues can hinder progress. For example, P10's cues were changed from ‘strong’ and ‘steady’ to ‘loud’ and ‘slow’ in session 5. Introducing ‘loud’ and ‘slow’ earlier may have led to clinically significant gains for P10.

Transitioning swiftly to tasks involving CS is vital, as this mirrors typical daily interactions, promotes generalisation, and allows for a more ecologically valid comparison of real-life performance (Pennington and Hustad, 2019; Miller *et al.*, 2014). This may promote better gains in CS intelligibility as it enables more practice of vocal cues on CS. Therapy sessions should feature relatable, practical activities, particularly for older children, such as practising ordering food or discussing hobbies, to reinforce skills in real-world contexts. There are pros and cons to both in-person and online delivery of the personalised intervention. Most children expressed their preference for in-person delivery, but online intervention is preferred by families of children with motor disorders. Given that both methods of delivery have been found feasible and effective, children and families should be given a choice of delivery. NHS Trusts would need to evaluate information governance concerns before implementing online intervention (Shaw *et al.*, 2018). Furthermore, online intervention may exacerbate socioeconomic health inequalities, as it is only accessible to families with a computer and internet access (Pennington *et al.*, 2019). If an intervention is to be delivered online, clinicians should consider delivering initial assessments or therapy sessions in-person to build an initial rapport with the children to promote engagement in therapy (Shaw *et al.*, 2018).

All children in the current study demonstrated some level of intelligible speech during the screening assessment. As a result, offering the personalised dysarthria intervention was consistent with NICE guidelines (NICE, 2017). However, some children were perceived as completely unintelligible by unfamiliar listeners. For individuals with CP who have little/no intelligible speech, the NICE guidelines recommend the use of AAC. Introducing AAC devices into children’s care plans may be a suitable next step for children in this study who achieved 0% (or near 0%) intelligibility scores. Children with CP and more severe or profound dysarthria may benefit more from AAC devices, either as a primary mode of communication or as a tool to support and enhance their communication (Hustad *et al.*, 2019). AAC systems have provided individuals with reduced intelligibility a means to communicate and have improved their ability to participate in a wide range of activities (Gracia, Rumbach and Finch, 2020; Simion, 2014).

8.8. Recommendations for Future Research

8.8.1. Therapy and Recording Procedure

Re-transitioning from online to in-person therapy could offer significant benefits, given children's preference for face-to-face sessions and the successful delivery of SSA in person in previous studies (Pennington, Miller, Robson and Steen, 2010; Pennington *et al.*, 2013). In-person delivery should be trialled to assess the feasibility of using acoustic analysis to guide the intervention when recordings are taken directly by the research SLT. This approach could eliminate delays associated with transferring recordings, enabling weekly acoustic analysis.

In-person sessions would facilitate precise standardisation of the mouth-to-microphone distance, improving the reliability of acoustic measurements, such as intensity. A greater mouth-to-microphone distance for some participants could result in an increase in background noise in their recordings, which may distort the quality of the acoustic signal. While this study used built-in microphones to avoid discomfort, head-mounted microphones, which have been used in other dysarthria research (Rusz, Tykalova, Ramig and Tripoliti, 2021; Pennington *et al.*, 2013), could provide a consistent mouth-to-microphone distance. However, head-mounted microphones have limitations, such as potential interference to the microphone cable from involuntary movements affecting microphone position (Rusz, Tykalova, Ramig and Tripoliti, 2021). Future studies should explore head-mounted microphones for better acoustic and perceptual intelligibility evaluation while addressing potential challenges, such as background noise and signal quality on spectrograms.

8.8.2. Eliciting and Scoring Speech Samples

The use of a spontaneous speech task to elicit CS posed challenges for acoustic analysis due to variations in phoneme composition and phrase lengths across participants, complicating direct comparisons. Creating accurate target gold transcriptions for CS was also difficult. Future studies should consider using both a spontaneous speech task, which maximises ecological validity (Flipsen Jr, Hammer and Yost, 2005), and a repetition task. Spontaneous tasks better reflect everyday speech and can be analysed perceptually, as used by Pennington et al. (2019; 2013; 2010). Repetition tasks, however, enable precise acoustic analysis and intelligibility comparisons across timepoints by using consistent target phrases, though they may not fully generalise to real-life speech (Hustad, 2007).

The limited number of WI and WF consonant clusters in SW word lists prevented analysis of their effects on production accuracy and intelligibility. Future word lists should include more words with WI and WF consonant clusters while maintaining early-acquired vocabulary to ensure younger children do not perceive them as non-words. To address variability in intelligibility at pre-therapy timepoints (as discussed in Section 8.5.1.1), longer word lists of 25–30 words could be used, as these have shown similar reliability to 50-word lists (Pennington *et al.*, 2019). Alternatively, using the same word list at both pre-therapy timepoints could reduce variability, though it risks learning effects and would require more listeners to avoid familiarity bias during orthographic transcription.

To improve the listener transcription task (see Section 8.6.2), clearer, more comprehensive listener instructions should be developed. This would facilitate the calculation of percentage intelligibility scores and enhance the accuracy and reliability of perceptual analysis.

8.8.3. Analysing Speech Samples

This study was limited by the lack of acoustic data to complete acoustic analysis on CS. Future research should aim to examine the acoustic changes in CS to see whether these are in line with acoustic changes found in SWs. Future research should investigate acoustic changes in CS to identify potential covert changes undetectable by ear, as highlighted by Pennington et al. (2023) who observed nasalisation of /d/ to differentiate between /t/ and /d/, despite both targets being perceived as [d].

Another limitation was the use of the same five SWs for acoustic analysis across participants, which overlooked individual differences in speech characteristics. Future studies should select SWs (and CS) for acoustic analysis tailored to each child's unique speech traits and expected changes post-therapy.

To identify the vocal cues contributing to specific speech changes, cues could be introduced incrementally, with weekly acoustic measurements. One vocal cue should be added each week so that the dosage required to acquire new speech behaviours can be tested and so weekly acoustic measurements better represent the effect of the most recent cue on intelligibility. It is important to consider that children may have delayed responses to certain cues, so complete certainty cannot be guaranteed. Fewer words and phrases should be elicited weekly as preparing the data and completing acoustic analysis on 20 words and five phrases per child each week to inform the intervention is not feasible. Future research needs to develop a smaller dataset to minimise the burden of acoustic analysis, but still be effective and efficient at informing therapy. The data undergoing acoustic analyses should contain obstruent sounds, as these are challenging for children with CP and dysarthria to produce but are thought to be the most identifiable post-therapy (Pennington *et al.*, 2023), and consonant clusters due to the lack of research on the intelligibility of clusters in the speech of children with CP and dysarthria, in both WI and WF position.

The lack of acoustic data 1 Week Post-Therapy may have missed immediate changes in speech characteristics. Future studies should collect acoustic data both 1 Week Post- and 12 Weeks Post-Therapy to assess the immediate and sustained effects of therapy on acoustic features, offering deeper insights into children's responsiveness to vocal cues.

Acoustic analysis should mainly focus on acoustic profiling of target phonemes, looking at the key visual patterns on the waveform and spectrogram, as articulation appeared to be a stronger predictor of intelligibility than duration and intensity measures. The acoustic measures of duration, speech rate, and intensity should be carried out on CS rather than SWs. Duration of SWs is not very informative due to SWs (especially monosyllabic words) being inherently short. Assessing duration and intensity in SWs may not fully capture the variability and coarticulatory effects present in natural speech. Taking acoustic measures from CS will allow for a more comprehensive assessment of acoustic characteristics and changes in the speech of children with CP and dysarthria. Children's speech rate and ability to sustain strong speech signals across longer utterances can be investigated in conditions more representative of their daily communication.

8.8.4. Continuing Research Investigating Personalisation of Dysarthria Intervention

Based on the intelligibility improvements observed in some children following the personalised dysarthria intervention, future research should continue exploring this approach, focusing on children with CP presenting with mild, moderate, or moderate-severe dysarthria. For children with very severe/profound dysarthria, interventions should prioritise the use of AAC devices. Research should examine whether individual characteristics, such as severity of the motor impairment, language comprehension, and cognition influence therapy outcomes, when there is less variation in dysarthria severity.

In-person delivery of the personalised intervention should be assessed to determine if it yields greater gains than online therapy, as interactive in-person activities may enhance engagement and outcomes.

Following further exploration of this personalised approach, conducting an RCT may be warranted to evaluate its effectiveness in clinical practice. Pennington et al. (2019) demonstrated the feasibility of an RCT to investigate intensive SLT delivered online for children with CP, with parents expressing willingness to participate due to the acceptability of therapy in a pilot study. Considering the comparable findings of improved intelligibility in this study and prior research by Pennington et al. (2010; 2013) involving in-person delivery of non-personalised SSA, as well as the feasibility of an RCT for online SLT, it is likely that an RCT could effectively assess the outcomes of online personalised dysarthria therapy.

SLT research lacks robust evidence, and pragmatic RCTs, which reflect real-world clinical contexts, are crucial. The eligibility criteria used in pragmatic RCTs is broader so that participants are more representative of clinicians' typical caseloads. The clinical setting is also similar to usual service delivery, with fewer resources required, flexibility in delivery of intervention, ease of follow-up, and primary outcomes relevant to patients (Dodd, 2021). Pragmatic research has been recommended in SLT to promote obtaining data which develops outcomes for real-world contexts (Schliep, Alonzo and Morris, 2017). The proposed RCT following this research should aim to be pragmatic by focusing on patient-centred goals through personalisation of the intervention.

8.9. Conclusion

Personalised speech and language therapy resulted in intelligibility gains in both SWs and CS for children with CP and dysarthria, with greatest gains observed 12 Weeks Post-Therapy. No single perceptual predictor variable has been found to account for changes in intelligibility, however the perception of WI and WF consonants have improved over time. Acoustic profiling seems to suggest that articulation is a strong predictor of intelligibility but future analysis should look at duration and intensity measures in CS. Gains in intelligibility were most notable for children with moderate to severe dysarthria rather than children with profound dysarthria. For children with profound motor speech impairments, SLT should focus on AAC to support their communication. Future research should further examine the utility of acoustic measures to inform decision making in personalising the dysarthria therapy. In-person delivery of the intervention may make weekly acoustic analysis more feasible.

Personalisation of the SSA shows promise and should be investigated further to assess the ordering and duration of vocal cues for individuals, as which cues work best and for whom has not yet been established. Research needs to test the effects of individual cues, given with sufficient repetition to allow acquisition and maintenance of new speech behaviours. The aim of future research should be to develop the most efficient therapy, so children can maximise their intelligibility as quickly as possible. Perceptual and acoustic measures should be minimal to reduce burden and inform therapy efficiently.

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Appendices

Appendix A. Mayo Clinic Form (Duffy, 2005)

Mayo Clinic Form for rating deviant speech characteristics associated with dysarthria From Duffy, 2005			
Name: Speech diagnosis: Neurologic diagnosis: Age: Date of examination: **Dysarthria Rating Scale** Rate speech by assigning a value of 0-4 to each of the dimensions listed below (0 = normal; 1 = mild; 2 = moderate; 3 = marked; 4 = severely deviant). When appropriate, use + to indicate excessive or high and – to indicate reduced or low.			
Pitch	Pitch level (+/-): Pitch breaks: Monopitch: Voice tremor: Myoclonus: Diplophonia:	**Respiration**	Forced inspiration – expiration: Audible inspiration: Inhalatory stridor: Grunt at end of expiration:
Loudness	Monoloudness: Excess loudness variation: Loudness decay: Alternating loudness: Overall loudness (+/-):	**Prosody**	Rate: Short phrases: Increased rate in segments: Increased rate overall: Reduced stress: Variable rate: Prolonged intervals: Inappropriate silences: Short rushes of speech: Excess and equal stress:
Voice quality	Harsh voice: Hoarse (wet): Breathy voice (continuous): Breathy voice (transient): Strained-strangled voice: Voice stoppages: Flutter:	**Articulation**	Imprecise consonants: Prolonged phonemes: Repeated phonemes: (assimilation) Irregular articulatory breakdowns: Distorted vowels:
Resonance (& intraoral pressure)	Hypernasality: Hyponasality: Nasal emission: Weak pressure: Consonants:	**Other**	Slow AMRs: Fast AMRs: Irregular AMRs: Simple vocal tics: Palilalia: Coprolalia:

Appendix B. Participant Information Sheets

B.1. Participant Information Sheet

Personalised Speech Therapy for Children and Young People with Cerebral Palsy

Parent Information Sheet

I would like to invite your child/young person to take part in this research study. Before you decide, I would like you to understand why the research is being done and what it would involve. I (Carol-Ann McConnellogue – the research speech and language therapist) will go through this booklet with you and answer any questions you have.

If you would like to, please discuss the study with others (including your local speech and language therapist and family) to help you decide whether to take part. Please ask the researcher about anything that is unclear.

Why is the research being done?

A therapy has been developed to help children and young people with cerebral palsy speak more clearly. After the therapy most of the children/young people were easier to understand. The children and young people told us that the therapy was acceptable. This study will test if the therapy can be improved by personalising it to each child/young person's individual speech characteristics and needs.

Sometimes it is difficult for children and young people to get to speech and language therapy appointments. This study will also test if I can assess children and young people's speech over the internet.

Why has my child/young person been chosen?

I have asked speech and language therapists in England if they are working with children and/or young people who have cerebral palsy and are 5 to 19 years old. Your child/young person's speech and language therapist has said that your child/young person has cerebral palsy and speech difficulties and that you may be interested in your child/young person taking part in the study.

Does my child/young person have to take part?

No, you and your child/young person do not have to join this study. I will describe the study to you; if you want your child/young person to take part, I will ask you to sign a consent form. You and your child/young person can stop being part of the study at any time, without giving a reason, but we will keep information about your child/young person that I already have.

If you do not want to take part or if you choose to withdraw your child/young person from the study, this will not affect the treatment your child/young person would normally receive in any way. If you do not want your child/young person to take part they will continue their usual speech and language therapy.

What is involved in joining the study?

If you decide that your child/young person can take part in the study, they will receive the six-week therapy. They will have three therapy sessions a week. Two therapy sessions per week will be carried out at school. The third session will be carried out at home. Their speech will be recorded before, during, and after the therapy so that their progress can be monitored. Listeners will hear the recordings, write down what they think the child/young person has said, and rate how much they understand the child/young person from one to seven. I will work out how many words listeners heard correctly and if children/young people were easier to understand after therapy.

Will my child/young person definitely be involved in the study if I give consent for them to take part?

If you decide that your child/young person can take part in the study, I will check their language comprehension, how many different speech sounds they can produce, if they are able to see pictures and videos clearly, if they can follow simple instructions, and if they can hear the difference between speech sounds. I will tell you if your child/young person has difficulty in any of these areas and is not able to join the study.

If you agree that your child/young person can take part in the study, I will contact their school/college to ask if therapy sessions can take place there. Teaching assistants will need to accompany children and young people in the therapy and recording sessions. If the school/college does not agree to the research taking place, then therapy session can take place when children/young people are at home.

The therapy

I am a speech and language therapist. I am doing this work as part of a PhD at Newcastle University. I will give therapy to the children and young people who join the study.

Children will receive three therapy sessions a week for six weeks. Most sessions will take place while the children and young people are at school. I will arrange sessions so that they are not missing important lessons. Children and young people will do the therapy over their school computer. Each therapy session will last for 30-40 minutes each. One session per week will occur at home, so that I can show you the therapy.

The therapy sessions will concentrate on controlling breathing. Phrases will be split into small "chunks" so that children and young people can use a loud clear voice across a phrase. I will work out which instructions help children and young people to speak clearer (e.g., big voice, loud, smooth). Exercises in the therapy will start by helping children and young people to coordinate their breathing and speech in simple vowel sounds (e.g., "ah"), with them starting to speak as soon as they start to breathe out. Therapy will then move on to phrases and changing pitch in sentences and conversation. It is hoped that by controlling their breathing and speaking more loudly the children and young people will produce speech sounds that are more controlled, easier to hear and understand.

Speech recordings

The children and young people's speech will be audio recorded 14 times: four times before therapy; once a week during the six-week therapy; and four times after therapy has ended. No video recordings will be taken.

The recordings taken before and after the six-week block of therapy will take about 20 minutes to complete. The speech recorded will include one vowel ("ah"), 20 single words, and five phrases describing a video clip. This will be repeated twice at each session. The children and young people will also be recorded doing an articulation assessment once before and once after therapy to see how many sounds in the English language they can produce.

The speech recordings taken during the six-week therapy will take around 10 minutes to complete. Only six single words, three phrases describing video clips, and one vowel (“ah”) will be recorded during the therapy sessions. These recording sessions will happen on the third therapy session each week.

Most recordings will be taken at school by the Teaching Assistant/usual Speech and Language Therapist. One recording will take place when your child/young person is at home, on the same day their therapy is at home. I will provide you and the school with a small recording device. I will train you, the Teaching Assistant and/or usual Speech and Language Therapist on how to carry out the recordings. The recordings will need to be uploaded on to a computer and sent to me via https://dropoff.ncl.ac.uk/ which is a secure file transfer used at Newcastle University. All files transferred across the Newcastle University File Drop-off network are encrypted. I will train you and the school on how to do this.

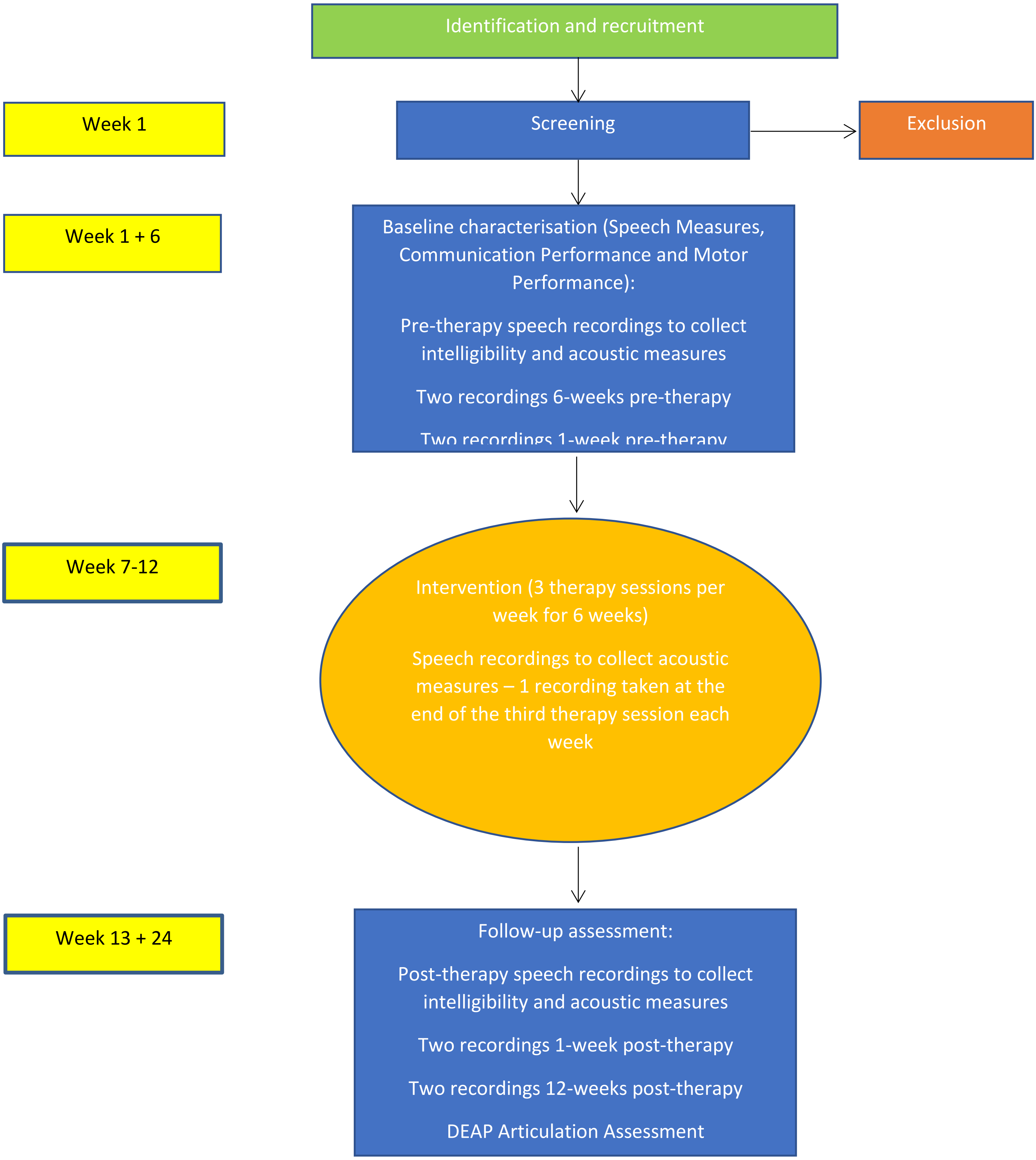
The audio recorders will remain with the school and at your home until all recordings have been made. Audio recorders will need to be posted back to the researcher using special delivery. I will provide you and the school with a pre-paid stamped envelope. No identifiable information will be held on the audio recorder.

The speech recordings will be downloaded by the researcher and split into individual words/utterances. Each word/utterance will be saved separately as individual files and each file will be stored in encrypted, password protected folders on the Newcastle University server. The passwords will only be known by the researcher and researcher’s supervisor [Dr Lindsay Pennington]. Dr Lindsay Pennington is also the Chief Investigator for this study. The speech recording files will be identified by the child/young person’s unique identification code only. Newcastle University has a data storage policy of 10 years. After this 10-year period the speech recordings will be deleted if no consent has been given for use of the audio recordings in future research.

People who do not know anything about the children/young people will listen to the recordings. I will calculate the number of words listeners hear correctly, to see if children and young people’s speech is easier to understand after the therapy. The listeners will also rate each speech recording from 1 to 7 based on how intelligible they find the speech (1 being ‘never intelligible’; 7 being ‘always intelligible’).

All data on the audio recordings will be non-identifiable, with no names of people or places included, to maintain participant confidentiality.

Study Flow Chart



What about alternative treatments?

Alternative treatments to the therapy being tested in the study are available from your child/young person's speech and language therapist. Your child/young person's therapist can tell you which treatments are available. Currently, the exact benefits of each different type of therapy are not known and we do not know which type of therapy is most effective in helping children and young people's speech. This research study will help us to begin to answer this question.

What are the possible side effects of the therapy?

The personalised therapy aims to teach children and young people to speak with a louder and clearer voice. This takes practice and the therapy involves repeating speech exercises. Practicing the speech exercises may be tiring for some children and young people. In the sessions the exercises are varied, so that children and young people do not become bored. If children/young people seem very tired or distressed, then I will stop the therapy session.

Possible benefits from joining the study

The personalised therapy may help your child/young person's speech become clearer.

Possible disadvantages from joining the study

The therapy provided in this study will mean that your child/young person may miss some of their usual lessons/activities in school. You, your child/young person, and their teacher will be involved in scheduling the therapy sessions so that they cause minimal disruption to your child/young person's learning.

If your child/young person takes part in the study, they will not receive other speech and language therapy for six weeks during the new therapy and for 12 weeks after it has finished. This is to help us work out the effects of the personalised therapy given in the study when it is given on its own, rather than it adding to the effects of the therapy children and young people usually receive.

When will the study stop?

Children and young people will be involved in the study for 24 weeks. After this I will contact you with a report about the results.

What if there is a problem?

If you have a concern about any aspect of this study, you should ask to speak with your child/young person's usual speech and language therapist, the research speech and language therapist [Carol-Ann McConnellogue], or the research supervisor [Dr Lindsay Pennington] who will do their best to answer your questions. If you remain unhappy and wish to complain formally, you can do this through the NHS Complaints Procedure.

If you are harmed and this is due to someone's negligence then you may have grounds for a legal action for compensation against Newcastle Upon Tyne Hospitals NHS Trust, but you may have to pay your legal costs. The normal National Health Service complaints mechanisms will still be available to you.

Newcastle University is acting as the sponsor for this study. Newcastle University has insurance in place to meet the potential legal liability for harm to participants arising from the management and design of this research. The legal liability will be covered by Public Products and Employer's Liability Policy held by Newcastle University.

If you or your child/young person is harmed during the research and you wish to make a complaint to the university, please contact them using this email: sponsorship@newcastle.ac.uk

If you wish to raise a complaint to Newcastle University on how any personal data has been handled, you can contact the Data Protection Officer using the email address below.

Data Protection Officer Email: rec-man@newcastle.ac.uk

If you are not satisfied with your response or believe your personal data has been processed in a way that is not lawful, you can complain to the Information Commissioner's Office using the telephone number below. You can also follow the link to their website for more information or to use their live chat.

Information Commissioner's Office Telephone Number: 0303 123 1113

Information Commissioner's Office Website: https://ico.org.uk/global/contact-us/

How will we use information about you? / Will information be confidential?

We will need to use information from you and your child/young person for this research project.

This information will include you and your child/young person's names, your contact details, and the information collected for the study. People will use this information to do the research or to check your records to make sure that the research is being done properly.

People who do not need to know who you are will not be able to see your name, your child/young person's name, or your contact details. Your child/young person's data will have a code number instead.

We will keep all information about you safe and secure. Information collected about your child will be kept in locked offices and on encrypted password protected Newcastle University computers. The information collected will only be available to study research staff.

Once we have finished the study, we will keep some of the data so we can check the results. We will write our reports in a way that no-one can work out that your child/young person took part in the study.

What are your choices about how your information is used?

We need to manage you and your child/young person's records in specific ways for the research to be reliable. This means that we won't be able to let you see or change the data we hold about you and your child/young person.

If you agree to take part in this study, you and your child/young person will have the option to take part in future research using your child/young person's data saved from this study.

Where can you find out more about how your information is being used?

You can find out more about how we use your information using one of the following options:

- At www.hra.nhs.uk/information-about-patients/
- At www.hra.nhs.uk/patientdataandresearch
- By asking one of the research team (contact details below)
- By contacting the Data Protection Officer: rec-man@newcastle.ac.uk

How long will the study data collected be kept for?

Information will be stored for at least 10 years and then disposed of securely. The records we will make for the study are:

- Audio recordings of your child/young person's speech
- Written descriptions of your child/young person's speech production and movements for speech
- Written records of therapy
- Online score sheets used by listeners when listening to your child/young person's recorded speech
- Computer files containing copies of your child/young person's speech (as back-ups to the originals), number of words heard correctly by listeners, and intelligibility ratings of your child/young person's recordings provided by the listeners

Some information will be passed on to your child/young person's usual speech and language therapist and/or neurodisability paediatrician. The health professionals involved in your child/young person's care need to be aware of their participation and progress in the study as involvement in the study may account for changes in their motor speech behaviours. Information shared with the speech and language therapist and neurodisability paediatrician will include:

- Knowledge that they are participating in the study
- Copies of the consent forms stored in their speech and language therapy notes
- A brief written summary about the therapy provided

All information collected for the research will be handled according to the Data Protection Act 1998.

The research has been approved by East Midlands – Nottingham 1 Research Ethics Committee.

What if new information becomes available?

If new information becomes available about the therapy the research speech and language therapist will discuss this with you. You can withdraw your child/young person from the study at any stage. Your local speech and language therapist will be able to discuss alternative treatments with you.

If the study is stopped for any other reason, you will be told why, and your child/young person's continuing speech and language therapy with their local therapist will be arranged.

What will happen to the results of the study?

The findings of the study will be written-up for publication in journals read by speech and language therapists and other health workers, and in the researcher's PhD Thesis. All results will be anonymous. None of the children or young people who participated in the study will be identifiable in the reports. Copies of a summary report will be provided to you. Full details of the study will be available from Carol-Ann McConnellogue.

If you give permission, information gathered from this study (e.g., recordings of speech) may be used in future research. No identifiable information about you or your child/young person will be used.

Who is organising and funding the research?

This study is organised and conducted by Carol-Ann McConnellogue (PhD Student and Speech and Language Therapist) at the Population Health Sciences Institute at Newcastle University. The sponsor of the study is Newcastle University. The sponsor is the organisation which takes overall responsibility for appropriate arrangements being in place to set up, run and report a research project. All health research needs a sponsor.

Who has reviewed the study?

The following Authorities and Committees who look at the way health research is done have reviewed the study and said they are happy with study plans:

- The East Midlands – Nottingham 1 NHS Research Ethics Committee
- The Research and Development Department of your NHS trust

Contact for Further Information

If you would like further information or need to contact someone during the study, please call/email:

Dr Lindsay Pennington (Research Supervisor and Chief Investigator)

Tel: +44 (0) 191 282 1360

Email: lindsay.pennington@newcastle.ac.uk

Carol-Ann McConnellogue (Research Speech and Language Therapist)

Email – c.mcconnellogue2@newcastle.ac.uk

Thank you very much for taking the time to read this information. If you agree to your child/young person taking part in the study, please sign the attached online parent consent form (by typing your name). Please email the consent form back to me using the above email address. An easy read child/young person information sheet, easy read consent form and/or child assent form has also been attached. Your child/young person will be required to sign the easy read consent form by typing their name or complete the assent form by typing a tick in the box (where physical skills allow). Please email the child/young person consent/assent forms back to me.

A paper copy of the information sheet and consent form can be requested. Please post the paper copies back to me using the envelope provided (no stamp needed).

B.2. Young Person Participant Information Sheet

Personalised Speech Therapy for Children and Young People with Cerebral Palsy

What is this study about?

This research is about the speech of young people with cerebral palsy.

People with cerebral palsy are sometimes hard to understand. I want to find out if a speech therapy can help children and young people with their speech.

Why have I been asked to take part?

I want children and young people with cerebral palsy to take part in a study.

Your parent has said we can tell you about the study.

Therapy

You will have therapy 3 times a week for 6 weeks.

You will have the therapy at school.

The therapy will happen on a video call using a school computer.

You will practice talking loudly, clearly, and slowly.

I will not be at your school.

Recording speech

I will record your speech before, during, and after therapy. I will record you saying words and sentences.

People who do not know you will listen to some of your recordings.

They will write down what they hear. I will work out how many words they hear correctly.

The same people will say how easily they understand your speech.

I will also record some of your therapy sessions. Only the research team (me and Dr Lindsay Pennington) will listen to these recordings. The therapy session recordings are to make sure I am carrying out the therapy in the same way each time.

Will it help my speech?

This study may make your speech clearer. People may understand you better.

Your parents/carers will be asked questions about your speech before and after the therapy. They will tell me if they think your speech has changed after the therapy. They will tell me if people can understand you better. This will let me know if the therapy has worked.

What do I do next?

If you want to take part in the research, please complete the online consent form.

Email it back to me using the email address below.

If you have a paper copy, post it back to me. You do not need a stamp for the envelope.

I will then visit you at school to check whether you can have the therapy. A member of staff will be in the room whilst I carry out the checks. I have an Enhanced DBS which allows me to work with children.

What happens to the information I give?

The information you give will be kept private. Your teaching assistant, usual speech and language therapist or a family member may sit with you during the therapy session. Only the researcher and whoever is with you in the therapy will know what you have said.

Do I have to take part?

No. You can choose to take part or not. Choosing not to take part will not affect your usual speech therapy.

Who else is taking part?

Other children and young people aged 5 to 19 years will take part in the study.

Other children and young people will not be at your therapy sessions.

How will I find out the results of the study?

I will send you a summary of the results.

Who is doing this study?

I am a student at Newcastle University is doing the study. My name is Carol-Ann McConnellogue. I am a Speech and Language Therapist.

The study is supported by the NHS.

Can I talk to someone before taking part?

Yes. If you have any questions or want to find out more about the study, please contact Dr Lindsay Pennington (Research Supervisor and Chief Investigator) or Carol-Ann McConnellogue (Research Speech and Language Therapist) by phone or email.

Telephone number: +44 (0) 191 282 1360 (Dr Lindsay Pennington)

Email address: lindsay.pennington@newcastle.ac.uk

Email address: c.mcconnellogue2@newcastle.ac.uk

What if I have worries?

If you have any worries about the study, you can contact Dr Lindsay Pennington who is teaching Carol-Ann.

Appendix C. Speech, Communication and Motor Performance Measures

C.1. Viking Speech Scale

Descriptions of children's speech taken from Murray, Pennington, Mjøen and Andrada (2011):

Descriptions of children's speech

I. Speech is not affected by motor disorder.

> *Children in Level I will be following the usual pattern of speech development. They may have some speech immaturities, similar to other children of their age/developmental level.*
>
> *Children in Level II have speech that is affected by their motor disorder. Their speech is usually understandable but is not following the usual pattern of development and does not sound like children of their age/developmental level.*

II. Speech is imprecise but usually understandable to unfamiliar listeners.

Loudness of speech is adequate for one to one conversation. Voice may be breathy or harsh sounding but does not impair intelligibility. Articulation is imprecise; most consonants are produced, but deterioration is noticeable in longer utterances. Although difficulties are noticeable, speech is usually understandable to unfamiliar listeners ***out of context***.

> *Children in Level II have speech that is affected by their motor disorder. Their speech may sound weak, slushy, slurred or loudness may be inappropriate but is usually understandable without contextual cues.*
>
> *Children in Level III will usually have speech that is severely affected by their motor disorder at multiple levels (e.g. breath control, vocal cord movement/voice, articulation). The severe difficulties that children experience in controlling each level act together to make the children's speech very difficult to understand without contextual cues.*

III. Speech is unclear and not usually understandable to unfamiliar listeners out of context.

Difficulties controlling breathing for speech - can produce one word per utterance and/or speech is sometimes too loud or too quiet to be understood. Voice may be harsh sounding; pitch may change suddenly. Speech may be markedly hyper nasal. A very small range of consonants are produced. The severity of the difficulties makes the speech difficult to understand out of context.

> *Children in Level III use speech as a method of communication. Their speech may be understandable to unfamiliar adults when they speak in single words or occasional words may be understood within longer phrases.*
>
> *Children in Level IV may produce vocalisations but cannot produce any words or word approximations that unfamiliar listeners can understand out of context.*

IV. No understandable speech.

C.2. Intelligibility in Context Scale

ICS form taken from McLeod, Harrison and McCormack (2012):

Intelligibility in Context Scale (ICS)

(McLeod, Harrison, & McCormack, 2012)

Child's name:__________

Child's date of birth:__________ Male/Female:__________

Language(s) spoken:__________

Current date: __________ Child's age:__________

Person completing the ICS:__________

Relationship to child:__________

The following questions are about how much of your child's speech is understood by different people. Please think about your child's speech over the past month when answering each question. Circle one number for each question.

	Always	Usually	Sometimes	Rarely	Never
1. Do you understand your child[1]?	5	4	3	2	1
2. Do **immediate members of your family** understand your child?	5	4	3	2	1
3. Do **extended members of your family** understand your child?	5	4	3	2	1
4. Do your **child's friends** understand your child?	5	4	3	2	1
5. Do **other acquaintances** understand your child?	5	4	3	2	1
6. Do your **child's teachers** understand your child?	5	4	3	2	1
7. Do **strangers**[2] understand your child?	5	4	3	2	1
TOTAL SCORE =	/35				
AVERAGE TOTAL SCORE =	/5				

[1] This measure may be able to be adapted for adults' speech, by substituting *child* with *spouse*.
[2] The term *strangers* may be changed to *unfamiliar people*

Further information: McLeod, S., Harrison, L. J., & McCormack, J. (2012). The Intelligibility in Context Scale: Validity and reliability of a subjective rating measure. *Journal of Speech, Language, and Hearing Research*, *55*(2), 648-656. http://jslhr.asha.org/cgi/content/abstract/55/2/648

McLeod, S., Harrison, L. J., & McCormack, J. (2012). *Intelligibility in Context Scale*. Bathurst, NSW, Australia: Charles Sturt University. Retrieved from http://www.csu.edu.au/research/multilingual-speech/ics. Published November 2012.

C.3. Communication Function Classification System

Descriptions taken from Hidecker et al., (2011):

Communication Function Classification System (CFCS) for Individuals with Cerebral Palsy

I. Effective Sender and Receiver with unfamiliar and familiar partners.
The person independently **alternates between sender and receiver** roles with most people in most environments. The communication occurs easily and at a **comfortable pace** with both **unfamiliar and familiar conversational partners**. Communication misunderstandings are quickly repaired and do not interfere with the overall effectiveness of the person's communication.

II. Effective but slower paced Sender and/or Receiver with unfamiliar and/or familiar partners. The person independently **alternates between sender and receiver** roles with most people in most environments, but the **conversational pace is slow** and may make the communication interaction more difficult. The person may need extra time to understand messages, compose messages, and/or repair misunderstandings. Communication misunderstanding are often repaired and do not interfere with the eventual effectiveness of the person's communication with both **unfamiliar and familiar partners**.

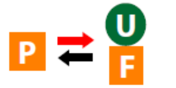
III. Effective Sender and Receiver with familiar partners. The person **alternates between sender <u>and</u> receiver roles with familiar** (but not unfamiliar) conversational partners in most environments. Communication is **not consistently effective** with most **unfamiliar partners**, but is **usually effective** with **familiar partners.**

IV. Inconsistent Sender and/or Receiver with familiar partners. The person does **<u>not</u>** consistently alternate **sender and receiver** roles. This type of inconsistency might be seen in different types of communicators including: a) an occasionally effective sender and receiver; b) an effective sender but limited receiver; c) a limited sender but effective receiver. Communication is **sometimes effective** with **familiar partners**.

V. Seldom Effective Sender and Receiver even with familiar partners. The person is limited as both a **sender and a receiver.** The person's communication is difficult for most people to understand. The person appears to have limited understanding of messages from most people. Communication is **seldom effective** even with **familiar partners.**

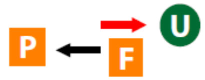
Key
P Person with CP
U Unfamiliar Partner
F Familiar Partner
—— Effective
••••• Less effective

I.



The difference between Levels I and II is the **pace** of the conversation. **In Level I**, the person communicates at a **comfortable** pace with little or no delay in order to understand, compose a message, or repair a misunderstanding. **In Level II**, the person **needs extra time** at least occasionally.

II.



The differences between Levels II and III concern **pace and the type of conversational partners. In Level II**, the person is an effective sender and receiver with all conversational partners, but pace is an issue. **In Level III**, the person is consistently effective with familiar conversational partners, but not with most unfamiliar partners.

III.

The difference between Levels III and IV is **how consistently the person alternates between sender and receiver roles with familiar partners. In Level III**, the person is generally able to communicate with familiar partners as a sender *and* as a receiver. **In Level IV**, the person does not communicate with familiar partners consistently. This difficulty may be in sending and/or receiving.

IV.

The difference between Levels IV and V is the **degree of difficulty that the person has when communicating with familiar partners. In Level IV**, the person has some success as an effective sender and/or an effective receiver with familiar partners. **In Level V**, the person is rarely able to communicate effectively, even with familiar partners.

V.

C.4. Functional Communication Classification System

Descriptions taken from Barty, Caynes and Johnston, (2016):

FCCS

Functional Communication Classification System (FCCS)

I. An effective communicator in most situations.

- Can **independently** communicate a wide variety of messages/topics to familiar and unfamiliar people in most environments.

II. An effective communicator in most situations, but does need some help.

- Can communicate a variety of messages/topics to familiar people but may experience some difficulties with unfamiliar people/topics and environments.
- Needs some help/support with some activities, or situations, where success may depend on environmental factors/context and with unfamiliar communication partners such as:
  - prompt questions to initiate with unfamiliar listeners or situations
  - repetitions (to make themselves understood)
  - speech loudness
  - short phrasing for breath control or oral motor control
  - extra time
- An AAC user who requires assistance with set up, and/or programming; and whose listener may need some assistance with orientation/interpretation of AAC strategies.
  [Note the type of AAC system on the cover page.]

III. An effective communicator in some situations. Can communicate a small range of messages/topics to most familiar people.

- Effective communicator with familiar people and activities and in familiar settings about their needs and wants, and things that are happening.
- Requires assistance with unfamiliar people/topics and environments.
- May use "conventional gestures" such as pointing, movements (e.g. waving), eye contact and/or vocalisations (e.g. ah, ehya), to gain attention or start the interaction.
- Relies on a familiar communication partner to interpret AAC or speech attempts, and to prepare, set up and support communication.

IV. Assistance is required in most situations, especially with unfamiliar people and environments. Communicates daily/routine needs and wants with familiar people.

- Can initiate and attract attention but needs a familiar person who is familiar with their routine, recent/significant experiences and likes and dislikes, and to interpret their communication.
- Responds to familiar voices, sounds, and routines using body movement, facial expression, and vocalisation.
- Can anticipate familiar activities and routines.
- Accepts, rejects/refuses and/or protests – from offered choices. This may be by using body movements or vocalisations.

V. Communicates unintentionally with others, using movement and behaviour.

- Daily/routine needs and wants are interpreted by familiar people from observation of the individual's emotional state, body movement and behaviour.
- Needs full assistance from a familiar person to observe, interpret movements and behaviours, anticipate, and problem solve based on their experience, training and observation.

Distinction between levels I and II: Children in level I will independently tell a range of people (including family, friends and other people) what they want to about things that are happening, have happened, or might happen. They can tell tales, talk about pretend/imagined events and use their communication skills to work out a problem. They will repeat or persist if not understood.

Children in level II will have difficulty communicating with some unfamiliar people and, although they may tell tales, talk about pretend/imagined events and use their communication skills to work out a problem, they do need some help/support with ensuring they are understood.

Distinction between levels II and III: Children in Level II do not need listeners who have special training in order to understand their message. AAC users in Level II may need "set up" help but can communicate about events in the near future or past.

Children in Level III can communicate without support about events in the "here and now" and about their wants and needs. They do need support from a familiar person to communicate about things that have happened or are going to happen.

Their "listeners" need to know or be trained to interpret use of gesture, pointing or "signing" or how to set up or help with other AAC strategies. They may need prompts or leading questions to be successfully understood, and "listeners" may need to check that they have understood using "yes/no" questions.

Distinction between levels III and IV: Children in level III can communicate with family, friends and other familiar people in familiar situations and activities, about things that are happening, their wants and needs.

Children in level IV need support from a familiar person who can understand their calls for attention and how they express choices. They need their listener to know their routines and the significant things that have happened recently and are happening in their life. Their "listener" needs to know or be trained to interpret their use of body language, facial expression, vocalisation, reaching or pushing away, and how to set up or help with other AAC strategies to help them to be understood and make choices.

Distinction between levels IV and V: Children in level IV communicate with family, friends and other familiar people in everyday situations and routine activities, about things that are happening to them, or their wants or needs. People who are unfamiliar with them will need help/support to ensure they are understood. They can make choices that are offered or can be anticipated during routine daily activities.

Children in level V do not initiate contact or communicate intentionally with others. Their communication is successful with familiar people who are able to observe and interpret their body language, movement patterns, facial expression, and vocalisations to understand their happiness, comfort, unhappiness, discomfort or pain, and readiness/need for familiar daily activities such as eating, drinking, bathing, and sleep. Communication partners need prior knowledge, experience and/or informed observation to anticipate and problem solve to help meet these children's needs.

C.5. Gross Motor Function Classification System

Definitions taken from Palisano et al., (1997):

OPERATIONAL DEFINITIONS

Body support walker – A mobility device that supports the pelvis and trunk. The child/youth is physically positioned in the walker by another person.

Hand-held mobility device – Canes, crutches, and anterior and posterior walkers that do not support the trunk during walking.

Physical assistance – Another person manually assists the child/youth to move.

Powered mobility – The child/youth actively controls the joystick or electrical switch that enables independent mobility. The mobility base may be a wheelchair, scooter or other type of powered mobility device.

Self-propels manual wheelchair – The child/youth actively uses arms and hands or feet to propel the wheels and move.

Transported – A person manually pushes a mobility device (e.g., wheelchair, stroller, or pram) to move the child/youth from one place to another.

Walks – Unless otherwise specified indicates no physical assistance from another person or any use of a hand-held mobility device. An orthosis (i.e., brace or splint) may be worn.

Wheeled mobility – Refers to any type of device with wheels that enables movement (e.g., stroller, manual wheelchair, or powered wheelchair).

GENERAL HEADINGS FOR EACH LEVEL

LEVEL I	-	Walks without Limitations
LEVEL II	-	Walks with Limitations
LEVEL III	-	Walks Using a Hand-Held Mobility Device
LEVEL IV	-	Self-Mobility with Limitations; May Use Powered Mobility
LEVEL V	-	Transported in a Manual Wheelchair

DISTINCTIONS BETWEEN LEVELS

Distinctions Between Levels I and II - Compared with children and youth in Level I, children and youth in Level II have limitations walking long distances and balancing; may need a hand-held mobility device when first learning to walk; may use wheeled mobility when traveling long distances outdoors and in the community; require the use of a railing to walk up and down stairs; and are not as capable of running and jumping.

Distinctions Between Levels II and III - Children and youth in Level II are capable of walking without a hand-held mobility device after age 4 (although they may choose to use one at times). Children and youth in Level III need a hand-held mobility device to walk indoors and use wheeled mobility outdoors and in the community.

Distinctions Between Levels III and IV - Children and youth in Level III sit on their own or require at most limited external support to sit, are more independent in standing transfers, and walk with a hand-held mobility device. Children and youth in Level IV function in sitting (usually supported) but self-mobility is limited. Children and youth in Level IV are more likely to be transported in a manual wheelchair or use powered mobility.

Distinctions Between Levels IV and V - Children and youth in Level V have severe limitations in head and trunk control and require extensive assisted technology and physical assistance. Self-mobility is achieved only if the child/youth can learn how to operate a powered wheelchair.

C.6. Manual Ability Classification System

Descriptions taken from Eliasson et al., (2006):

MACS

What do you need to know to use MACS?

The child's ability to handle objects in important daily activities, for example during play and leisure, eating and dressing.

In which situation is the child independent and to what extent do they need support and adaptation?

I. **Handles objects easily and successfully.** At most, limitations in the ease of performing manual tasks requiring speed and accuracy. However, any limitations in manual abilities do not restrict independence in daily activities.

II. **Handles most objects but with somewhat reduced quality and/or speed of achievement.** Certain activities may be avoided or be achieved with some difficulty; alternative ways of performance might be used but manual abilities do not usually restrict independence in daily activities.

III. **Handles objects with difficulty; needs help to prepare and/or modify activities.** The performance is slow and achieved with limited success regarding quality and quantity. Activities are performed independently if they have been set up or adapted.

IV. **Handles a limited selection of easily managed objects in adapted situations.** Performs parts of activities with effort and with limited success. Requires continuous support and assistance and/or adapted equipment, for even partial achievement of the activity.

V. **Does not handle objects and has severely limited ability to perform even simple actions.** Requires total assistance.

Distinctions between Levels I and II

Children in Level I may have limitations in handling very small, heavy or fragile objects which demand detailed fine motor control, or efficient coordination between hands. Limitations may also involve performance in new and unfamiliar situations. Children in Level II perform almost the same activities as children in Level I but the quality of performance is decreased, or the performance is slower. Functional differences between hands can limit effectiveness of performance. Children in Level II commonly try to simplify handling of objects, for example by using a surface for support instead of handling objects with both hands.

Distinctions between Levels II and III

Children in Level II handle most objects, although slowly or with reduced quality of performance. Children in Level III commonly need help to prepare the activity and/or require adjustments to be made to the environment since their ability to reach or handle objects is limited. They cannot perform certain activities and their degree of independence is related to the supportiveness of the environmental context.

Distinctions between Levels III and IV

Children in Level III can perform selected activities if the situation is prearranged and if they get supervision and plenty of time. Children in Level IV need continuous help during the activity and can at best participate meaningfully in only parts of an activity.

Distinctions between Levels IV and V

Children in Level IV perform part of an activity, however, they need help continuously. Children in Level V might at best participate with a simple movement in special situations, e.g. by pushing a button or occasionally hold undemanding objects.

Appendix D. Protocols

D.1. Protocol for Selecting Phrases for Analysis and Listener Instructions

Recording Speech Samples:

- Each participant was recorded on a Tascam DR-05X Audio Recorder (44.1 kHz sampling rate; 16-bit quantization) while producing the target vowel, single words, and connected speech
- Recordings took place at the participants' school, home, or organisation (e.g., charity)- noisy environments so background noise has been picked up by the recorders

Preparing Speech Samples for Playback:

- Recorded speech samples were transferred to the researcher via File Drop-off- the SD card from the recorder was inserted into a laptop/computer and the recordings were uploaded on to the file drop-off service and sent using the researcher's email address
- Once the researcher received the link to the recordings via email, the recordings were downloaded on to a university laptop and stored in an encrypted, password protected folder which only the research team had access to
- The recordings were then uploaded on to PRAAT to be cleaned and segmented
- Any recordings which happened to be recorded using the stereo setting were converted to mono before cleaning and segmenting
- Recordings of each vowel sound, single word, and phrase were separated into individual sound files and named using the participant ID, recording number, and vowel/word/phrase number
- Any phrase which contained identifiable information was deleted
- The 20 individual words and 5 chosen phrases for each child and timepoint were then combined using the Concatenate feature on PRAAT so that each child ended up with 8 sound files, each containing the 20 single words and 5 phrases
- The three children's recordings designated to each listener were then stored in folders assigned to each listener (e.g., Listener 1's folder contained child 7's 7th recording, child 9's 3rd recording, and child 13's 6th recording)
- The researcher paused the recording after each word and phrase and waited until the listener had finished typing before moving on to the next word/phrase
- Listeners only listened to each word and phrase once

Considerations for Phrases:

- Confounding factors:
  - Listeners' working memory
  - Word complexity – some children used complex, infrequent vocabulary whilst others used simpler, more frequent vocabulary (which listeners may be more familiar with)
  - Utterance length – some children produced very short phrases (1 or 2 words) and others produced very long utterances (over 20 words at a time)
- Initially I had considered dividing utterances into phrases based on phrase group; however, this resulted in very short, ungrammatical phrases
- Other researchers used 8/9 syllables- this also resulted in ungrammatical utterances
- Therefore, I decided to split phrases into grammatically correct phrases (sensible start and end point)
- I omitted fillers which came at the beginning of utterances, e.g., 'ah', 'ehm' as these will not be included in the analyses

- I decided (where possible) to use phrases which did not contain duplicate content words (e.g., ‘pinata’) as this could aid listener perception
- Parameters for phrases- first 5 phrases which:
    - Contained phonemes of interest (those participants had most difficulty with)
    - Did not contain similar vocabulary (where possible)
    - Had the least amount of background noise

Experimental Task:

- Listeners completed the study in a sound-attenuated booth at the university
- The researcher attended the listening study to play the speech samples
- The listener was seated beside a high-quality external speaker
- They were given a university laptop to record their transcriptions on a pre-made Excel spreadsheet
- The researcher played the speech samples from a university computer at a standardised volume (100% volume on the computer and 50% on the external speaker)

Listener Instructions:

- **Please sign the consent form by putting your initial the box (do not tick).**
- Carol-Ann (the PhD Speech and Language Therapist Researcher) is investigating the effect of personalised dysarthria intervention on speech intelligibility in children with cerebral palsy.
- Each child received 6 weeks of intervention 3 times a week. The children were recorded producing single words and phrases twice before and twice after therapy.
- Your task is to transcribe the children’s speech typing what you hear. You will not know if the speech samples you are listening to were recorded before or after therapy.
- You will listen to three different children each producing 20 single words and 5 phrases.
- All the words said by the children are real words.
- Do not write any non-words.
- Do not write two words for the single word task.
- Put an X if you do not know the word.
- The five phrases were elicited from a video description task. The children watched a video about a plasticine character called Morph and his friend Chas. You can see a picture of Morph and Chas on sheet 2 of the Excel spreadsheet.
- If you understand some of the phrase but not it all, put X’s in place of words not understood – e.g., ‘the X dog X X’
- I will pause the recording in between each word and phrase to give you time to type your answer. Please let me know when you have completed typing each word or phrase. You will only hear each word and phrase once.
- If you have any queries during the study, please don’t hesitate to ask.

D.2. Recording Protocol

Recording Protocol for Teaching Assistants

Place the audio recorder mic 25cm from child's mouth – input bar should be fluctuating around -12.

Tascam DR-05X Audio-Recorder

Link to online manual: DR-05X REFERENCE MANUAL (tascam.com)

The recorder will be given to the TA with the correct recording settings already installed and the batteries and SD card inserted. If any settings have been changed, please contact the research SLT who will explain how to correct this.

The settings (which can be accessed using the MENU button) should be:

- Format: WAV 16bit
- Sample: 44.1k
- Level Mode: Manual
- Recording Mode: MONO
- PRE REC: On
- Connect to: PC/MAC

When the settings have been changed correctly, press the HOME button to return to the home screen.

How to record (research SLT will also show TA how to do this):

1. Point the mics at the sound source (the child) and place the audio recorder in a stable location where there is little vibration.
2. Press RECORD button to start recording standby – REC indicator will blink, and the recording screen will open.
3. Press the QUICK button to open the quick menu. Use the + or – button to selected LEVEL MODE and press the play button. Use the + or – button to change the LEVEL MODE setting to MANUAL.
4. Get the child to speak into the mic to check the input level. Use the rewind and fast forward button to adjust the input level.
5. If the input is too high, the PEAK indicator on the upper left above the display lights up.
6. Set the input level so that the indicator bar fluctuates centred on -12 (shown with a black triangle) without causing the PEAK indicator to light red when the loudest sounds occur.
7. Press RECORD button once to begin recording standby: the screen should show the recording file name, the recording audio file type and sampling frequency. Please confirm with the research SLT that these are as desired before recording.
8. Starting the recording: press RECORD button again to begin recording. When recording starts, the REC indicator lights continuously, and the display shows the elapsed recording time and the remaining recording time.

9. Pausing recording: press RECORD button. Press RECORD button again to restart recording in the same file.
10. Stopping the recording: press HOME button to end recording and create the audio file.

How to view recordings on device:

1. Press MENU button and use the + or – button to select BROWSE and press PLAY button.
2. On the BROWSE screen, you can view the contents of the MUSIC folder containing the audio files on the SD card. You can also play and delete selected audio files/folders.
3. Use the + and – buttons to select files and folders. Press the arrows going right (fast forward) to show the contents of that folder.
4. When a file or folder is selected (highlighted), press the arrows going left (rewind) to exit the currently open folder and go to a higher level in the folder structure.
5. When a file or folder is selected, press QUICK button to open a pop-up menu.
6. When a file is selected, press the play button to return to the Home Screen and play that file.

How to delete a file/folder:

1. Press MENU button and select BROWSE.
2. Select (highlight) the desired file/folder to be deleted.
3. Press QUICK button which opens a pop-up window.
4. Use + or – button to select an item and press play button to delete the chosen file/folder.

How to upload recordings:

1. Connect the recorder with a computer using a USB cable to use it as an SD card reader.
2. You can transfer recorded audio files to a computer and transfer audio files from a computer to the recorder.
3. Connect the recorder to the computer using a USB cable.
4. Press MENU button and use the + or – button to select USB. Press play button to open the USB screen.
5. Use the + or – button to select SD CARD READER and press the play button. The SD CARD READER screen will open.
6. Upload the recordings on to Newcastle University's File Drop-off Service; https://dropoff.ncl.ac.uk/

Disconnecting the unit from a computer:

1. Before disconnecting the computer and recorder, use the proper procedures for the computer to unmount the recorder and press the left (rewind) arrow button.
2. Press the left arrow button to disconnect from the computer and return to the Home Screen.

File Transfer

About the Newcastle University File Drop-off Service; https://dropoff.ncl.ac.uk/:

This service can be used to share large files (over 1MB). It temporarily makes a file (or files) available to another user across the Internet, in a secure and efficient manner.

There are two distinct kinds of users that will be accessing the Newcastle University File Drop-off system: *inside* users, who are associated with the University running the service, and *outside* users, which encompasses the rest of the Internet.

You, as the TA, will be classified as an *outside* user. You will transfer the file to the research SLT (Carol-Ann McConnellogue) who is an *inside* user. An *inside* user is allowed to send a drop-off to anyone, whether they are an *inside* or *outside* user. An *outside* user is only allowed to send a drop-off to an *inside* user.

What is a drop-off?

One or more files uploaded to Newcastle University File Drop-off as a single item for delivery to a person or people.

There is the possibility that multiple recordings may have been made in the one session; for example, if the child needed a break, background noise began etc…

There are several ways in which a user can drop-off multiple files at once:

- Drag-and-drop multiple files at once onto the drop-off page
- Click on the "Add Files" button on the drop-off page, and select 1 or more files at once using combinations of click, Shift+click and Ctrl+click (Cmd+click on a Mac)
- Archive and compress the files into a single package and attach the resulting archive file on the drop-off page. There are many ways to archive and compress files:
    - Mac users can select the files in the Finder and "Compress" (see the File menu)
    - Windows users can create a "compressed folder" or use 7-Zip
    - Linux/Unix users could try "PeaZip" or "File Roller"

Creating A Drop-off:

When a user creates a drop-off, they enter some identifying information about themself (name, organisation, and email address); identifying information about the recipient(s) (name and email address); and choose what files should be uploaded to make the drop-off.

If the files are successfully uploaded, an email is sent to the recipient(s) explaining that a drop-off has been made. This email also provides a link to access the drop-off. Other information (the Internet address and/or computer name from which the drop-off was created, for example) is retained, to help the recipient(s) check the identity of the sender.

Retrieval of a drop-off by a recipient can only be done with both the drop-off's Claim ID and Passcode. When dropping off files, you can choose *not* to send either or both to the recipient automatically: you would then need to send that information by hand yourself.

Research SLT's Contact Details:

Name: Carol-Ann McConnellogue

Email: c.mcconnellogue2@newcastle.ac.uk

Telephone: 07955311466

Appendix E. Datasets

E.1. Single Word Perceptual Dataset

Target:

Child	Recording	Item	Target	L	L Perceived	Lcorrect	Initial C Present	Target Initial C	Initial Cluster Present	Target Initial Cluster	Final C Present	Target Final C	Final Cluster Present	Target Final Cluster
1	6 Weeks Pre	1	bell	1	milk	0	1	b	0		1	l	0	
1	6 Weeks Pre	2	face	1	please	0	1	f	0		1	s	0	
1	6 Weeks Pre	3	jam	1	jam	1	1	dg	0		1	m	0	

Perceived:

Child	Recording	Item	Target	L	L Perceived	Lcorrect	Perceived Initial C	Initial Cluster Perceived	Perceived Initial Cluster	Final C Perceived	Perceived Final C
1	6 Weeks Pre	1	bell	1	milk	0	m	0	999	1	k
1	6 Weeks Pre	2	face	1	please	0	p	1	pl	1	z
1	6 Weeks Pre	3	jam	1	jam	1	dg	0	999	1	m

Final Cluster Perceived	Final Cluster Perceived	Perceived Initial C Correct	Initial Cluster Perceived Correct	Final C Perceived Correctly	Word Initial Cluster Perceived Correct	Word Final Cluster Perceived Correct
1	lk	2		2		
0	999	2		2		
0	999	1		1		

Example of data stored in the single word perceptual database.

*Note: L = Listener; C = consonant; Lcorrect 0 = listener incorrect; Lcorrect 1 = listener correct; 0 = no consonant present in target; 1 = consonant present in target; 1 = perceived correct; 2 = perceived incorrect; 999 = no consonant in target to perceive

E.2. Connected Speech Perceptual Dataset

Target:

Child	Recording Code	Recording	Phrase	No. Of Words	Transcription Of Phrase	Word Number	Target Word	Listener	Perceived Word	Perceived Correct	Target Syllables	Perceived Syllables
1	6 Weeks Pre	1	1	5	they were in the sun	1	they	1	he	0	[CVV]	[CV]
1	6 Weeks Pre	1	1	5	they were in the sun	1	they	2	do	0	[CVV]	[CV]
1	6 Weeks Pre	1	1	5	they were in the sun	1	they	3	@	0	[CVV]	

TW Initial C Present	TW Initial C	TW Initial Cluster Present	TW Initial Cluster	TW Final Consonant Present	TW Final Consonant	TW Final Cluster Present	TW Final Cluster	TW Word Initial Cluster C3 Present	TW Word Initial Cluster C3	TW Word Final Cluster C3 Present	TW Word Final Cluster C3
1	ht	0		0		0		0		0	
1	ht	0		0		0		0		0	
1	ht	0		0		0		0		0	

Perceived:

PW Initial C Present	PW Initial C	PW Initial Cluster Present	PW Initial Cluster	PW Final Consonant Present	PW Final Consonant	PW Final Cluster Present	PW Final Cluster	PW Word Initial Cluster C3 Present	PW Word Initial Cluster C3	PW Word Final Cluster C3 Present	PW Word Final Cluster C3
1	h	0		0		0		0		0	
1	d	0		0		0		0		0	
999		999	999	999	999	999	999	999	999	999	999

TW syllable number	PW syllable number	Initial C perceived correctly	Final C perceived correctly	Initial Cluster perceived correctly	Final cluster perceived correctly
1	1	2			
1	1	2			
1	999	2			

Example of data stored in the connected speech perceptual database.

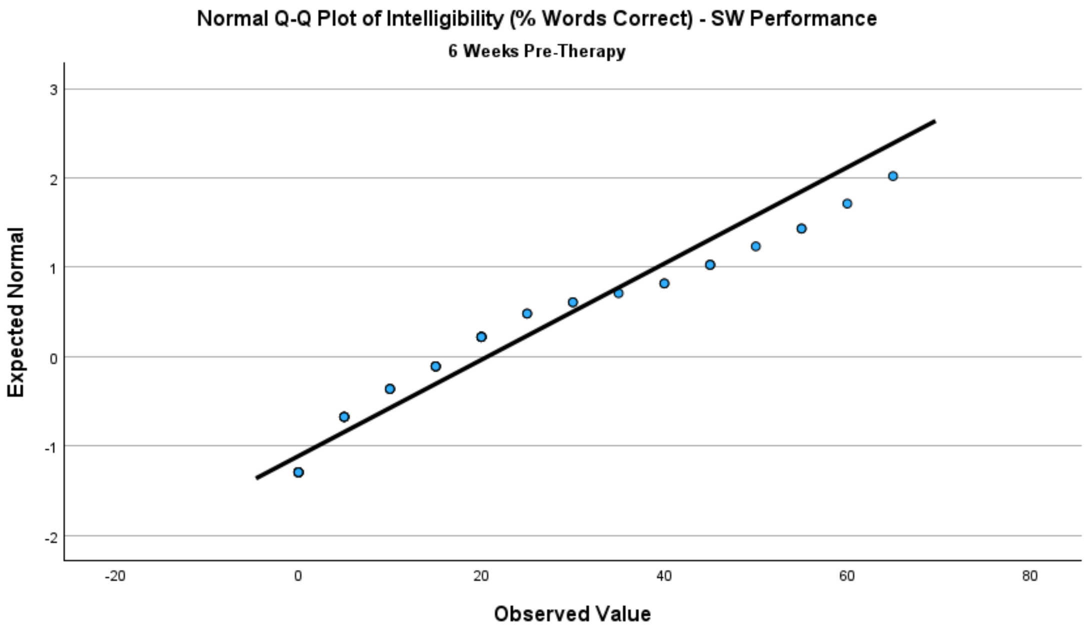
*Note: TW = target word; PW = perceived word; @ = listener did not perceive a word; [CV] = consonant vowel

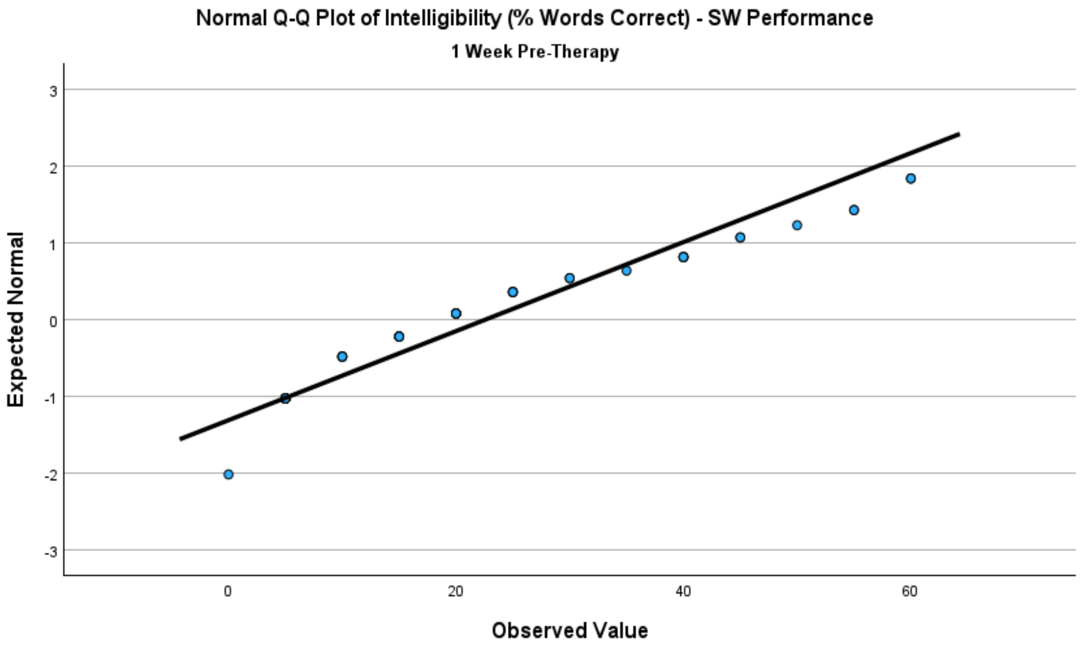
Appendix F. Single Word (SW) Performance Perceptual Results

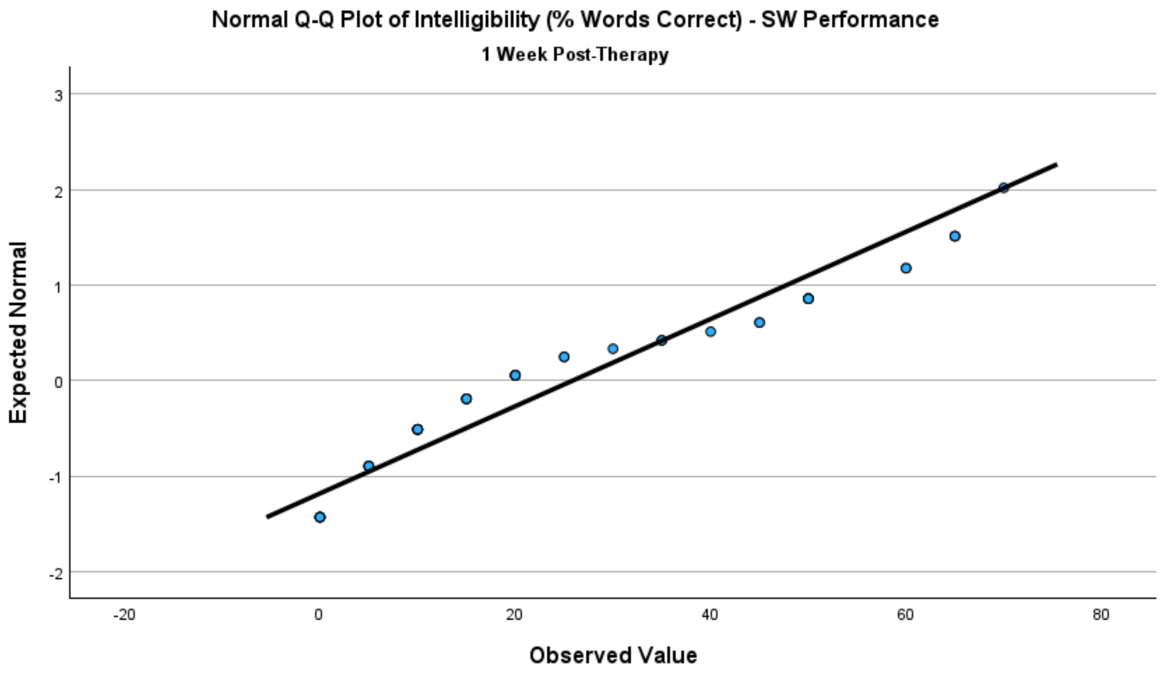
F.1. Tests of Normality and ICC with 95% Confidence Intervals (CI) for Raw Listener Data of SWs (Performance)

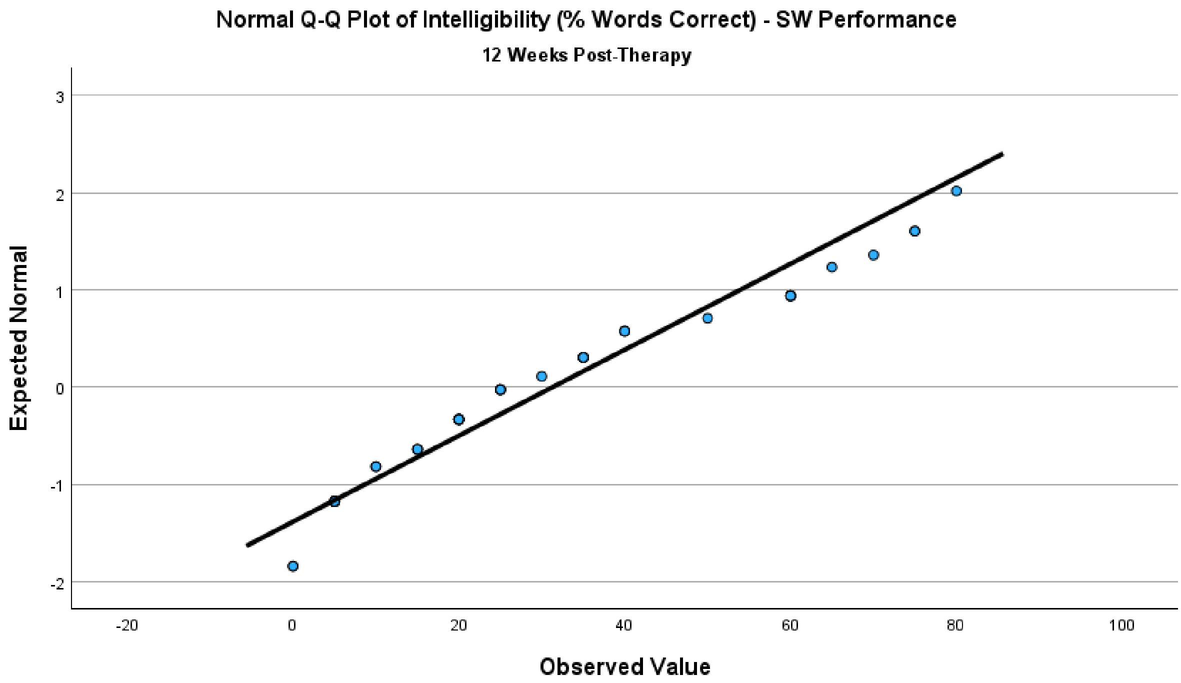
Timepoint	Shapiro-Wilk			ICC (Average Measures)	95% CI Lower, Upper
	Statistic	df	p		
6-Weeks Pre-Therapy	0.90	45	< 0.001	0.96	0.90, 0.98
1 Week Pre-Therapy	0.90	45	< 0.001	0.92	0.82, 0.97
1 Week Post-Therapy	0.89	45	< 0.001	0.97	0.92, 0.92
12 Weeks Post-Therapy	0.92	45	0.01	0.96	0.91, 0.99

Appendix F.2. QQ Plots for SW Performance Intelligibility at Each Timepoint



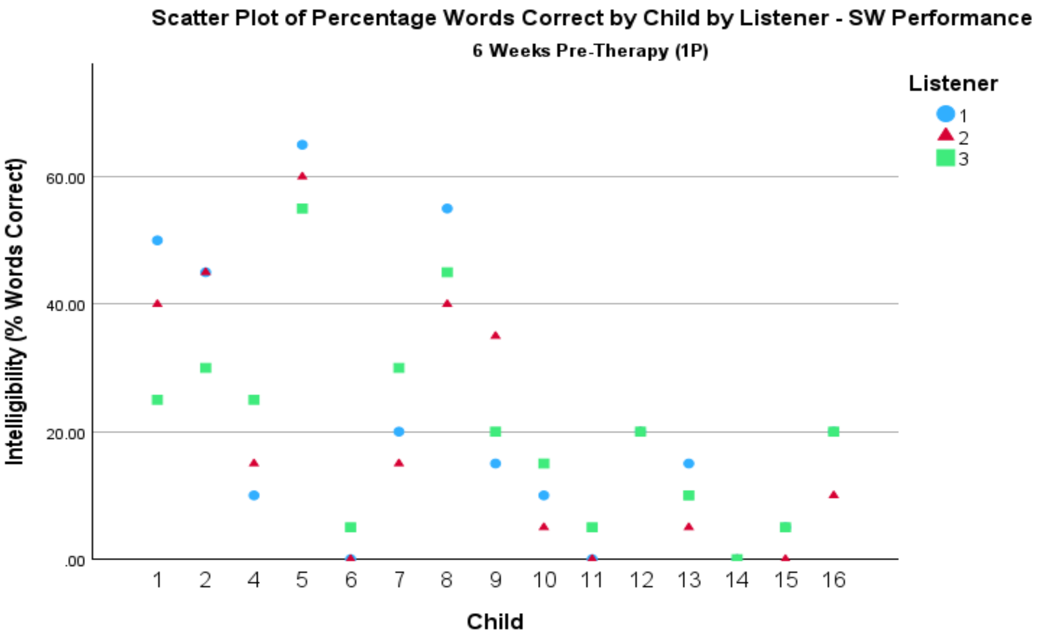


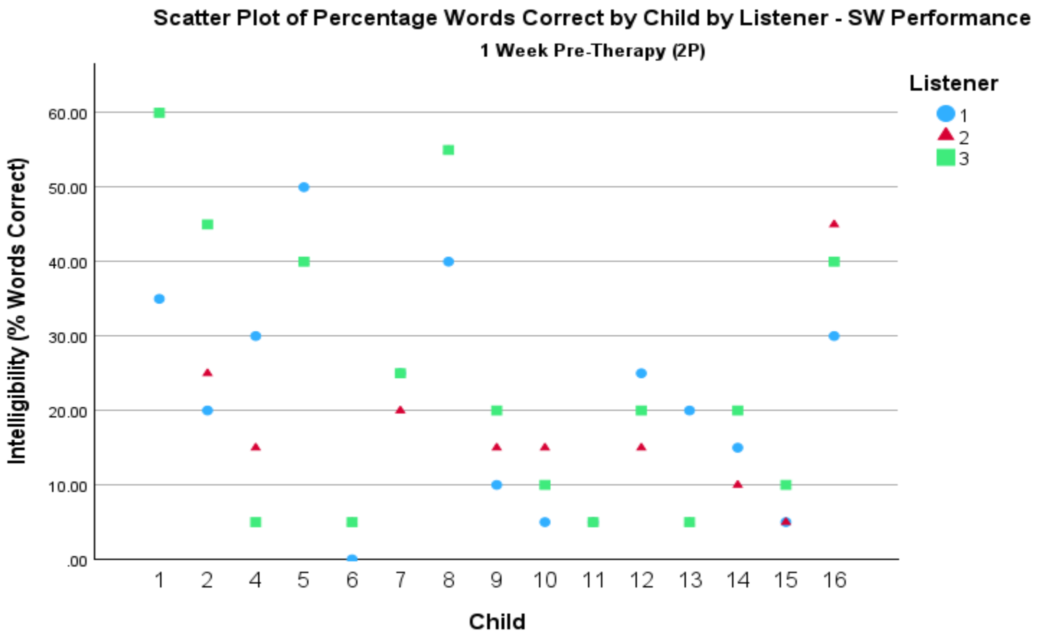

Normal Q-Q Plot of Intelligibility (% Words Correct) - SW Performance
1 Week Post-Therapy
Expected Normal
Observed Value
3
2
1
0
-1
-2
-20
0
20
40
60
80

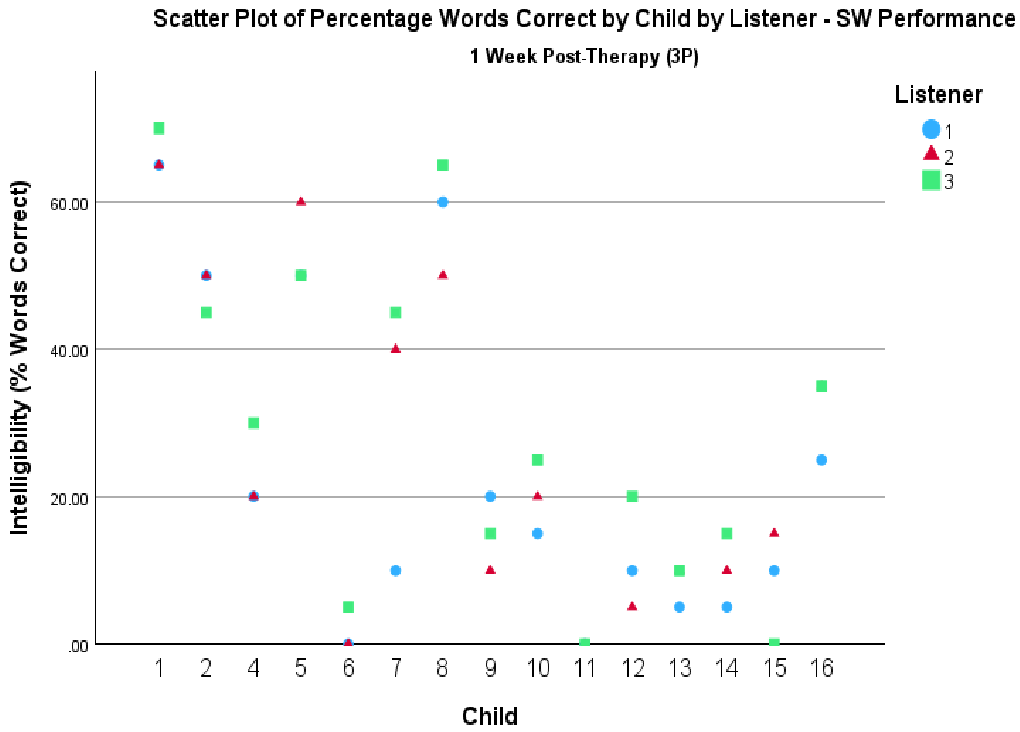

Normal Q-Q Plot of Intelligibility (% Words Correct) - SW Performance
12 Weeks Post-Therapy
Expected Normal
Observed Value
3
2
1
0
-1
-2
-20
0
20
40
60
80
100

F.3. Scatter Plots Showing Percentage Word Correct by Each Listener at Each Timepoint (SW Performance)

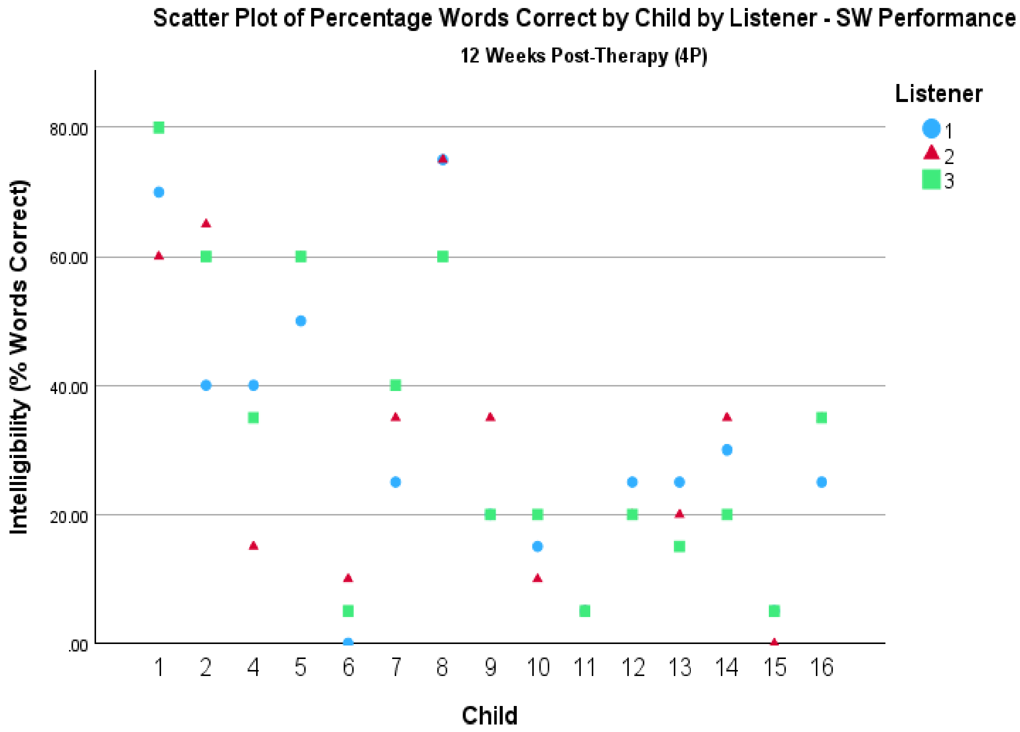
*Note: All children were rated by three listeners at each timepoint, but some points are hidden due to the same score from multiple listeners.







Scatter Plot of Percentage Words Correct by Child by Listener - SW Performance
1 Week Post-Therapy (3P)
Intelligibility (% Words Correct)
60.00
40.00
20.00
.00
1 2 4 5 6 7 8 9 10 11 12 13 14 15 16
Child
Listener
1
2
3



Scatter Plot of Percentage Words Correct by Child by Listener - SW Performance
12 Weeks Post-Therapy (4P)
Intelligibility (% Words Correct)
80.00
60.00
40.00
20.00
.00
1 2 4 5 6 7 8 9 10 11 12 13 14 15 16
Child
Listener
1
2
3

F.4. Table Showing Percentage Increase in Intelligibility Over Time for SW Performance

Key:

Colour Code	Changes in Intelligibility
Green	Clinical Significance
Blue	Non-Clinically Significant Gains
Orange	No Change
Red	Decrease

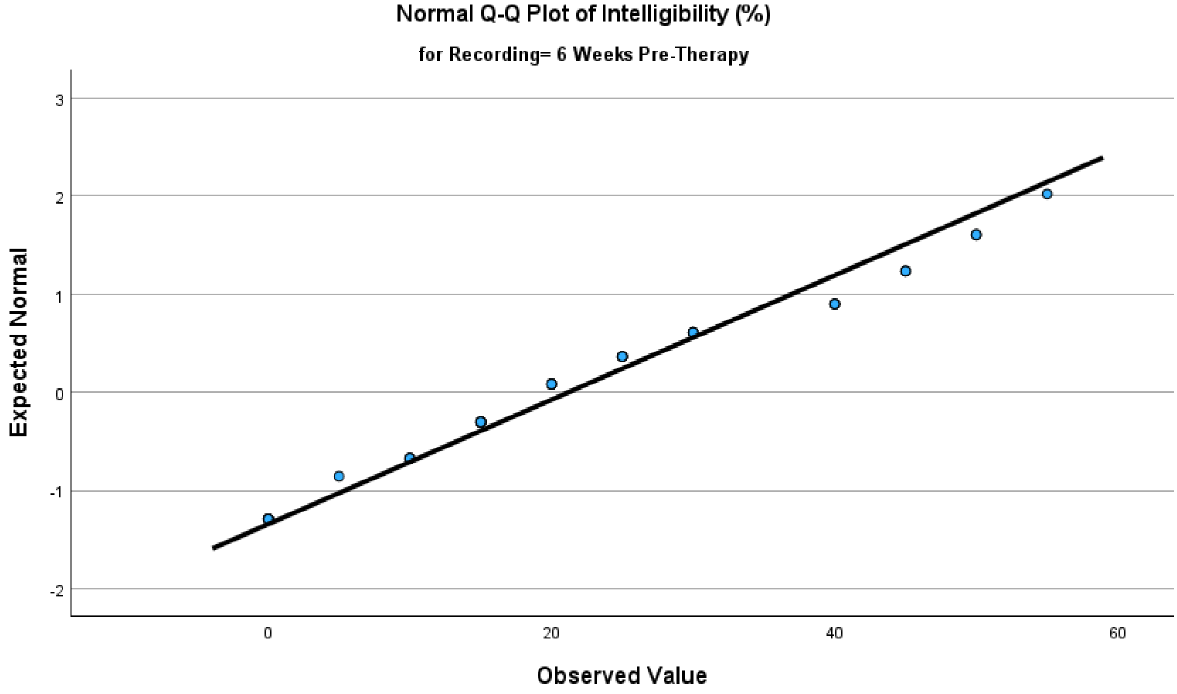
Child	1 Week Pre-Therapy vs 1 Week Post-Therapy	Child	1 Week Post-Therapy vs 12 Weeks Post-Therapy	Child	1 Week Pre-Therapy vs 12 Weeks Post-Therapy
P1	15.00	P1	3.33	P1	18.33
P2	18.33	P2	6.67	P2	25.00
P4	6.67	P4	6.67	P4	13.33
P5	10.00	P5	3.33	P5	13.33
P6	-1.67	P6	3.33	P6	1.67
P7	8.33	P7	1.67	P7	10.00
P8	8.33	P8	11.67	P8	20.00
P9	0.00	P9	10.00	P9	10.00
P10	10.00	P10	-5.00	P10	5.00
P11	-5.00	P11	5.00	P11	0.00
P12	-8.33	P12	10.00	P12	1.67
P13	-1.67	P13	11.67	P13	10.00
P14	-5.00	P14	18.33	P14	13.33
P15	1.67	P15	-5.00	P15	-3.33
P16	-6.67	P16	0.00	P16	-6.67

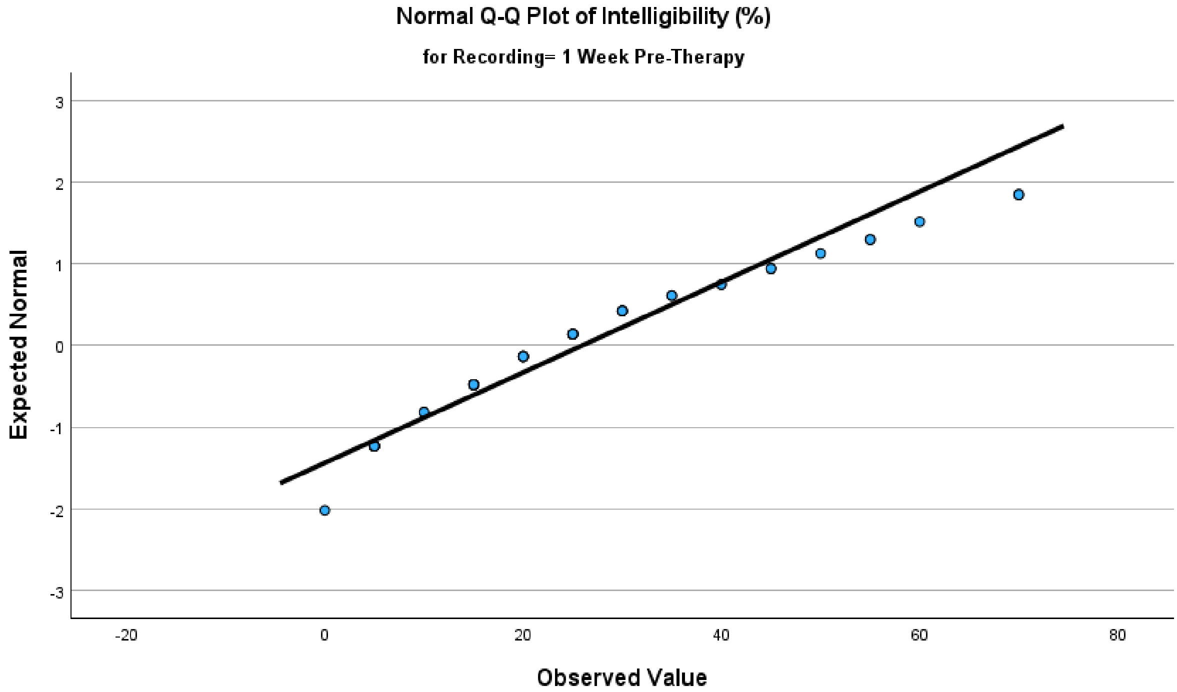
Appendix G. SW Capacity Perceptual Results

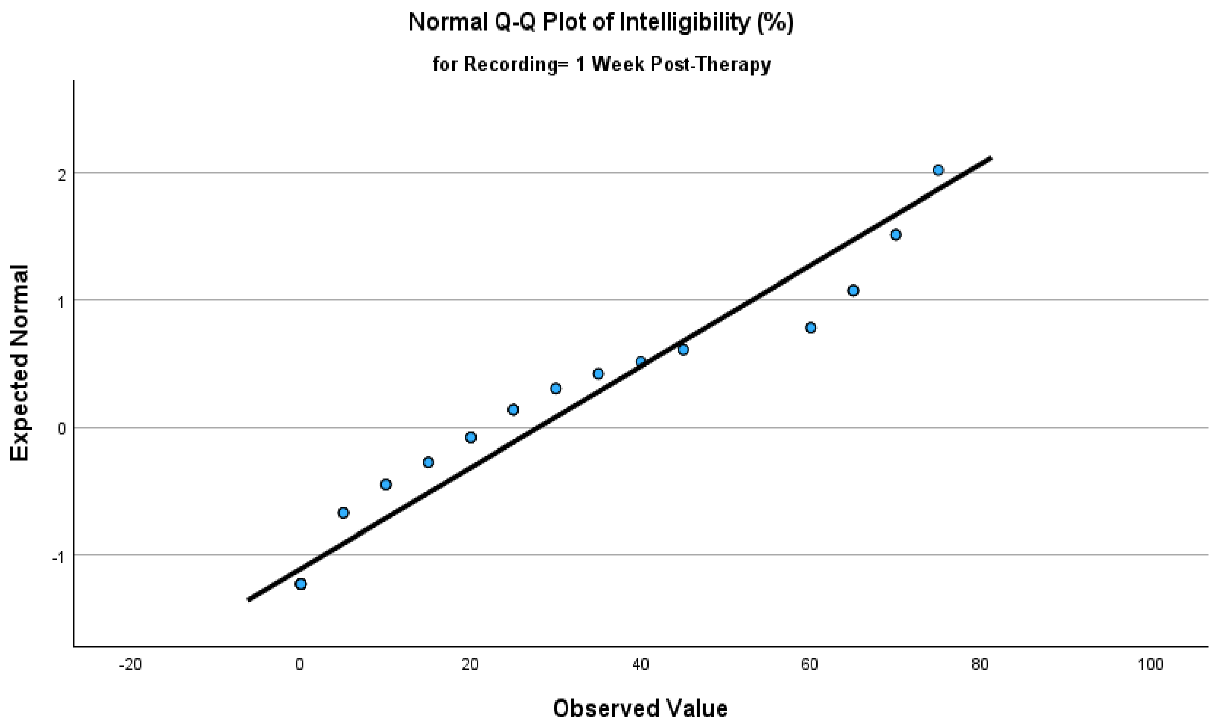
G.1. Tests of Normality and ICC with 95% Confidence Intervals for Raw Listener Data of Single Words (Capacity)

Timepoint	Shapiro-Wilk			ICC (Average Measures)	95% CI Lower, Upper
	Statistic	df	p		
6-Weeks Pre-Therapy	0.93	45	0.01	0.94	0.86, 0.98
1 Week Pre-Therapy	0.93	45	0.007	0.95	0.89, 0.98
1 Week Post-Therapy	0.88	45	< 0.001	0.96	0.91, 0.99
12 Weeks Post-Therapy	0.87	45	< 0.001	0.94	0.85, 0.98

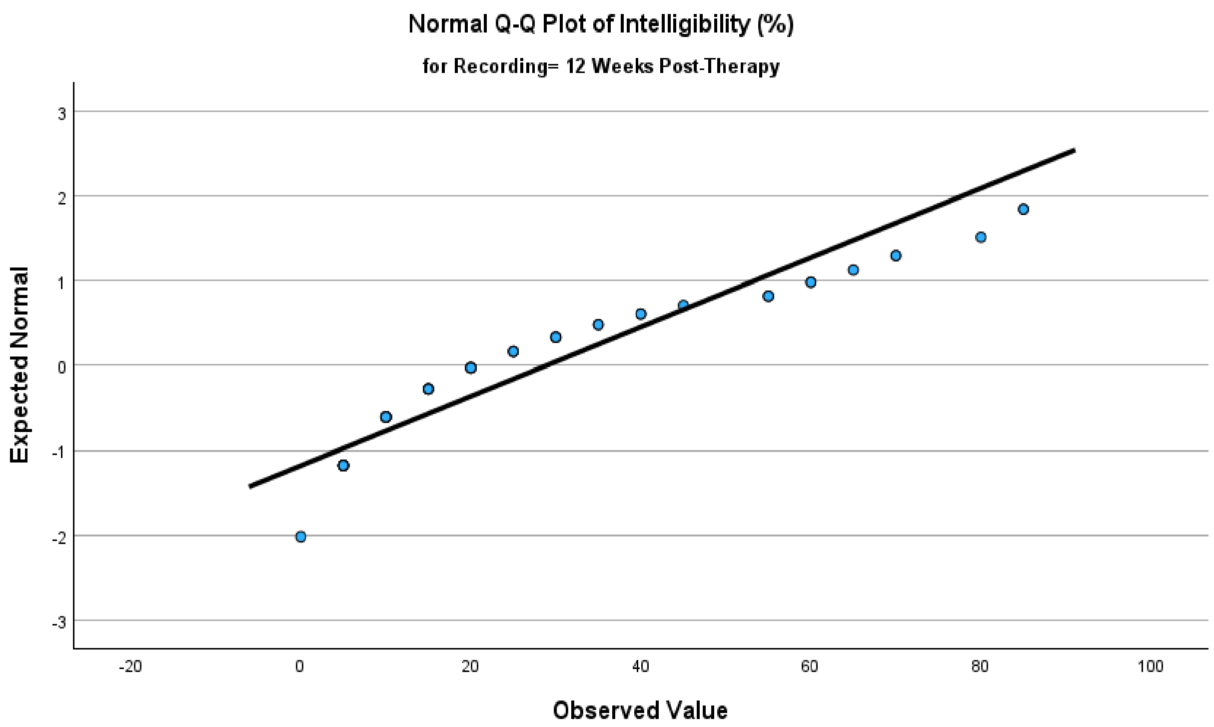
G.2. QQ Plots for SW Capacity Intelligibility at Each Timepoint





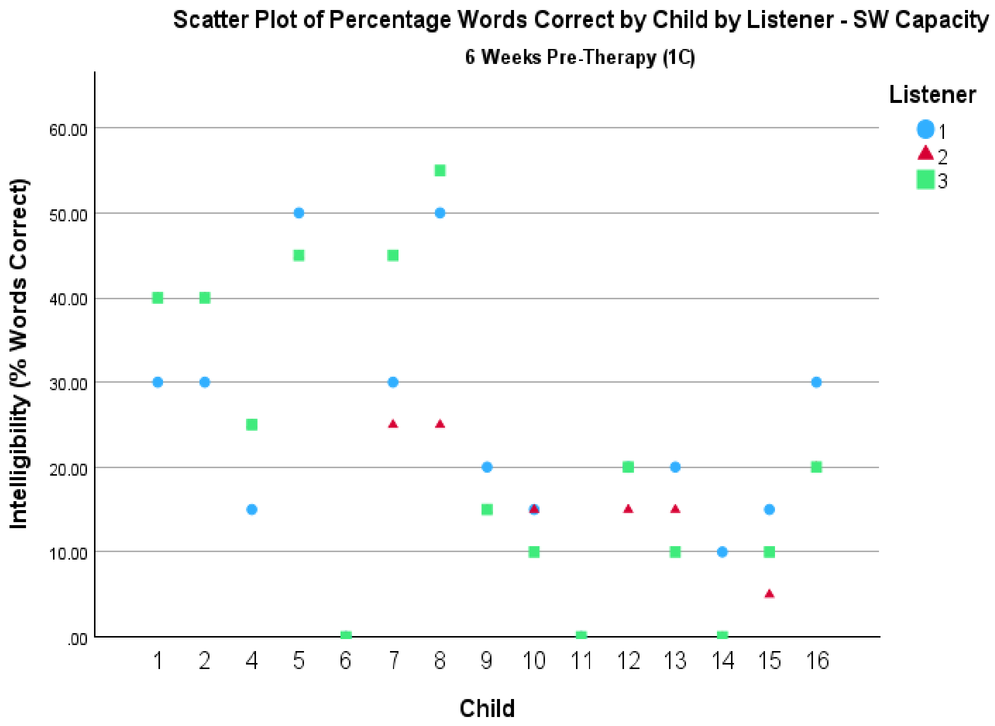


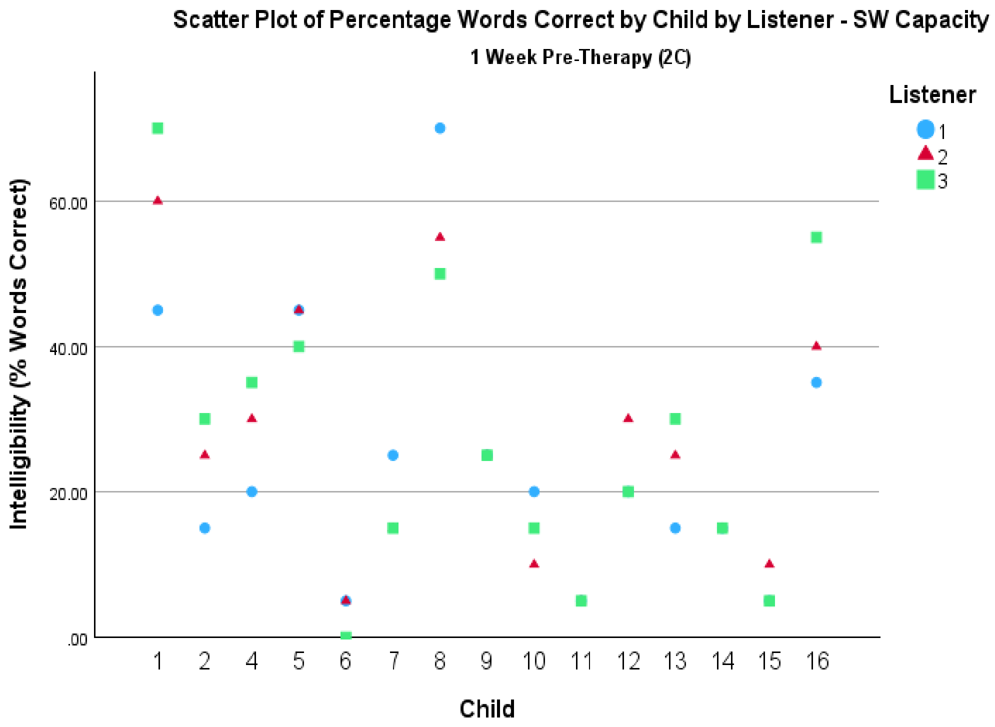
Normal Q-Q Plot of Intelligibility (%)
for Recording= 1 Week Post-Therapy
Expected Normal
Observed Value
2
1
0
-1
-20
0
20
40
60
80
100

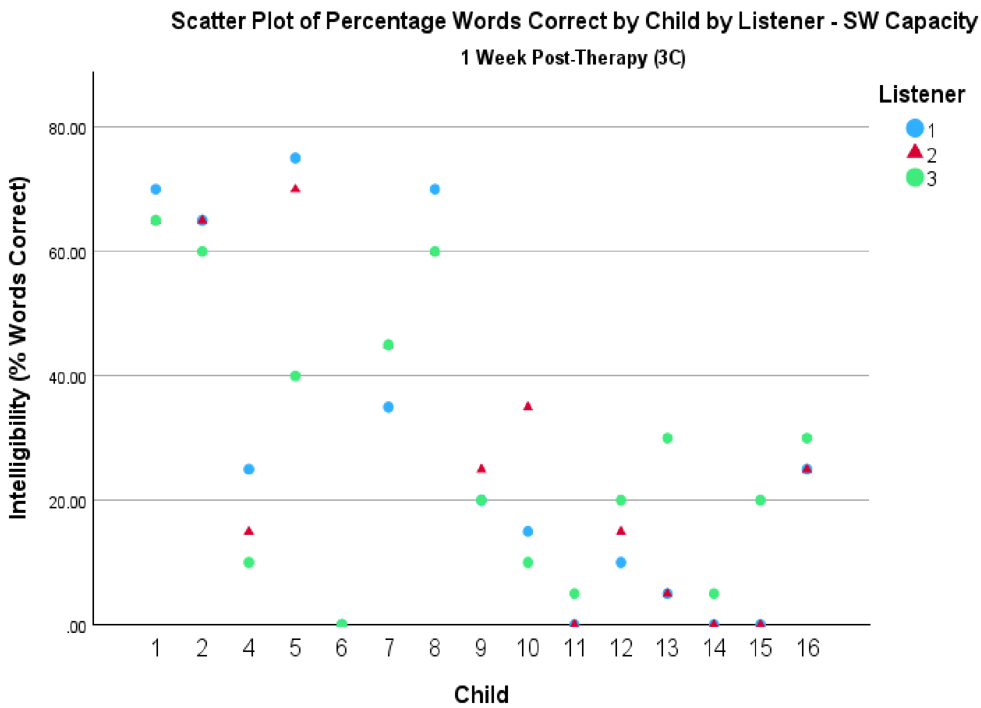


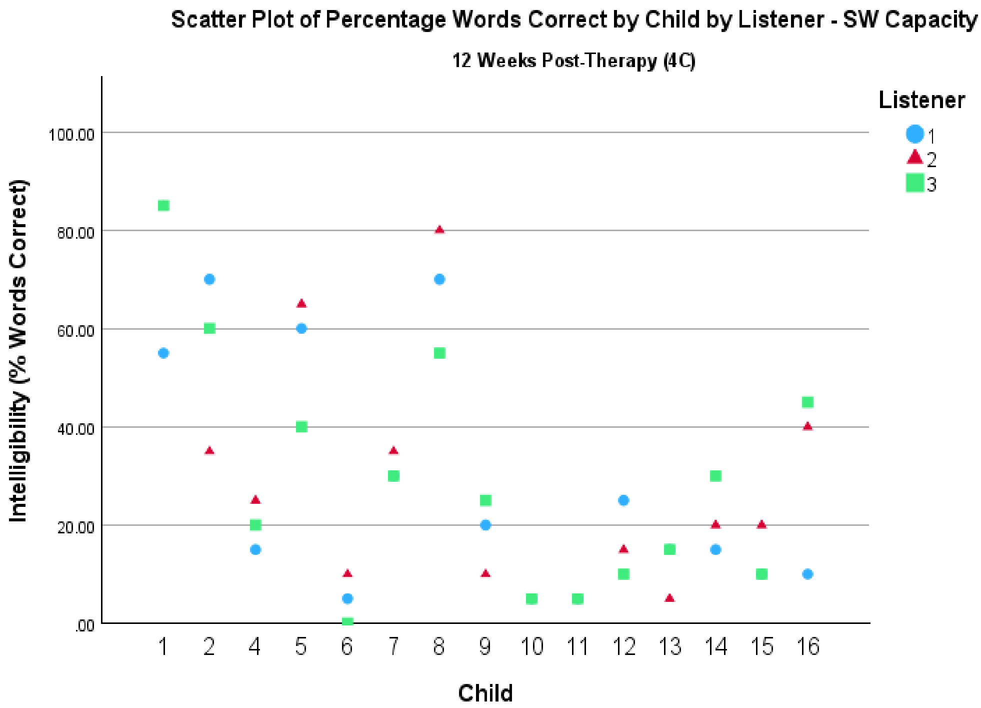
Normal Q-Q Plot of Intelligibility (%)
for Recording= 12 Weeks Post-Therapy
Expected Normal
Observed Value
3
2
1
0
-1
-2
-3
-20
0
20
40
60
80
100

G.3. Scatter Plots Showing Percentage Word Correct by Each Listener at Each Timepoint (SW Capacity)

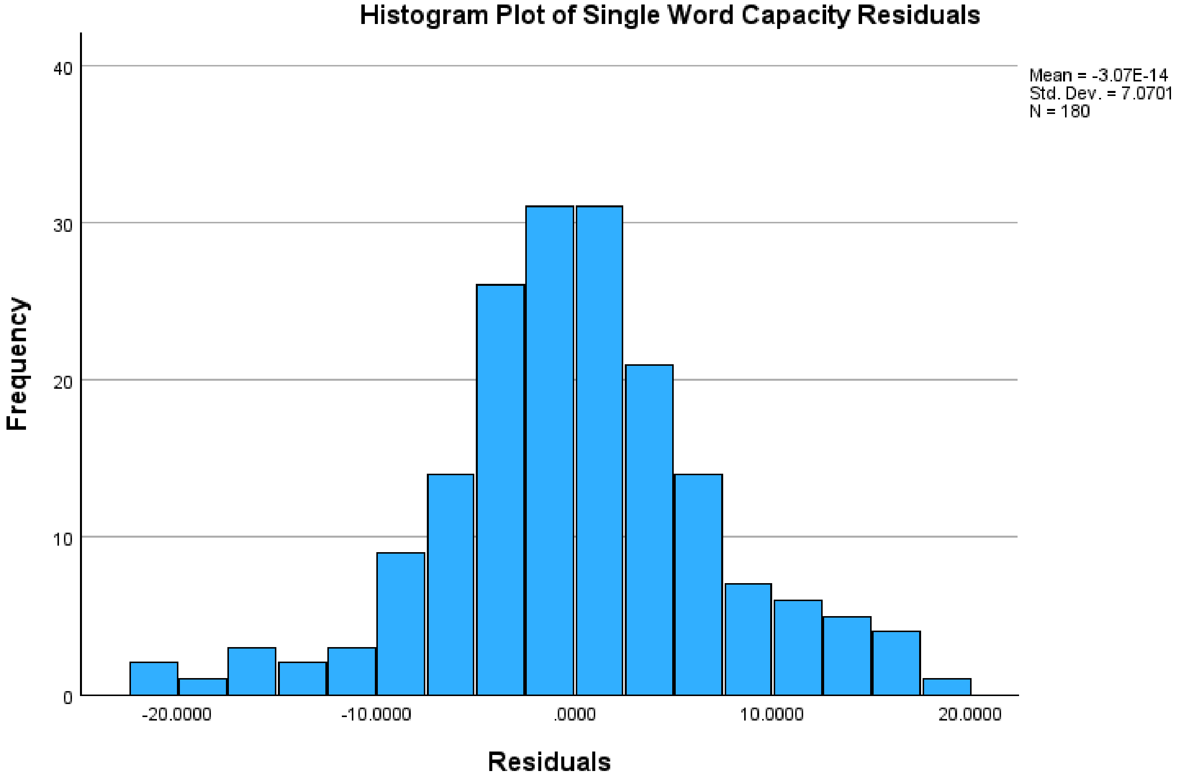





Scatter Plot of Percentage Words Correct by Child by Listener - SW Capacity
1 Week Post-Therapy (3C)
Listener
1
2
3
80.00
60.00
40.00
20.00
.00
Intelligibility (% Words Correct)
1 2 4 5 6 7 8 9 10 11 12 13 14 15 16
Child


Scatter Plot of Percentage Words Correct by Child by Listener - SW Capacity
12 Weeks Post-Therapy (4C)
Listener
1
2
3
100.00
80.00
60.00
40.00
20.00
.00
Intelligibility (% Words Correct)
1 2 4 5 6 7 8 9 10 11 12 13 14 15 16
Child

G.4. Histogram Showing the Distribution of Residuals for SWs (Capacity)



G.5. Pairwise Comparisons of Mean Intelligibility Scores at Each Timepoint (SW Capacity)

(I) Recording	(J) Recording	Mean Difference (I-J)	Std. Error	df	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
6 Weeks Pre-Therapy	1 Week Pre-	-4.78	2.99	45	0.70	-13.03	3.48
	1 Week Post-	-6.78	2.99	45	0.17	-15.03	1.48
	12 Weeks Post-	-7.67	2.99	45	0.08	-15.92	0.59
1 Week Pre-Therapy	6 Weeks Pre-	4.78	2.99	45	0.70	-3.48	13.03
	1 Week Post-	-2.00	2.99	45	1.00	-10.25	6.25
	12 Weeks Post-	-2.89	2.99	45	1.00	-11.14	5.36
1 Week Post-Therapy	6 Weeks Pre-	6.78	2.99	45	0.17	-1.48	15.03
	1 Week Pre-	2.00	2.99	45	1.00	-6.25	10.25
	12 Weeks Post-	-0.89	2.99	45	1.00	-9.14	7.36
12 Weeks Post-Therapy	6 Weeks Pre-	7.67	2.99	45	0.08	-0.59	15.92
	1 Week Pre-	2.89	2.99	45	1.00	-5.36	11.14
	1 Week Post-	.89	2.99	45	1.00	-7.36	9.14

Based on estimated marginal means
b. Adjustment for multiple comparisons: Bonferroni.

G.6. Table Showing Percentage Increase in Intelligibility Over Time for SW Capacity

Child	1 Week Pre-Therapy vs 1 Week Post-Therapy	Child	1 Week Pre-Therapy vs 12 Weeks Post-Therapy
P1	8.33	P1	16.67
P2	40.00	P2	31.67
P4	-11.67	P4	-8.33
P5	18.33	P5	11.67
P6	-3.33	P6	1.67
P7	23.33	P7	13.33
P8	5.00	P8	10.00
P9	-3.33	P9	-6.67
P10	5.00	P10	-10.00
P11	-3.33	P11	0.00
P12	-8.33	P12	-6.67
P13	-10.00	P13	-11.67
P14	-13.33	P14	6.67
P15	0.00	P15	6.67
P16	-16.67	P16	-11.67

Appendix H. Connected Speech (CS) Performance Results

H.1. Results from ICC Assumption Testing on Raw Intelligibility Data for CS (Performance)

Tests of Normality			Tests of Homogeneity of Variances			
	Shapiro-Wilk				Levene Statistic (df1, df2)	Sig.
	Statistic (df)	Sig.	Intelligibility (%)	Based on Mean	0.21 (3, 56)	0.89
6 Weeks Pre-Therapy	0.90 (15)	0.09		Based on Median	0.13 (3, 56)	0.94
1 Week Pre-Therapy	0.93 (15)	0.23		Based on Median with adjusted df	0.13 (3, 50.37)	0.94
1 Week Post-Therapy	0.90 (15)	0.08		Based on trimmed mean	0.17 (3, 56)	0.91
12 Weeks Post-Therapy	0.91 (15)	0.14				

H.2. Results from ICC with 95% Confidence Intervals for Raw Listener Data of CS (Performance)

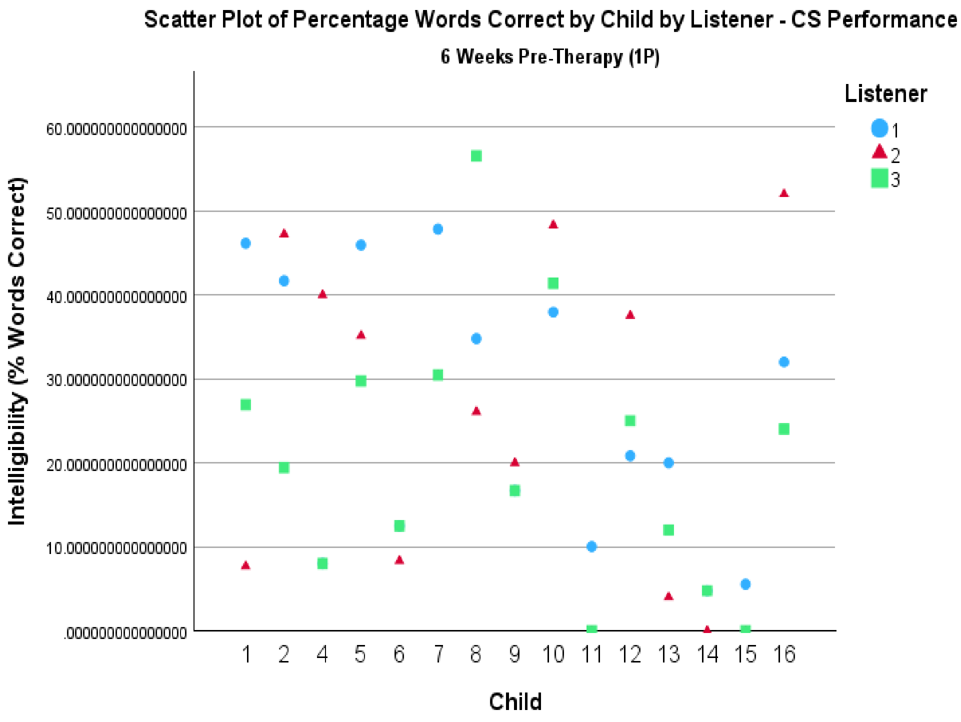
Timepoint	ICC (Average Measures)	95% CI Lower, Upper
6-Weeks Pre-Therapy	0.81	0.56, 0.93
1 Week Pre-Therapy	0.94	0.86, 0.98
1 Week Post-Therapy	0.93	0.84, 0.99
12 Weeks Post-Therapy	0.91	0.80, 0.97

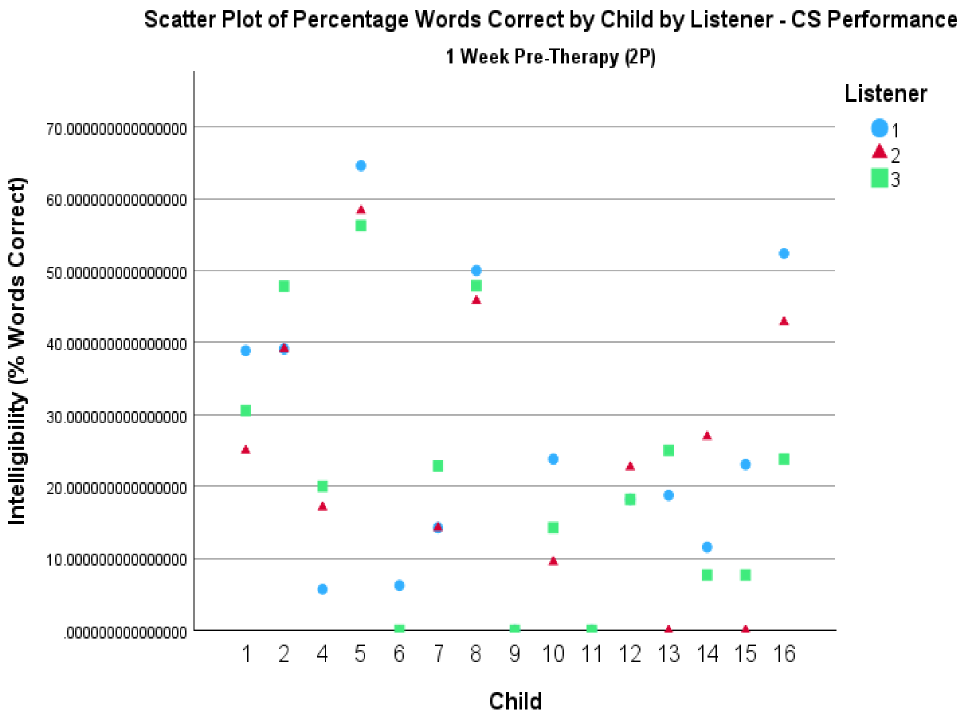
H.3. Results from Assumption Testing for Range of Listener Scores Data (CS Performance)

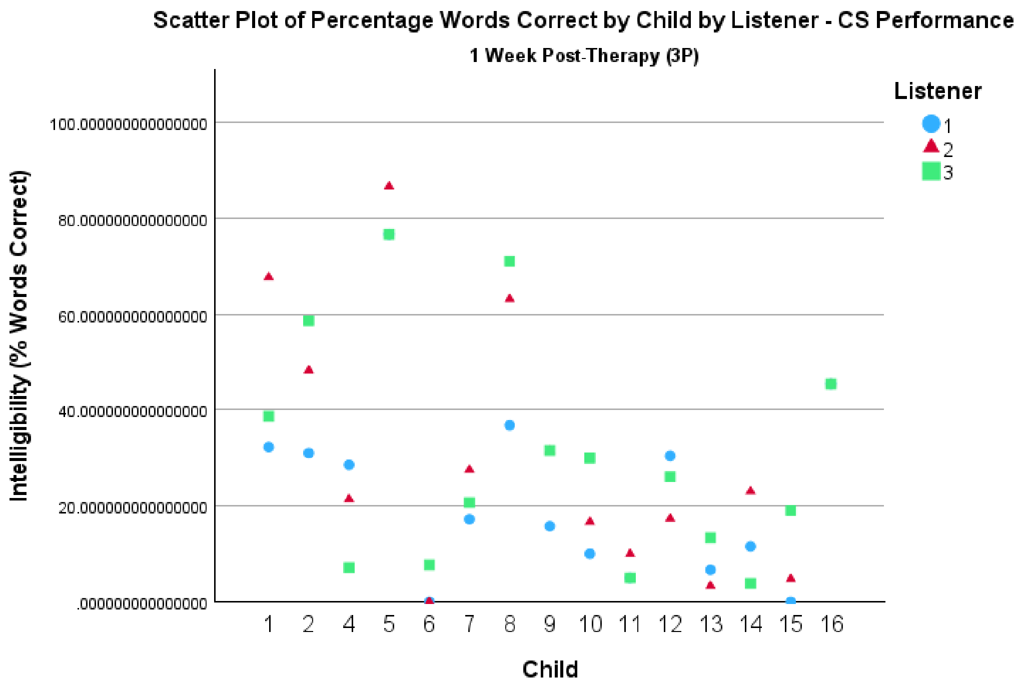
Tests of Normality			**Tests of Homogeneity of Variances**			
	Shapiro-Wilk				Levene Statistic (df1, df2)	Sig.
	Statistic (df)	Sig.	Range	Based on Mean	1.06 (3, 56)	0.37
6 Weeks Pre-Therapy	0.92 (15)	0.18		Based on Median	0.86 (3, 56)	0.47
1 Week Pre-Therapy	0.94 (15)	0.42		Based on Median with adjusted df	0.86 (3, 54.58)	0.47
1 Week Post-Therapy	0.96 (15)	0.65		Based on trimmed mean	1.01 (3, 56)	0.40
12 Weeks Post-Therapy	0.96 (15)	0.71				

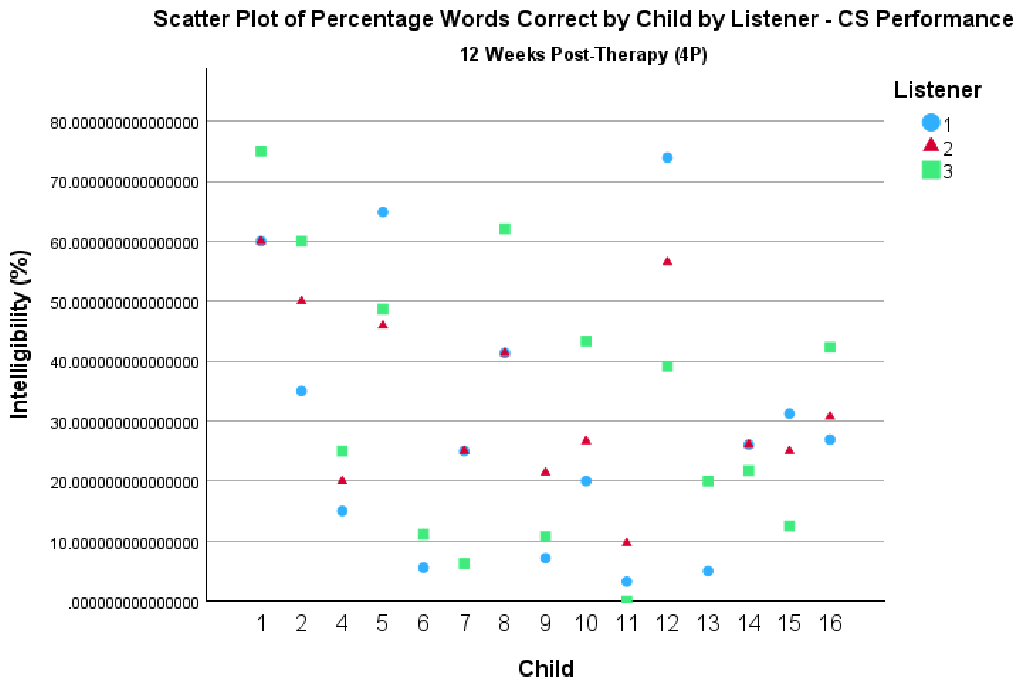
Mauchly's Test of Sphericity			
	Mauchly's W[a]	Approx. Chi-Square (df)	Sig.
Recording	0.89	1.48 (5)	0.92

H.4. Scatter Plots Showing Percentage Word Correct by Each Listener at Each Timepoint (CS Performance)






Scatter Plot of Percentage Words Correct by Child by Listener - CS Performance
1 Week Post-Therapy (3P)
Intelligibility (% Words Correct)
100.000000000000000
80.000000000000000
60.000000000000000
40.000000000000000
20.000000000000000
.000000000000000
1 2 4 5 6 7 8 9 10 11 12 13 14 15 16
Child
Listener
1
2
3


Scatter Plot of Percentage Words Correct by Child by Listener - CS Performance
12 Weeks Post-Therapy (4P)
Intelligibility (%)
80.000000000000000
70.000000000000000
60.000000000000000
50.000000000000000
40.000000000000000
30.000000000000000
20.000000000000000
10.000000000000000
.000000000000000
1 2 4 5 6 7 8 9 10 11 12 13 14 15 16
Child
Listener
1
2
3

H.5. Pairwise Comparisons of Mean Intelligibility Scores at Each Timepoint (CS Performance)

(I) Recording	(J) Recording	Mean Difference (I-J)	Std. Error	df	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
6 Weeks Pre-Therapy	1 Week Pre-	1.29	3.38	45	1.00	-8.03	10.62
	1 Week Post-	-4.91	3.38	45	0.92	-14.24	4.42
	12 Weeks Post-	-7.54	3.38	45	0.19	-16.86	1.79
1 Week Pre-Therapy	6 Weeks Pre-	-1.29	3.38	45	1.00	-10.62	8.03
	1 Week Post-	-6.20	3.38	45	0.44	-15.53	3.13
	12 Weeks Post-	-8.83	3.38	45	0.07	-18.16	0.50
1 Week Post-Therapy	6 Weeks Pre-	4.91	3.38	45	0.92	-4.42	14.24
	1 Week Pre-	6.20	3.38	45	0.44	-3.13	15.53
	12 Weeks Post-	-2.63	3.38	45	1.00	-11.96	6.70
12 Weeks Post-Therapy	6 Weeks Pre-	7.54	3.38	45	0.19	-1.79	16.86
	1 Week Pre-	8.83	3.38	45	0.07	-0.50	18.16
	1 Week Post-	2.63	3.38	45	1.00	-6.70	11.96

Based on estimated marginal means

b. Adjustment for multiple comparisons: Bonferroni.

H.6. Table Showing Percentage Increase in Intelligibility Over Time for CS Performance

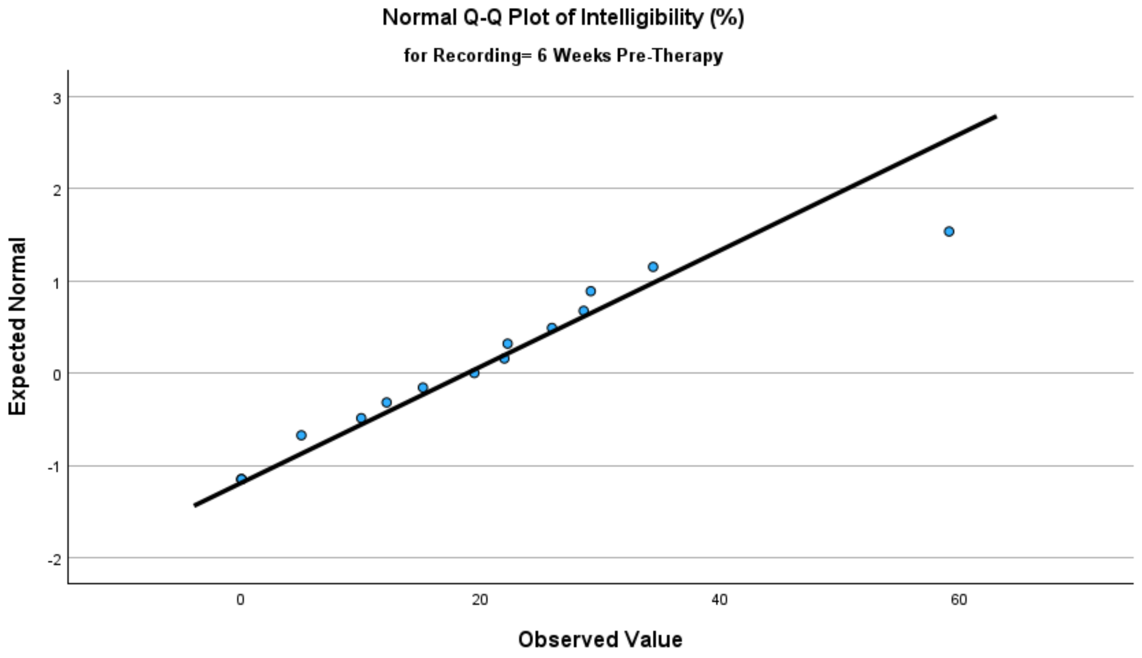
Child	1 Week Pre-Therapy vs. 1 Week Post-Therapy	Child	1 Week Pre-Therapy vs. 12 Weeks Post-Therapy
P1	14.76	P1	33.52
P2	3.95	P2	6.30
P4	4.76	P4	5.71
P5	20.28	P5	-6.57
P6	0.48	P6	7.18
P7	4.70	P7	1.61
P8	9.10	P8	0.36
P9	26.32	P9	13.10
P10	3.02	P10	14.13
P11	6.67	P11	4.30
P12	4.94	P12	36.82
P13	-6.81	P13	0.42
P14	-2.56	P14	9.25
P15	-2.32	P15	12.66
P16	5.77	P16	-6.35

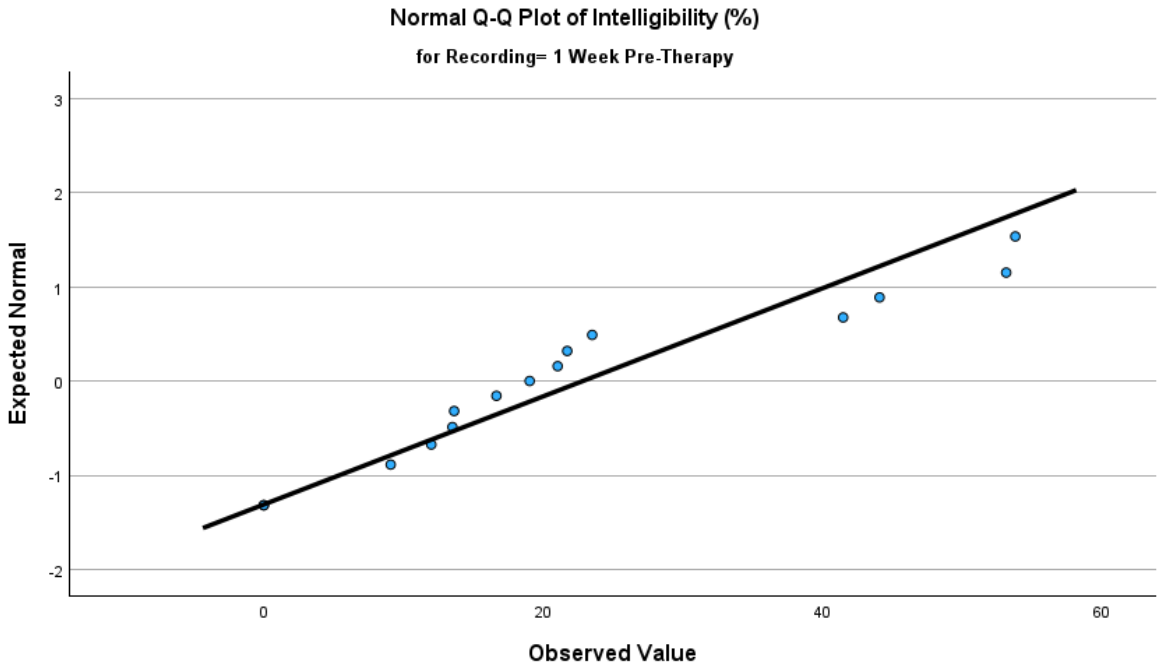
Appendix I. CS Capacity Perceptual Results

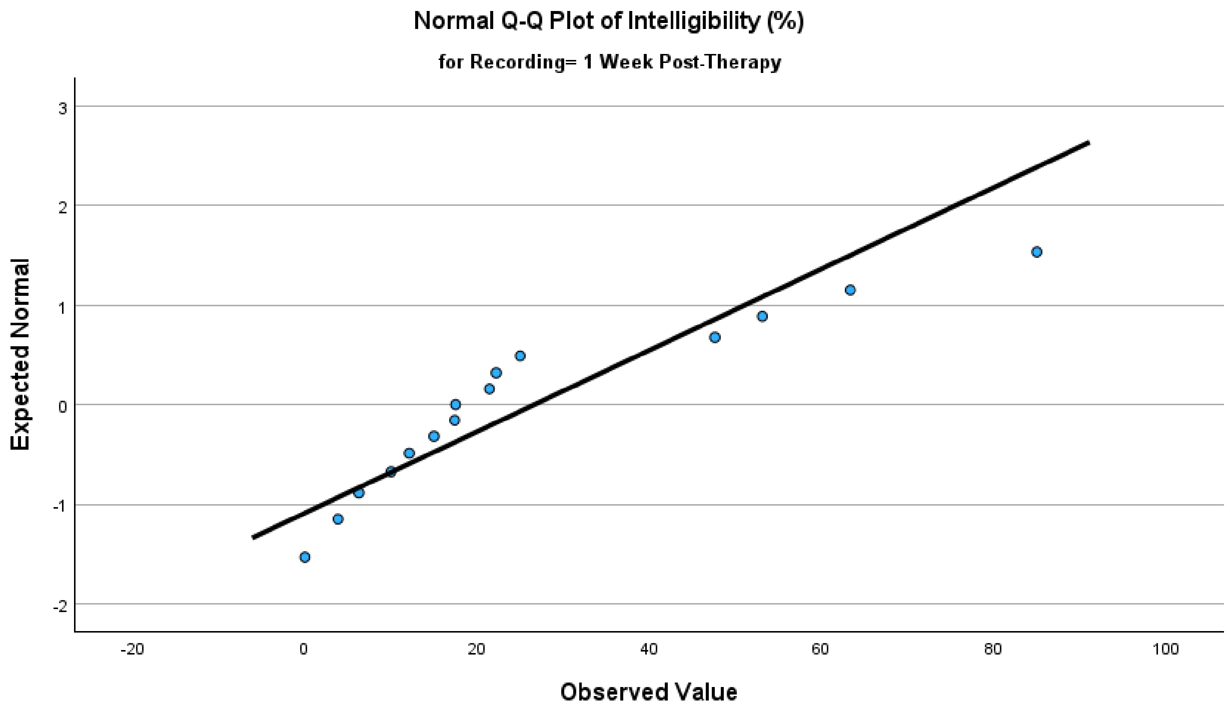
Appendix I.1. Results from ICC Assumption Testing on Raw Intelligibility Data for CS (Capacity)

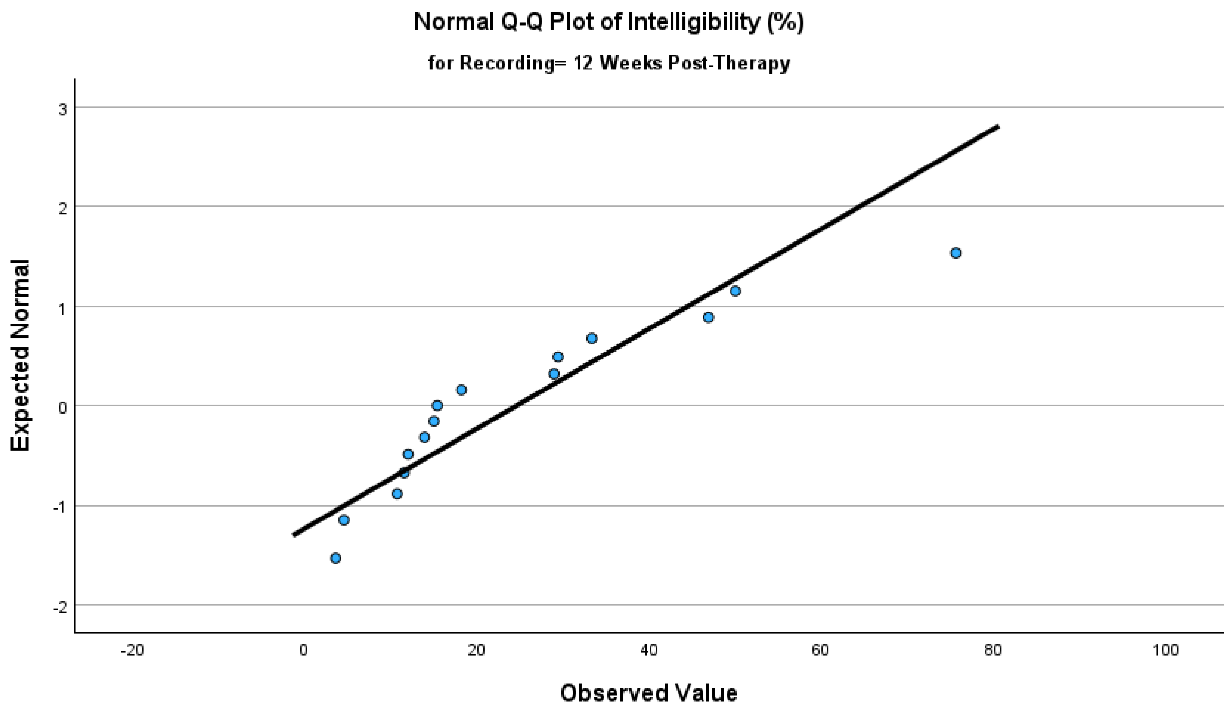
Tests of Normality			Tests of Homogeneity of Variances			
	Shapiro-Wilk				Levene Statistic (df1, df2)	Sig.
	Statistic (df)	Sig.	Intelligibility (%)	Based on Mean	0.99 (3, 56)	0.41
6 Weeks Pre-Therapy	0.2 (15)	0.17		Based on Median	0.30 (3, 56)	0.82
1 Week Pre-Therapy	0.90 (15)	0.09		Based on Median with adjusted df	0.30 (3, 44.82)	0.82
1 Week Post-Therapy	0.86 (15)	0.02		Based on trimmed mean	0.69 (3, 56)	0.56
12 Weeks Post-Therapy	0.86 (15)	0.02				

Appendix I.2. QQ Plots for CS Capacity Intelligibility at Each Timepoint





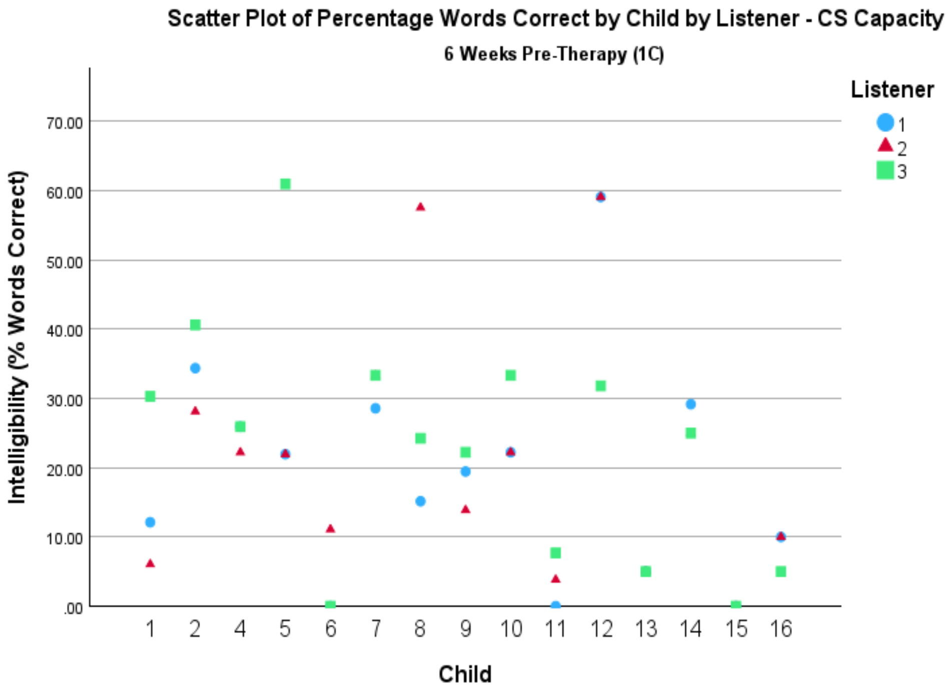

Normal Q-Q Plot of Intelligibility (%)
for Recording= 1 Week Post-Therapy
Expected Normal
3
2
1
0
-1
-2
-20
0
20
40
60
80
100
Observed Value

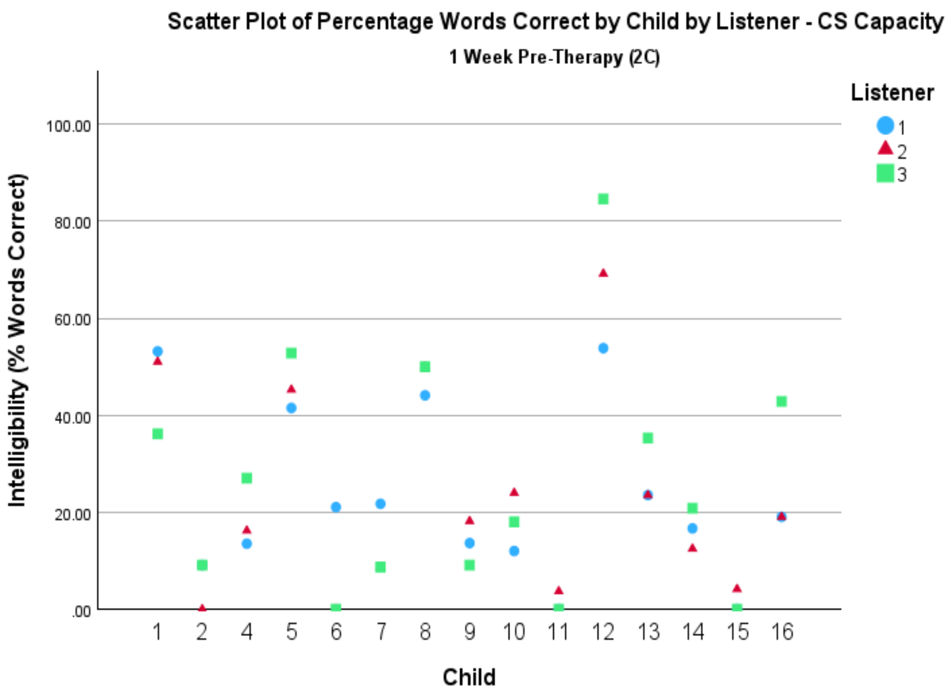

Normal Q-Q Plot of Intelligibility (%)
for Recording= 12 Weeks Post-Therapy
Expected Normal
3
2
1
0
-1
-2
-20
0
20
40
60
80
100
Observed Value

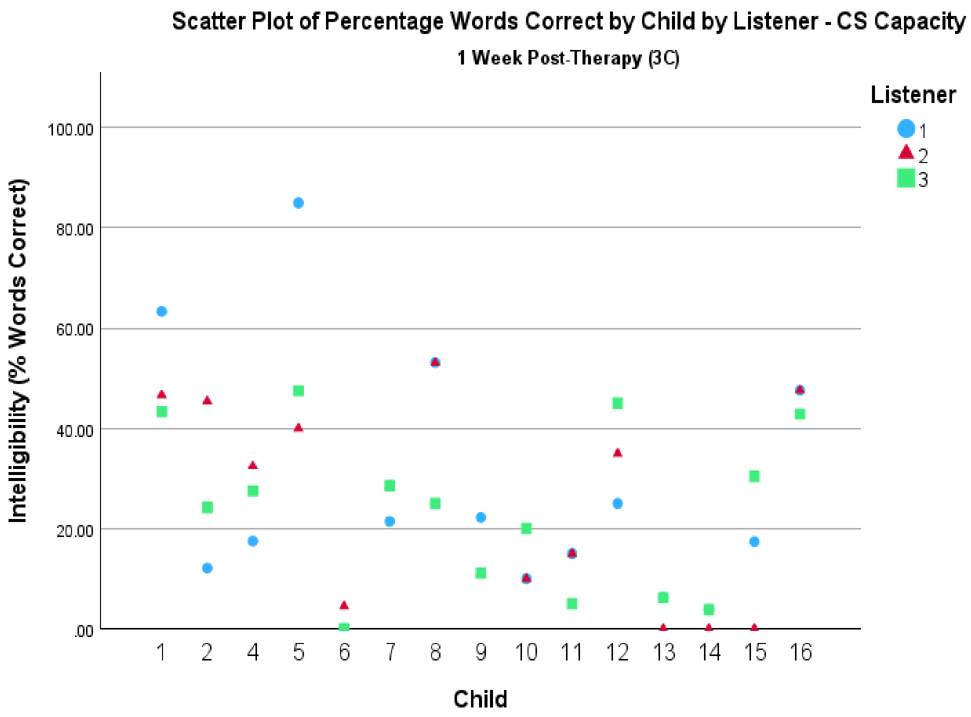
I.3. Results from ICC with 95% Confidence Intervals for Raw Listener Data of CS (Capacity)

Timepoint	ICC (Average Measures)	95% CI Lower, Upper
6-Weeks Pre-Therapy	0.84	0.61, 0.94
1 Week Pre-Therapy	0.95	0.88, 0.98
1 Week Post-Therapy	0.88	0.72, 0.96
12 Weeks Post-Therapy	0.83	0.60, 0.94

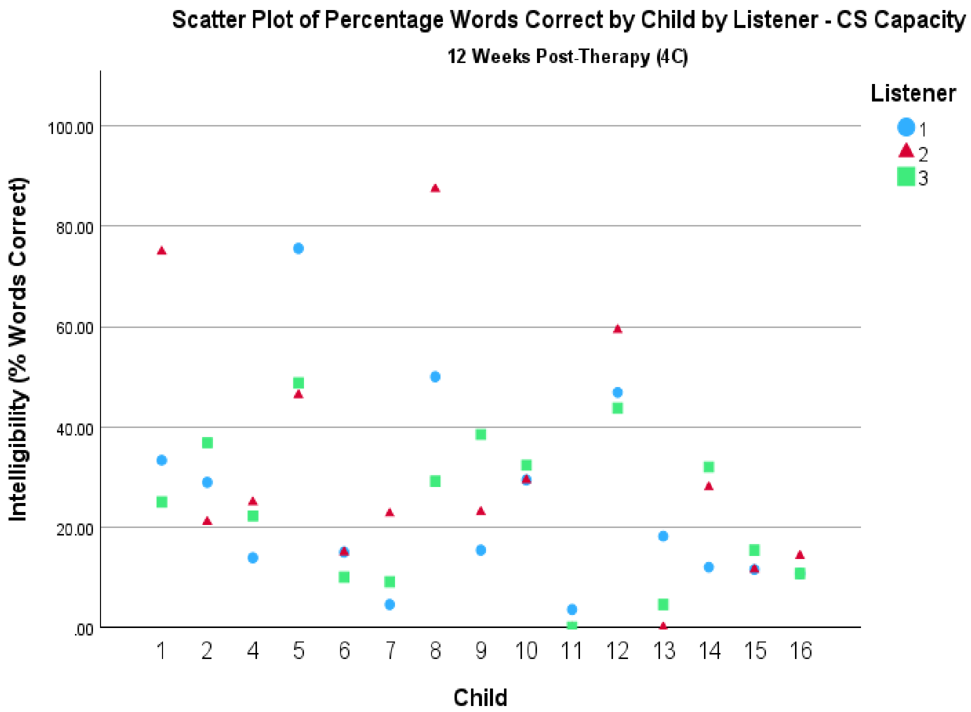
I.4. Scatter Plots Showing Percentage Word Correct by Each Listener at Each Timepoint (CS Capacity)







Scatter Plot of Percentage Words Correct by Child by Listener - CS Capacity
1 Week Post-Therapy (3C)
Intelligibility (% Words Correct)
100.00
80.00
60.00
40.00
20.00
.00
1
2
4
5
6
7
8
9
10
11
12
13
14
15
16
Child
Listener
1
2
3



Scatter Plot of Percentage Words Correct by Child by Listener - CS Capacity
12 Weeks Post-Therapy (4C)
Intelligibility (% Words Correct)
100.00
80.00
60.00
40.00
20.00
.00
1
2
4
5
6
7
8
9
10
11
12
13
14
15
16
Child
Listener
1
2
3

I.5. Results from Assumption Testing for Mean Intelligibility Data (CS Capacity)

Tests of Normality			Tests of Homogeneity of Variances			
	Shapiro-Wilk				Levene Statistic (df1, df2)	Sig.
	Statistic (df)	Sig.	Mean Intelligibility (% Words Correct)	Based on Mean	0.42 (3, 56)	0.74
6 Weeks Pre-Therapy	0.94 (15)	0.41		Based on Median	0.24 (3, 56)	0.87
1 Week Pre-Therapy	0.90 (15)	0.09		Based on Median with adjusted df	0.24 (3, 48.06)	0.87
1 Week Post-Therapy	0.94 (15)	0.34		Based on trimmed mean	0.36 (3, 56)	0.78
12 Weeks Post-Therapy	0.92 (15)	0.17				

Mauchly's Test of Sphericity			
	Mauchly's W[a]	Approx. Chi-Square (df)	Sig.
Recording	0.76	3.42 (5)	0.64

I.6. Table Showing Percentage Increase in Intelligibility Over Time for CS Capacity

Child	1 Week Pre- vs. 1 Week Post-Therapy	Child	1 Week Pre- vs. 12 Weeks Post-Therapy	Child	6 Weeks Pre- vs. 12 Weeks Post-Therapy
P1	4.30	P1	-2.36	P1	28.28
P2	21.21	P2	22.89	P2	-5.43
P4	6.91	P4	1.45	P4	-4.32
P5	10.96	P5	10.37	P5	21.95
P6	-5.50	P6	6.32	P6	9.63
P7	13.15	P7	-0.92	P7	-19.62
P8	-4.29	P8	7.52	P8	23.23
P9	1.18	P9	12.00	P9	7.12
P10	-4.67	P10	12.39	P10	4.47
P11	10.43	P11	-0.04	P11	-2.66
P12	-34.23	P12	-19.23	P12	0.00
P13	-23.28	P13	-19.88	P13	2.58
P14	-14.10	P14	7.33	P14	-2.39
P15	14.55	P15	11.43	P15	12.82
P16	19.05	P16	-15.08	P16	3.57

Appendix J. Predictor Variables Accounting for Changes in Intelligibility

J.1. Table Showing the Percentage of Monosyllabic and Polysyllabic Words Perceived Correctly at Each Timepoint

Recording	Syllable Count	Listener Correct		Total	% Correct
		0 (Incorrect)	1 (Correct)		
6 Weeks Pre-Therapy	Monosyllabic	405	90	495	18.18
	Polysyllabic	310	95	405	23.46
	Total	715	185	900	20.56
1 Week Pre-Therapy	Monosyllabic	418	77	495	15.56
	Polysyllabic	279	126	405	31.11
	Total	697	203	900	22.56
1 Week Post-Therapy	Monosyllabic	394	101	495	20.40
	Polysyllabic	273	132	405	32.59
	Total	667	233	900	25.89
12 Weeks Post-Therapy	Monosyllabic	374	121	495	24.44
	Polysyllabic	244	161	405	39.75
	Total	618	282	900	31.33

J.2. Table Showing the Mean Number of Words in a Phrase and the Range of Number of Words Produced for CS (Performance)

Timepoint	Mean Number of Words in a Phrase	Range of Number of Words in a Phrase
6 Weeks Pre-Therapy	6.78	2-13 (11)
1 Week Pre-Therapy	7.06	2-16 (14)
1 Week Post-Therapy	6.36	2-12 (10)
12 Weeks Post-Therapy	5.94	2-11 (9)

Appendix K. Binary Logistic Regressions for Single Word Data (Performance)

K.1. Results from Binary Logistic Regression for the Effect of Word Initial Singleton Consonant one the Outcome of Word Perceived Correct (SW Performance)

Predictors	Model 1				Model 2			
	AIC	B (SE)	p	Exp(B) (95% CI)	AIC	B (SE)	P	Exp(B) (95% CI)
6 Weeks Pre-Therapy	2836.7	-0.15 (0.14)	0.30	0.86 (0.65 to 1.14)	1854.1	0.10 (0.18)	0.57	1.10 (0.78 to 1.65)
1 Week Pre-Therapy (reference)		0 (0)	.	.	.	.	.	.
1 Week Post-Therapy		0.18 (0.14)	0.19	1.2 (0.91 to 1.58)		0.33 (0.17)	0.06	1.39 (0.99 to 1.95)
12 Weeks Post-Therapy		0.59 (0.13)***	1.04e-05	1.81 (1.39 to 2.35)		0.50 (0.17)**	0.003	1.65 (1.19 to 2.29)
WI Singleton Consonant						4.09 (0.20)***	<2e-16	59.46 (40.52 to 87.23)
Syllable Number								
WI*6 Weeks Pre-Therapy								
WI*1 Week Post-Therapy								
WI* 12 Weeks Post-Therapy								
Syllable*6 Weeks Pre-Therapy								
Syllable*1 Week Post-Therapy								
Syllable*12 Weeks Post-Therapy								

Predictors	Model 3				Model 5			
	AIC	B (SE)	P	Exp(B) (95% CI)	AIC	B (SE)	p	Exp(B) (95% CI)
6 Weeks Pre-Therapy	1797.7	0.21 (0.18)	0.25	1.23 (.86 to 1.76)	1797.2	0.53 (0.55)	0.34	1.69 (0.58 to 4.93)
1 Week Pre-Therapy (reference)		0 (0)	.	.		.	.	.
1 Week Post-Therapy		0.40 (0.18)*	0.02	1.49 (1.06 to 2.11)		0.06 (0.54)	0.91	1.06 (0.37 to 3.05)
12 Weeks Post-Therapy		0.51 (0.17)**	0.003	1.66 (1.19 to 2.32)		1.37 (0.52)**	0.01	3.92 (1.40 to 10.94)
WI Singleton Consonant		4.13 (0.20)***	<2e-16	61.91 (41.99 to 91.27)		4.16 (0.20)***	<2e-06	64.10 (43.31 to 94.87)
Syllable Number		0.92 (0.12)***	6.1E-14	2.52 (1.98 to 3.20)		1.08 (0.24)***	8.24e-06	2.93 (1.83 to 4.70)
WI*6 Weeks Pre-Therapy								
WI*1 Week Post-Therapy								
WI* 12 Weeks Post-Therapy								
Syllable*6 Weeks Pre-Therapy						-0.21 (0.36)	0.55	0.81 (0.40 to 1.63)
Syllable*1 Week Post-Therapy						0.25 (0.35)	0.47	1.29 (0.65 to 2.54)
Syllable*12 Weeks Post-Therapy						-0.57 (0.33)	0.08	0.57 (0.30 to 1.08)

K.2. Results from Binary Logistic Regression for the Effect of Word Final Singleton Consonant one the Outcome of Word Perceived Correct (SW Performance)

Predictors	Model 1				Model 2				Model 3			
	AIC	B (SE)	p	Exp(B) (95% CI)	AIC	B (SE)	p	Exp(B) (95% CI)	AIC	B (SE)	p	Exp(B) (95% CI)
6 Weeks Pre-	1499.2	-0.38 (0.24)	0.11	0.69 (0.43 to 1.09)	949.5	-0.14 (0.26)	0.59	0.87 (0.53 to 1.44)	903.5	-0.33 (0.27)	0.23	.72 (0.42 to 1.23)
1 Week Pre- (reference)		0 (0)	.	.		0 (0)	.	.		0 (0)	.	.
1 Week Post-		0.10 (0.22)	0.65	1.11 (0.71 to 1.72)		0.07 (0.24)	0.77	1.07 (0.67 to 1.73)		-0.12 (0.26)	0.63	.88 (0.53 to 1.47)
12 Weeks Post-		0.59 (0.22)**	0.01	1.81 (1.18 to 2.77)		0.63 (0.24)**	0.01	1.87 (1.17 to 2.99)		0.66 (0.25)**	0.01	1.93 (1.18 to 3.16)
WF Singleton Consonant						4.26 (0.27)***	<2e-16	70.75 (41.32 to 121.11)		4.31 (0.28)***	<2e-16	74.42 (42.98 to 128.87)
Syllable Number										1.27 (0.19)***	2.15E-11	3.57 (2.46 to 5.18)
WF*6 Weeks Pre-												
WF*1 Week Post-												
WF*12 Weeks Post-												
Syllable*6 Weeks Pre-												
Syllable*1 Week Post-												
Syllable*12 Weeks Post-												

Predictors	Model 4				Model 5			
	AIC	B (SE)	p	Exp(B) (95% CI)	AIC	B (SE)	p	Exp(B) (95% CI)
6 Weeks Pre-Therapy	839.9	-.50 (0.62)	0.43	0.61 (0.18 to 2.07)	907.5	-0.89 (0.81)	0.27	.41 (0.08 to 2.02)
1 Week Pre-Therapy (reference)		0 (0)	.	.		0 (0)	.	.
1 Week Post-Therapy		-.20 (0.62)	0.75	0.82 (0.24 to 2.78)		0.19 (0.75)	0.8	1.21 (0.27 to 5.30)
12 Weeks Post-Therapy		-16.27 (0.61)	0.61	8.60e-8 (1.45e-34 to 5.09e+19)		1.07 (0.73)	0.15	2.91 (0.69 to 12.28)
WF Singleton Consonant		3.71 (0.46)***	1.45E-15	40.77 (16.40 to 101.36)		4.31 (0.28)***	<2e-16	74.58 (43.00 to 129.34)
Syllable Number		1.30 (0.19)***	1.36E-11	3.67 (2.52 to 5.35)		1.33 (0.39)***	0.001	3.78 (1.75 to 8.17)
WF*6 Weeks Pre-Therapy		.19 (0.68)	0.78	1.21 (0.32 to 4.60)				
WF*1 Week Post-Therapy		.10 (0.67)	0.88	1.10 (0.30 to 4.13)				
WF*12 Weeks Post-Therapy		17.19 (31.45)	0.59	2.93e+07 (4.95e-20 to 1.74e+34)				
Syllable*6 Weeks Pre-Therapy						0.37 (0.55)	0.50	1.45 (0.50 to 4.25)
Syllable*1 Week Post-Therapy						-0.22 (0.52)	0.67	0.8 (0.29 to 2.22)
Syllable*12 Weeks Post-Therapy						-0.32 (0.53)	0.55	0.72 (0.25 to 2.07)

Appending L. Binary Logistic Regressions for Connected Speech Data (Performance)

L.1. Results from Binary Logistic Regression for the Effect of Word Initial Singleton Consonant one the Outcome of Word Perceived Correct (CS Performance)

Predictors	Model 1				Model 2			
	AIC	B (SE)	P	Exp(B) (95% CI)	AIC	B (SE)	p	Exp(B) (95% CI)
6 Weeks Pre-Therapy	3291.2	0.31 (0.22)	0.16	1.37 (0.88 to 2.12)	1260.2	0.13 (0.31)	0.68	1.13 (0.62 to 2.07)
1 Week Pre-Therapy (reference)		0 (0)	.	.		0 (0)	.	.
1 Week Post-Therapy		0.56 (0.22)*	0.01	1.76 (1.13 to 2.73)		0.42 (0.32)	0.18	1.53 (0.82 to 2.85)
12 Weeks Post-Therapy		0.81 (0.22)***	3.00E-04	2.26 (1.46 to 3.51)		0.40 (0.31)	0.20	1.49 (0.81 to 2.74)
WI Singleton Consonant						6.45 (0.31)***	<2e-16	633.49 (347.65 to 1154.43)
Number of Words								
WI*6 Weeks Pre-Therapy								
WI*1 Week Post-Therapy								
WI*12 Weeks Post-Therapy								

Predictors	Model 3				Model 4			
	AIC	B (SE)	p	Exp(B) (95% CI)	AIC	B (SE)	p	Exp(B) (95% CI)
6 Weeks Pre-Therapy	1262.1	0.13 (0.31)	0.68	1.14 (0.62 to 2.07)	1261	1.49 (1.16)	0.2	4.42 (0.46 to 4.29)
1 Week Pre-Therapy (reference)		0 (0)	.	.		0 (0)	.	.
1 Week Post-Therapy		0.43 (0.32)	0.18	1.54 (0.82 to 2.87)		2.24 (1.12)*	0.05	9.40 (1.04 to 84.83)
12 Weeks Post-Therapy		0.41 (-0.31)	0.19	1.50 (0.82 to 2.78)		1.17 (1.27)	0.35	3.23 (0.27 to 38.67
WI Singleton Consonant		6.45 (0.31)***	<2e-16	633.81 (347.86 to 1154.80)		7.73 (1.04)***	1.02E-13	2270.03 (296.27 to 17396.70)
Number of Words		0.01 (0.03)	0.74	1.01 (0.95 to 1.08)				
WI*6 Weeks Pre-Therapy						-1.45 (1.17)	0.21	.23 (0.02 to 2.31)
WI*1 Week Post-Therapy						-1.98 (1.13)	0.08	.14 (0.01 to 1.27)
WI*12 Weeks Post-Therapy						-0.82 (1.27)	0.52	.44 (0.04 to 5.36)

L.2. Results from Binary Logistic Regression for the Effect of Word Final Singleton Consonant one the Outcome of Word Perceived Correct (CS Performance)

Predictors	Model 1				Model 2			
	AIC	**B (SE)**	**p**	**Exp(B) (95% CI)**	**AIC**	**B (SE)**	**p**	**Exp(B) (95% CI)**
6 Weeks Pre-	2652.8	0.15 (0.24)	0.51	1.17 (0.75 to 1.85)	938	.39 (0.38)	0.31	1.47 (0.70 to 3.12)
1 Week Pre- (reference)		0 (0)	.	.		0 (0)	.	.
1 Week Post-		0.58 (0.23)*	0.01	1.79 (1.13 to 2.82)		.99 (0.39)*	0.01	2.70 (1.26 to 5.76)
12 Weeks Post-		0.63 (0.24)**	8.00E-03	1.87 (1.18 to 2.97)		.59 (0.39)	0.13	1.81 (0.84 to 3.87)
WF Singleton Consonant						6.11 (0.26)***	<2e-16	448.25 (268.11 to 749.43)
Number of Words								
WF*6 Weeks Pre-Therapy								
WF*1 Week Post-								
WF*12 Weeks Post-								

Predictors	Model 3					Model 4			
	AIC	AIC	B (SE)	p	Exp(B) (95% CI)	AIC	B (SE)	p	Exp(B) (95% CI)
6 Weeks Pre-	2652.8	939.5	0.39 (0.38)	0.31	1.47 (0.70 to 3.11)	940	0.70 (0.64)	0.28	2.01 (0.57 to 7.09)
1 Week Pre- (reference)			0 (0)	.	.		0 (0)	.	.
1 Week Post-			1.02 (0.39)**	0.008	2.76 (1.30 to 5.88)		1.05 (0.63)	0.1	2.86 (0.83 to 9.80)
12 Weeks Post-			0.62 (0.39)	0.11	1.86 (0.87 to 3.99)		-0.20 (0.80)	0.81	.82 (0.17 to 3.95)
WF Singleton Consonant			6.11 (.26)***	<2e-16	451.65 (270.31 to 754.64)		6.08 (0.51)	<2e-16	438.46 (160.03 to 1201.32)
Number of Words			0.03 (0.04)	0.46	1.03 (0.95 to 1.11)				
WF*6 Weeks Pre-Therapy							-0.42 (0.66)	0.53	.66 (0.18 to 2.39)
WF*1 Week Post-							-0.10 (0.66)	0.89	0.91 (0.25 to 3.33)
WF*12 Weeks Post-							0.99 (0.83)	0.24	2.68 (.53 to 13.67)

Appendix M. Percentage of Consonant Clusters Perceived Correctly for Connected Speech Data (Performance)

M.1. Mean Change in Percentage Intelligibility of Words Containing Word Initial Consonant Clusters for Each Child in CS (Performance)

Child	Mean % Intell 6 Weeks Pre	Mean % Intell 1 Week Pre	Mean % Intell 1 Week Post	Mean % Intell 12 Weeks Post	Mean % Change 1 Week Post vs 1 Week Pre	Mean % Change 12 Weeks Post vs 1 Week Pre
1	0.00	8.30	N/A	0.00	N/A	-8.30
2	22.20	N/A	33.30	33.30	N/A	N/A
4	33.30	0.00	0.00	11.10	0.00	11.10
5	11.10	66.70	83.30	22.20	16.60	-44.50
6	N/A	16.70	N/A	0.00	N/A	-16.70
7	25.00	16.70	33.30	27.80	16.60	11.10
8	25.00	33.30	83.30	25.00	50.00	-8.30
9	0.00	0.00	N/A	8.30	N/A	8.30
10	0.00	0.00	33.30	0.00	33.30	0.00
11	N/A	0.00	N/A	0.00	N/A	0.00
12	16.70	0.00	N/A	33.30	N/A	33.30
13	0.00	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	N/A	0.00	N/A	0.00
15	0.00	0.00	N/A	0.00	N/A	0.00
16	0.00	0.00	N/A	0.00	N/A	0.00
Group Mean	10.25	10.12	38.07	10.73		

M.2. Mean Change in Percentage Intelligibility of Words Containing Word Final Consonant Clusters for Each Child in CS (Performance)

Child	Mean % Intell 6 Weeks Pre	Mean % Intell 1 Week Pre	Mean % Intell 1 Week Post	Mean % Intell 12 Weeks Post	Mean % Change 1 Week Post vs 1 Week Pre	Mean % Change 12 Weeks Post vs 1 Week Pre
1	22.20	16.70	45.50	N/A	28.80	N/A
2	20.00	16.70	44.40	72.20	27.70	27.80
4	0.00	19.00	33.30	0.00	14.30	-33.30
5	41.70	50.00	66.70	71.40	16.70	4.70
6	0.00	0.00	0.00	0.00	0.00	0.00
7	50.00	0.00	0.00	0.00	0.00	0.00
8	55.60	41.70	33.30	44.40	-8.40	11.10
9	16.70	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	38.90	0.00	38.90
11	11.10	0.00	6.70	8.30	6.70	1.60
12	8.30	0.00	28.60	N/A	28.60	N/A
13	0.00	0.00	4.80	25.00	4.80	20.20
14	0.00	0.00	22.20	50.00	22.20	27.80
15	0.00	16.70	0.00	0.00	-16.70	0.00
16	55.60	33.30	33.30	16.70	0.00	-16.60
Group Mean	18.75	12.94	21.25	25.15		