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Perceptual and acoustic features of speech in individuals with Down syndrome and  
their impact on speech intelligibility

Thesis submitted in fulfilment of the requirements for degree of Doctor of  
Philosophy (PhD)

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## **Abstract**

Speech production involves five major components: respiration, phonation, articulation, resonance, and prosody and number of methods can be used to evaluate these aspects. Perceptual analysis methods are frequently employed; however, their reliability has been called into question. Acoustic analysis methods can provide a more objective view of certain aspects of speech production. For example, mean fundamental frequency can provide an accurate measure for vocal pitch. Due to a number of factors such as anatomical features and neurological involvement, difficulties with all five of the components of speech production have been frequently reported for people with Down syndrome (DS).

When producing speech, the five components combine to produce a spoken message via the acoustic signal. The amount of acoustic signal that is transferred from the speaker to the listener is referred to as speech intelligibility. When a speaker's speech intelligibility is reduced, it can negatively impact on their communication and affect their quality of life. Difficulties with speech intelligibility are common in people with DS. Reduced speech intelligibility can affect people with DS of all ages and may never be fully resolved. Several methods also exist for specifically measuring speech intelligibility. The most commonly used methods are rating scales and orthographic transcription. Some studies have examined how aspects of speech production contribute to speech intelligibility scores in different clinical populations. However, to date, no study has evaluated all five components of speech production in people with DS in one study or examined their impact on speech intelligibility. It is important to understand more about the nature of reduced speech intelligibility for this group in order to plan and deliver appropriate intervention.

This thesis includes four studies which aimed to address the gap in knowledge around the nature of speech intelligibility difficulties in people with DS and its measurement. The speakers in all four studies were 30 adolescents and adults with DS aged 16 years and over. Thirty typical adolescent and adult speakers matched for age and gender were included in the second study to provide a comparison for acoustic analysis findings. Sixteen experienced listeners were recruited to judge the speech samples to obtain a measure of speech intelligibility. Another group of 16 listeners who were not experienced, were also recruited to judge speech intelligibility for the fourth study. Recruiting a group of inexperienced (naive) listeners allowed for comparison of speech intelligibility scores when judged by listeners who were exposed and not exposed to hearing unclear speech.

Study 1 used perceptual analysis methods to evaluate the five major components of speech production—respiration, phonation, articulation, resonance, and prosody—for the speakers with DS. The experienced listeners then completed orthographic transcription of sentences to obtain a measure of speech intelligibility for the speakers with DS. Regression analysis was used to examine which perceptual parameters impacted on speech intelligibility scores. Results showed that a measure of phonation, breathiness, and a measure of articulatory accuracy, percent consonants correct, were the two strongest predictors of speech intelligibility.

Study 2 was similar to the first study in that it also used regression analysis to examine which parameters impacted on speech intelligibility scores for the speakers with DS. However, in this case, acoustic analysis methods were used to evaluate the five components of speech production and a group of typical speakers was included to serve as a comparison. Results showed that the slope of the second formant of /a/



and the voice onset time of /d/ were the strongest acoustic predictors of speech intelligibility for the speakers with DS.

Study 3 investigated how language ability impacted on speech intelligibility for the speakers with DS. Regression analysis was used to examine which receptive language measures and expressive language measures contributed to speech intelligibility scores. Results showed that mean length of utterance was the strongest predictor of intelligibility for those with DS.

Study 4 compared speech intelligibility scores using two different methods to measure intelligibility; and involved listeners with varying levels of experience to judge intelligibility. Orthographic transcription and visual analogue scale of sentences were used as the measurement methods of intelligibility. Results showed that speech intelligibility scores were significantly higher when orthographic transcription was used as the method of measurement compared to visual analogue scale. Results also showed that speech intelligibility scores were significantly higher when judged by the group of experienced listeners compared to the naive listener group across both measurement methods.

This thesis concludes that, when all aspects of speech production are considered, speech and language therapists (SLTs) should be aware that voice quality can play an influential role in the speech intelligibility of those with DS. They should also take into account articulation, motor speech performance, and language ability when assessing and treating speech intelligibility for this group. Additionally, when obtaining a measure of speech intelligibility, SLTs should be aware that the method of measurement they choose to employ can impact on outcome scores and that different methods may be measuring different aspects of speech intelligibility. SLTs should also bear in mind that, as an experienced listener,

their judgement of speech intelligibility for a speaker with DS may be different compared to when judged by an inexperienced listener. That is, even if an SLT perceives a speaker with DS to have a high level of speech intelligibility, the same speaker may not be so intelligible to listeners who are not familiar with the speech characteristics of people with DS.

These findings have provided more insight into the nature of speech intelligibility difficulties in individuals with DS. If SLTs knew about these difficulties, they would be more informed when making decisions regarding assessment and treatment and may lead to be better communicative performance and increased quality of life for those with DS.

### **Declaration**

This is to certify that the work I am submitting is my own and has not been submitted for another degree, either at University College Cork or elsewhere. All external references and sources are clearly acknowledged and identified within the contents. I have read and understood the regulations of University College Cork concerning plagiarism.

Signed .....

Deirdre O'Leary

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my outlook in regard to my PhD topic. If a problem arose, I was always confident that Fiona would know what to do or facilitate me in solving the problem independently. I will always be thankful for her contribution to my PhD study. All three of my supervisors have played a part in my undergraduate degree, my masters study, and now my PhD study. Even before my PhD commenced, they were already integral components in my career development. I only hope I can do them proud with this thesis.

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*“Love doesn’t count chromosomes”*



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### **List of Abbreviations**

|        |                                                    |
|--------|----------------------------------------------------|
| ANOVA  | Analysis of variance                               |
| ASSIDS | Assessment of Intelligibility of Dysarthric Speech |
| CAPE-V | Consensus Auditory-Perceptual Evaluation of Voice  |
| CHAT   | Codes for the Human Analysis of Transcripts        |
| CLAN   | Computerised Language Analysis                     |
| dB     | Decibels                                           |
| DME    | Direct magnitude estimation                        |
| DS     | Down syndrome                                      |
| EAI    | Equal-appearing interval                           |
| F0     | Fundamental frequency                              |
| F1     | First formant                                      |
| F2     | Second formant                                     |
| HNR    | Harmonics-to-noise ratio                           |
| HvD    | /h/ + /vowel sound/ + /d/                          |
| Hz     | Hertz                                              |
| M1     | First spectral moment                              |
| MLU    | Mean length of utterance                           |
| MPT    | Maximum phonation time                             |
| PCC    | Percent consonants correct                         |

|      |                                                            |
|------|------------------------------------------------------------|
| PVC  | Percent vowels correct                                     |
| SLD  | Stuttering-like dysfluency                                 |
| SLT  | Speech and language therapy/ speech and language therapist |
| SLTs | Speech and language therapists                             |
| SS   | Spontaneous speech                                         |
| TACL | Test for Auditory Comprehension of Language                |
| TTR  | Type-token ratio                                           |
| VAS  | Visual analogue scale                                      |
| VIF  | Variance inflation factor                                  |
| VOT  | Voice onset time                                           |
| VSA  | Vowel space area                                           |

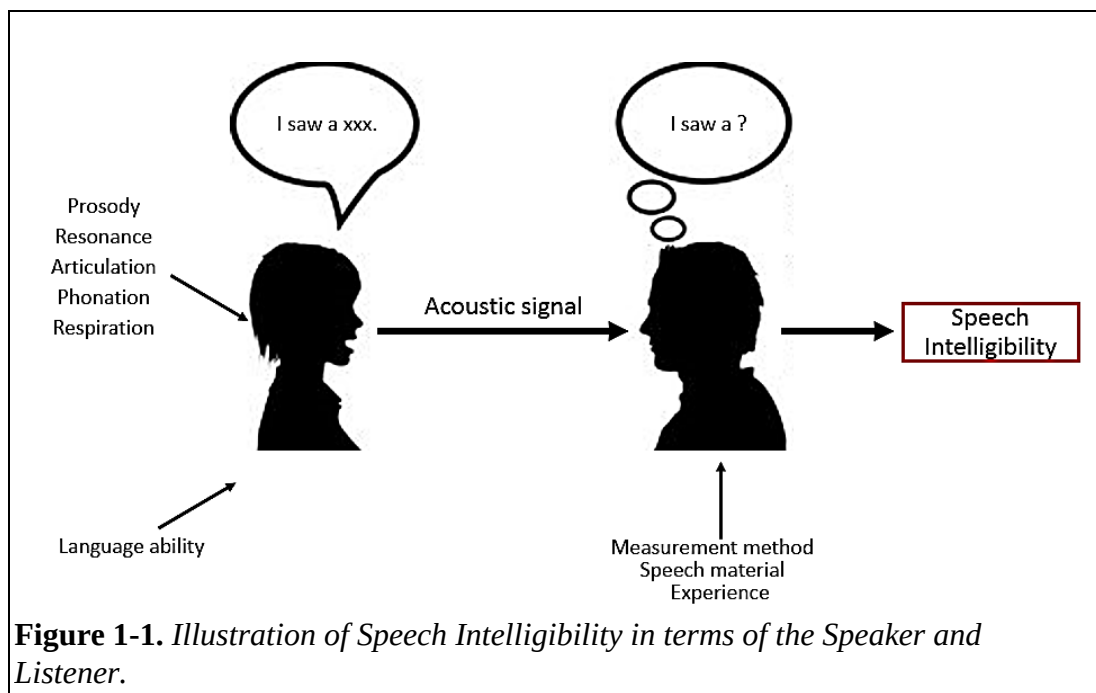


## Chapter 1

### INTRODUCTION AND LITERATURE REVIEW

#### 1.1 Background to study

Speech production involves fine co-ordination of five major components: *respiration, phonation, articulation, resonance* and *prosody*. A disruption to the typical function of any one of these components during speech production can result in changes to the acoustic signal which can impact on how much spoken information is understood by the listener, that is, *speech intelligibility* (Yorkston, Strand, & Kennedy, 1996, see Figure 1-1).



In relation to speech and language therapy (SLT), speech intelligibility is often viewed as one of the most important indicators of communicative effectiveness (Price & Kent, 2008). A measure of speech intelligibility can be used as a global indication of the severity of a speech difficulty, to evaluate compensatory strategies for speech production, to monitor treatment progress, or to monitor speech during disease progression (DePaul & Kent, 2000; Kent, Weismer, Kent, & Rosenbek,

1989b). Additionally, an indication of speech intelligibility can be a more accessible concept (in comparison to a phonological process for example) that can be easily communicated to parents and/or caregivers when reporting assessment results (Yorkston & Buekelman, 1981). One of the most important aspects of a speech intelligibility measure is that it can influence key decisions around care and services for people (Yorkston, Dowden, & Beukelman, 1992). Therefore, a valid and reliable method for measuring speech intelligibility is highly important in clinical practice.

Unintelligible speech (i.e. reduced speech intelligibility) is a common characteristic in the speech and language profile of individuals with Down syndrome (DS, Foda, Nassar, & Baraka, 2020). DS is a chromosomal abnormality caused by an error in cell division of the 21<sup>st</sup> chromosome. The genetic makeup of DS usually results in certain characteristic features of the syndrome including physical and medical difficulties, and a cognitive impairment. Cognitive impairment in DS usually results in delays in most areas of development and can contribute to the speech and language difficulties that are commonly reported in this population.

In regard to speech intelligibility, a widely cited survey by Kumin (1996) found that 95% of parents reported that their children with DS had unclear speech. In fact, people with DS can have poorer speech intelligibility even when compared to individuals with other types of cognitive impairment matched for mental age (Abbeduto & Murphy, 2004; Barnes et al., 2009; Chapman, Seung, Schwartz, & Kay-Raining Bird, 1998). Although clearer speech, or increased intelligibility of speech, is a common goal in SLT for people with DS, reduced speech intelligibility can be a lifelong limitation for this population (Kumin, 1996). Greater description of what can cause the breakdown in speech intelligibility is necessary so that interventions can target the specific impairment in each individual with DS.

All of the five components of speech production have been shown to be impaired in speakers with DS (these aspects will be discussed in more detail later in section 1.4). Moreover, most research has supported the theory of a motor speech difficulty being the main cause of reduced speech intelligibility for this group, including two recent studies by Wilson, Abbeduto, Camarata, and Shriberg (2019a, 2019b). The first study (Wilson et al. 2019a) examined the conversational speech samples of 45 adolescents with DS using both perceptual and acoustic analyses, along with the Speech Disorder Classification System (Shriberg, Strand, Jakielski, & Mabie, 2019) to investigate the types and prevalence of motor speech difficulties among the speakers with DS. Dysarthria was found to be the most common type of motor speech impairment, as well as motor speech delay, apraxia, and concurrent dysarthria and apraxia. For the speakers who were classified as having dysarthria, ataxic dysarthria was the most prominent. In the second study, Wilson et al. (2019b) used both perceptual and acoustic methods to analyse the articulation, voice, and prosody of the same group of speakers. They also measured the speakers' intelligibility and divided the speakers into two groups: one deemed to have high intelligibility and one deemed to have low intelligibility; and then compared aspects of the speech components across the two groups. For the speakers who met the criteria for dysarthria, apraxia or both (in the first study), the majority were also judged to have low intelligibility. Low intelligibility was associated with difficulties across all three speech production components – articulation, voice, and prosody.

However, the majority of studies that have examined speech production in people with DS have examined just one or two major components, no study has investigated all five of the components of speech production in one single study, nor have previous studies examined how each component might impact on speech

intelligibility. Hence, examination of the relative contribution of each component to speech intelligibility can allow for a profile of speech intelligibility to be established for speakers with DS and shed more light on the nature of reduced speech intelligibility in this population. People with DS are a heterogeneous group in many ways. Nevertheless, it would be beneficial to identify if there are features of speech intelligibility that are common across speakers or if there are some features that are more common than others.

This introduction chapter contains seven main sections. Section 1.2 outlines the five major components of speech production and section 1.3 discusses how these components of speech production are typically evaluated. Section 1.4 summarises DS and the major features of speech production in this population. Then, section 1.5 discusses the various methods used to measure speech intelligibility, and section 1.6 gives an overview of the factors that have been shown to influence outcomes when measuring speech intelligibility. Section 1.7 summarises the features specific to DS that can impact on listener judgement of speech intelligibility and finally, section 1.8 outlines the aims of this study.

## **1.2 Mechanism of speech production**

When a person wants to speak, they first formulate the plan in their brain and the plan is transmitted through their body via nerve impulses. The impulses reach the muscles in the lungs causing them to expand and contract, facilitating the movement of air; this movement of air through the body is referred to as *respiration* (Gick, Derrick, & Wilson, 2013). The basic function of the respiratory system is to move air

in and out of the body, but respiration for speech production facilitates the production of sound to enable communication (Ryalls & Behrens, 2000).

As the person exhales, the air leaves the lungs and travels through the trachea to the larynx. The larynx is an adjustable tube consisting of cartilage and ligaments that vertically links the trachea with the pharynx (Gick et al., 2013; Hixon, Weismer, & Hoit, 2020). The vocal folds are situated in the larynx; these are two ligament and muscle sets that adduct and abduct together in a periodic manner. The space in between the vocal folds forms the glottis (Johnson, 2012). During speech production, the periodic abduction and adduction of the vocal folds modifies the air and produces a vibration (or acoustic signal; this vibration is called *phonation* or voicing). Next, the air travels upwards from the vocal folds through the vocal tract. The vocal tract extends from the vocal folds in the larynx to the mouth (Kent & Read, 2010). Here in the vocal tract, the acoustic signal is further modified by altering the configuration of the tract through blocking or releasing air and creating turbulence. This alteration of the shape and length of the vocal tract is carried out via movement of anatomical structures such as the lips, tongue and jaw to produce specific acoustic properties relating to specific consonants and vowels; this process is known as *articulation* (Ladefoged & Johnson, 2015).

During speech production, the speaker must maintain a balance of the acoustic energy across the oral and the nasal cavities, which is referred to as *resonance* (Kent & Read, 2010). The oral cavity extends from the larynx to the mouth and the nasal cavity is the upper portion that extends from the soft palate to the nasal cavity (Bauman-Wängler, 2009). The airflow between the oral and nasal cavities is mainly controlled by a valve-like structure called the velopharyngeal port which is the space between the velum and the pharyngeal walls. During typical

production of some nasal sounds such as /n/, the velopharyngeal port is open but for the majority of oral sounds such as plosives and fricatives, the velopharyngeal port is closed (Bauman-Wängler, 2009). A resonance disorder usually results when there is inappropriate coupling between the nasopharynx and the other vocal tract cavities arising from difficulties with the velopharyngeal port. When there is too much nasal resonance, hypernasality can be perceived whereas when there is too little nasal resonance, an observation of hyponasality results. Lastly, during speech production, the speaker also uses additional features such as pitch, volume, timing, and stress to augment the speech output and add meaning to the verbal message; this is known as *prosody* (Peppé, 2009). A number of structures play a role in controlling the variations of these prosodic features (pitch, volume, timing, and stress) including the lungs, the larynx and the articulators.

### **1.3 Evaluation of speech production**

The evaluation of *respiration*, *phonation*, *articulation*, *resonance*, and *prosody* is an integral aspect of this study. The evaluation of speech production can be carried out using both perceptual and instrumental analysis methods. *Perceptual analysis* is a subjective method where a listener listens to a speech sample, either in real-time or from an audio-recording, and makes judgements based on specific parameters (Bauman-Wängler, 2009). The listener judges whether certain atypical speech features are present or absent and if present, how severe they sound. One commonly used perceptually-based judgement task is a rating scale, for example an equal-appearing interval scale (EAI). The scores from the rating scale can provide an indication of the severity of a difficulty. However, due to its subjective nature, perceptual analysis is not without its limitations. Perceptual judgement can be influenced by various factors. These include the type of speech material used for

analysis, the type of rating scale used to measure a certain feature, and the variable internal standards of the listener (De Bodt, Wuyts, Van de Heyning, & Croux, 1997; Fletcher, Risi, Wisler, & McAuliffe, 2019; Kreiman, Gerratt, Kempster, Erman, & Berke, 1993). Nevertheless, perceptual assessment methods of speech production are still utilised by speech and language therapists (SLTs) mainly due to their face validity, ease of use, low cost and because clinicians are more familiar with them (Kent, 1996; Theodoros, Murdoch, & Horton, 1999). Moreover, SLTs usually begin with the use of perceptual analysis methods before determining the areas that require further examination involving the use of instrumental measures (Lee, Potts, & Bressmann, 2020). When evaluating speech production, it is encouraged to supplement perceptual assessment methods with instrumental methods which are relatively more objective. Instrumental methods can be divided into three main types based on the types of techniques involved: imaging techniques, physiological measures, and acoustic analysis (Kent & Kim, 2003). Although not used to evaluate speech production in the current study, imaging techniques can include ultrasound of the tongue and physiological methods include electropalatography which evaluates tongue-palate contact. *Acoustic analysis* is where the physical properties of speech samples are analysed (Bauman-Wängler, 2009) and is the focus of this study.

Acoustic analysis of speech is largely based on the source-filter theory of speech production (Fant, 1970). According to Ludlow, Kent, and Gray (2019), the source-filter theory outlines how the acoustic signal of speech is produced by a form of energy source, that can be glottal or supraglottal; then the energy (or air) is filtered by the vocal tract and further altered by how the energy is released from the mouth into the external air. Hence, the acoustic signal is the final product of speech production. By investigating the acoustic signal during speech production and

examining differences and changes, it can be possible to infer which components of speech production are not functioning properly. Acoustic analysis facilitates several functions such as the display, annotation, and editing of speech samples, extracting acoustic parameters from speech samples, and carrying out spectral analysis. For both typical and clinical populations, this specialised software allows for the measurement of specific features of speech production which can be compared to measurements taken from speech samples of typical speakers. “Acoustic analysis can be informative because it affords quantitative analyses that carry potential for subsystem description and for determining the correlates of perceptual judgements” (Kent, Weismer, Kent, Vorperian, & Duffy, 1999, p. 141). Acoustic analysis can also help to overcome some of the limitations of perceptual analysis such as the variable internal standards of the listener. It can also be an affordable, readily accessible method and its use in the clinic is likely to increase (Kent et al., 1999).

The following sections will give an overview of each of the components of speech production, how each are typically evaluated using perceptual and acoustic analyses, and how the components can impact on speech intelligibility. Later in this introductory chapter, section 1.4 will discuss these components of speech production specifically in relation to speakers with DS.

### **1.3.1 Respiration**

The elements of the respiratory system are the driving forces behind speech production because they provide aerodynamic energy for the other components (Huber, Chandrasekaran, & Wolstencroft, 2005). Respiration can also contribute to the control of volume, pitch, and linguistic stress during speech production (Hixon et al., 2020). If a speaker’s respiratory function is impaired in some way, it can impact on their control of aspects such as spoken volume, which can then impact on the



speech signal and how a listener perceives the speech signal, thus, affecting speech intelligibility. In the clinic, an SLT is more likely to employ methods that are more readily accessible to evaluate a speaker's respiratory function.

One method for perceptually evaluating respiration during speech production is the completion of a rating scale. The most well-known perceptual protocol for rating specific aspects of speech production is the long-standing method introduced by Darley, Aronson, and Brown (1969a). This protocol was initially developed as a differential diagnosis tool for speakers with dysarthria, which is a speech disorder arising from damage to the nervous system resulting in poor co-ordination of the muscles used for speech (Webb & Elsevier, 2017). The assessment protocol outlined 38 speech dimensions that can be perceptually evaluated on a 7-point EAI scale (rating scales will be discussed in more detail in section 1.5). Three of the 38 dimensions are related to respiratory function: forced inspiration/expiration, audible inspiration, and grunt at end of expiration.

Another acoustic method that has been used for evaluating respiration is measuring the maximum phonation time (MPT). The MPT requires the person to expend the maximum amount of air available for voicing; hence, it measures the efficiency of the larynx to utilise air to sustain vocal fold vibration (Hirano, Koike, & Von Leden, 1968). The MPT is a quick and easy way to obtain a broad measure of respiration and it carries high validity and reliability (Speyer et al., 2010). The speaker is instructed to take a deep breath and produce the vowel /a/ at a comfortable pitch and volume level for as long as they can while the duration of production is measured. Usually, three attempts are made and the mean duration is recorded as the MPT (Hixon et al., 2020). Typical young adults usually have an MPT of at least 20 seconds and males usually have a longer MPT compared to females (Goy,

Fernandes, Pichora-Fuller, & van Lieshout, 2013). MPT has been noted to decrease with some form of respiratory impairment (Kent, Kent, & Rosenbek, 1987). A speaker who has inefficient airflow due to poor co-ordination between respiration and phonation will also have a shorter MPT (Kent & Read, 2010). MPT has been found to strongly correlate with slow vital capacity (Lima et al., 2014). Slow vital capacity reflects the greatest amount of air that can be released from the lungs and can reflect lung function (Barros, Pires, & Raposo, 2013). However, it must be noted that although MPT can be used as a basic measure of respiration, it can also reflect laryngeal function (Johnson & Goldfine, 2016). Hence, if a speaker presents with a reduced MPT, a respiratory problem may be indicated, but dysphonia due to vocal fold pathology is also possible and should be explored (Maslan, Leng, Rees, Blalock, & Butler, 2011).

To date, although it is acknowledged that respiration plays a role in the process of speech production, few studies have examined its role when compared to the other components of speech production, or how its function, if impaired in some way, can impact on speech intelligibility. Furthermore, little empirical evidence exists that has investigated the relationship between speaker respiration and listener judgement of speech intelligibility.

### **1.3.2 Phonation**

As explained in section 1.2, phonation occurs when the vocal folds adduct and abduct together in a repetitive pattern to alter the airflow and produce acoustic energy (Ladefoged, Disner, & ProQuest, 2012). When the movement of the vocal folds is atypical in some way or the phonatory tract is disrupted, a voice problem can occur. Phonation can be evaluated using both perceptual and acoustic analysis methods. However, research has shown that the combination of these approaches can

be the most reliable way to identify a voice difficulty in the clinic (Eadie & Doyle, 2005). The rest of this section will discuss the most common methods that have been previously used to evaluate phonation, with a focus on those used in the current study.

A well-known example of a perceptual method for evaluating voice is the GRBAS scale. The GRBAS scale evaluates five areas of voice quality—general grade of dysphonia (voice problem), roughness, breathiness, asthenia, and strain—on a scale from 0-3 (Hirano & McCormick, 1986). Asthenia refers to a weak voice. Another more recently developed tool for perceptually evaluating voice is the Consensus Auditory-Perceptual Evaluation of Voice (CAPE-V, Kempster, Gerratt, Verdolini Abbott, Barkmeier-Kraemer, & Hillman, 2009). The use of the CAPE-V by both clinicians and researchers to evaluate voice is steadily increasing (Solomon, Helou, & Stojadinovic, 2011). The CAPE-V allows for the perceptual evaluation of voice through completion of visual analogue scale (VAS) under the following parameters: overall dysphonia rating, breathiness, roughness, strain, pitch and loudness (Kempster et al., 2009). A VAS consists of a line usually 100 mm in length, with descriptive labels on each end indicating the outer extremes of measurement (Freyd, 1923). The speech tasks for the perceptual rating judgements are prolonged vowel production, production of sentences, and spontaneous speech. The CAPE-V has been demonstrated to have stronger reliability compared to the GRBAS scale (de Almeida, Mendes, & Kempster, 2019) and has been previously used in research to examine the relationship between phonation and speech intelligibility (Evitts et al., 2016).

For acoustic evaluation of phonation, the most common acoustic parameters are mean fundamental frequency (F0), mean amplitude, jitter, shimmer, and

harmonics-to-noise ratio (HNR). F0 is the acoustic correlate of pitch. In theory, a higher mean F0 would indicate a higher pitch. Adult males usually have a mean F0 of around of 100-150 hertz (Hz) and adult females would usually be around 200-270 Hz (Goy et al., 2013). Amplitude is the acoustic correlate of loudness with typical mean amplitude levels during spoken conversation usually being around 70 decibels (dB, Colton, Casper, & Leonard, 2011). Jitter is a measure of frequency perturbation and represents the variability in the frequency of vocal fold vibration from one cycle to the next. Shimmer is a similar measurement except it relates to the variability in amplitude (Baken & Orlikoff, 2000). Typical voices contain some level of variability, however, higher than normal levels of jitter and/or shimmer can indicate a vocal pathology. For adults, typical jitter levels tend to be less than 1% and typical shimmer values are less than 3% (Kent et al., 1987). The HNR is also an acoustic parameter that is used to evaluate voice quality. The HNR represents the proportion of added noise compared to harmonics in an acoustic signal (Hillenbrand, 1987). A low HNR, that is, less than 7 dB can indicate a vocal pathology (Boersma, 1993). The low HNR is usually caused by inadequate closure of the vocal folds that allows excessive airflow through the glottis resulting in a higher noise level (Ferrand, 2002). The HNR has been shown to relate to the perceptual features hoarseness and breathiness (Muñoz, Mendoza, Fresneda, Carballo, & López, 2003; Yumoto, Gould, & Baer, 1982) and it has also been found to have a higher correlation with perceptual features of voice quality compared to jitter and shimmer (Wolfe, Fitch, & Cornell, 1995).

In regard to speech intelligibility, impaired phonation, or an atypical voice, can impact on the speech acoustic signal and affect how the listener perceives the spoken message, thus influencing intelligibility. A small number of studies have

investigated the impact of phonation on speech intelligibility in those with dysarthria and hearing loss when compared to other aspects of speech production. The general findings from these groups showed that phonation, as measured by both perceptual and acoustic analysis methods, did not contribute to intelligibility as much as articulation and prosody (De Bodt, Hernández-Díaz Huici, & Van De Heyning, 2002; Lee, Hustad, & Weismer, 2014; Metz, Samar, Schiavetti, Sitler, & Whitehead, 1985).

### **1.3.3 Articulation**

Articulation is referred to as the production of speech sounds using anatomical structures such as the jaw, lips, teeth, tongue, hard palate, and soft palate to modify the shape of the vocal tract (Kent, 2009). If articulation is impaired, the speaker's ability to accurately produce certain speech sounds would be affected, which would have knock-on impact on how the listener perceives the speech signal. In the clinic, articulation is usually perceptually evaluated by eliciting all the sounds of the speaker's spoken language in all word positions via a single word picture naming task (McLeod & Baker, 2014). The SLT would phonetically transcribe speech productions and identify any errors that may need to be considered for treatment (Skahan, Watson, & Lof, 2007). Errors may occur with vowels or consonants. The SLT may also obtain a general measure of severity by calculating the percent consonants correct (PCC) and percent vowels correct (PVC). These measures are obtained by adding the number of sounds produced correctly, dividing by the total number of sounds produced, and multiplying by 100 to get a percentage score (Shriberg, 1997a). The PCC and PVC can be used by the SLT to help with prioritisation of treatment by determining severity of the speech sound disorder and to monitor change during treatment (Bankson, Bernthal, & Flipsen, 2009). It should

be noted that, as well as a measure of articulation, PCC can also be used to measure phonology. Therefore, when a PCC score is calculated, it can reflect both articulatory and/or phonological errors and the nature of the errors cannot be identified from the PCC score alone.

Phonology is a component of linguistics and concerns the rules that govern the speech sounds of a spoken language (Bankson et al., 2009). Bauman-Wängler (2009) distinguishes between phonetics and phonology by describing phonetics as representing the *form* of speech sounds by describing their articulatory, perceptual, and acoustic aspects; whereas phonology refers to their *function* in establishing meaning within a language system. Phonology and disordered phonology will be discussed in more detail under the heading “language ability” in section 1.6.1.

Other factors that would be considered during assessment of articulation include the consistency of errors, types of errors, stimulability, and oro-motor skills (Bankson et al., 2009). Analysis of these factors can provide important information for the differential diagnosis of speech disorders. Inconsistent errors or substitution errors can be a feature apraxia of speech. Apraxia is an impairment with planning and/or programming of movement sequences for speech resulting in speech sound errors and prosody difficulties (Shriberg, Paul, Black, & van Santen, 2011). Consistent errors accompanied by poor oro-motor skills may indicate a difficulty with dysarthria. As discussed previously, dysarthria refers to a group of speech disorders resulting from impairment to muscular control for speech production due to neurological impairment (Brookshire, 2014). Both apraxia and dysarthria are types of motor speech disorder.

Regarding acoustic analysis of articulation, many parameters have been used by researchers to evaluate consonants and vowels; this section will focus on the most

common acoustic parameters that have been used to evaluate articulation, as reviewed by Kent et al. (1999). The measurement of parameters relating to formant frequencies is a major method used for quantifying vowels. F1 is the first formant frequency and can reflect tongue height when producing a vowel; the higher the tongue, the lower the F1 value (Hixon et al., 2020). F2 is the second formant frequency and reflects the frontness or backness of the tongue and rounding of the lips; typically, the more anterior the tongue, the higher the F2 value (Ladefoged & Johnson, 2015). The F2 slope, then, reflects the rate of change of the vocal tract configuration when changing from a vowel sound to another sound (Ansel & Kent, 1992). The F2 slope can be calculated by first obtaining the difference between the F2 at the onset and offset of the vowel, and dividing by the entire vowel duration (Lansford & Liss, 2014). In previous studies, a reduced F2 slope has been found to associate with impaired lingual musculature (Kent, 1990).

Another acoustic parameter that has been used to evaluate articulation of vowels is the vowel space area (VSA). The VSA is the quadrilateral area bounded by the lines connecting the F1 and F2 co-ordinates of the four corner vowels. A larger VSA is associated with more precise articulation, while smaller VSAs indicate restricted tongue movement (Bradlow, Torretta, & Pisoni, 1996; Higgins & Hodge, 2002; Lam, Tjaden, & Wilding, 2012; Liss, Spitzer, Caviness, Adler, & Edwards, 2000; Turner, 1995).

For acoustic analysis of consonant production, one method that has been used is spectral moment analysis of fricatives (Forrest, Weismer, Milenkovic, & Dougall, 1988). Spectral moment analysis examines the spectral characteristics of a speech sample in terms of multiple statistical moments: the first moment is the mean or centre of gravity (M1), the second moment is the standard deviation, the third

moment is the skewness, and the fourth moment is the kurtosis (Nissen & Fox, 2005). The spectral mean and variation represent the central tendency and variation of the spectrum respectively. The skewness reflects the spectral tilt or slope and the kurtosis represents the peakedness of the spectrum (Tanner, Roy, Ash, & Buder, 2005). Analysis of spectral moments has been shown to relate to the place of articulation for voiceless fricatives in speech (Nissen & Fox, 2005).

Voice onset time (VOT) has also been used to acoustically evaluate articulation of plosive sounds. VOT represents the length of time between the release of closure of a plosive and the onset of voicing of the following vowel (Ladefoged et al., 2012). Hence, VOT reflects the fine co-ordination of laryngeal function (phonation) and articulation (Orlikoff & Baken, 1993). VOT has been found to discriminate between typical speakers and those with atypical speech in that those with speech difficulties had longer VOTs compared to typical speakers (Liu, Ng, Wan, Wang, & Zhang, 2007). VOT has also been shown to vary due to place of articulation, in that the VOT duration increases as articulation moves posteriorly from the lips to the velum (Steinschneider, Fishman, & Arezzo, 2003). In addition, VOT has been shown to discriminate between voiced and voiceless plosives in that VOTs of voiced plosives are typically shorter than that of voiceless plosives (Cho & Ladefoged, 1999).

In general, articulation is known to play an influential role in how a speaker is perceived by the listener. For example, the F2 slope has been found to correlate highly with speech intelligibility in speakers with dysarthria (Kent et al., 1989a; Kim, Weismer, Kent, & Duffy, 2009; Lee et al., 2014) and is viewed as one of the most sensitive acoustic contributors to speech intelligibility for speakers with motor speech difficulties (Weismer, Martin, Kent, & Kent, 1992). In addition, a smaller



VSA has been found to correlate with reduced speech intelligibility (Bradlow et al., 1996). However, the majority of studies that have examined how aspects of articulation impact on intelligibility in those with speech difficulties have examined articulation in isolation or compared two or three components of speech production in their analysis, they did not include all five (Ansel & Kent, 1992; De Bodt et al., 2002; Lee et al., 2014; Whitehill & Ciocca, 2000).

#### **1.3.4 Resonance**

Perceptually, resonance is typically evaluated by listening to a speech sample and judging whether there is too much or insufficient nasal quality for the sounds produced. That is, too much nasal quality (i.e. hypernasality) is not expected in utterances when oral (non-nasal) sounds are produced by typical speakers. Darley et al. (1969a) used rating scales to evaluate three parameters pertaining to resonance and velopharyngeal function as part of their protocol for evaluating the speech of those with dysarthria: these were hypernasality, hyponasality, and nasal emissions. Other assessment protocols measure parameters related to resonance but which are more specific to those with cleft lip and palate, such as nasal turbulence and grimace (Sell, Harding-Bell, & Grunwell, 1994).

Acoustic analysis has shown that nasalised vowels can affect the amplitude of the formants and a number of acoustic methods have used vowel formants to evaluate resonance (Kent & Read, 2010; Ludlow et al., 2019). For example, one acoustic method involves measuring the “voice low tone to high tone ratio” (Lee, Yang, & Kuo, 2003). However, the method that has received the most positive reports in the research is one-third-octave analysis. This method was first developed by Kataoka and colleagues in 1996 and has been used by other researchers since being introduced (e.g. Lee, 2004; Yoshida et al., 2000). One-third-octave analysis

measures the mean energy level for each frequency band, which is one-third of an octave in bandwidth, within a frequency range (Kataoka, Michi, Okabe, Miura, & Yoshida, 1996). Previous studies have shown one-third-octave analysis to be a robust and generalisable method for comparing typical and hypernasal speech in various clinical populations. For example, Vogel, Ibrahim, Reilly, and Kilpatrick (2009) compared one-third-octave analysis to the “voice low tone to high tone ratio” method for evaluating nasality. The “voice low tone to high tone ratio” method divides the low-frequency and high-frequency amplitudes in the spectrum (Lee et al., 2003). A lower “voice low tone to high tone ratio” would indicate lower levels of hypernasality (Dodderi, Narra, Varghese, & Deepak, 2016). Vogel et al. (2009) found that one-third-octave analysis was better at discriminating between speakers with hypernasality in their speech and those who did not exhibit hypernasal speech. A study by Kimura, Imatomi, Kataoka, Sato, and Okubo (2009) also found that when combined with perceptual judgements of hypernasality, one-third-octave analysis is an appropriate tool to identify hypernasality during speech.

Studies have shown that resonance can play an important role in the perception of speech intelligibility. For example, hypernasality and hyponasality can interfere with the production of phonetic contrasts, which would have a knock-on effect on the speech signal and how the listener perceives speech (Kent & Vorperian, 2013). Two studies have compared the relative contribution of resonance to speech intelligibility in those with dysarthria compared to articulation, phonation and prosody. Findings showed that resonance was usually the component that contributed the least to speech intelligibility (De Bodt et al., 2002; Lee et al., 2014). However, no study has compared the relative contribution of all five components of speech production to speech intelligibility in any speaker group.

### **1.3.5 Prosody**

Prosody refers to the suprasegmental features of speech, such as pitch, intensity, pauses, and timing that contribute to the production of stress, rhythm, tempo, and lexical tone of an utterance (Fletcher, 2013; Peppé, 2009). As with other aspects of speech production, both perceptual and acoustic analysis methods can be used to evaluate prosody. Ten perceptual parameters in the Darley et al. (1969a) assessment protocol for dysarthria pertain to prosody. These parameters were excess and equal stress, reduced stress, rate slow/fast, short phrases, increased rate in segments, increased rate overall, variable rate, prolonged intervals, inappropriate silences, and short rushes of speech.

Acoustic analysis of prosody primarily relates to aspects of F0, amplitude, and duration. The most common stimulus used to acoustically evaluate prosody is usually a spontaneous speech sample because it reflects natural speech production (Liss et al., 2009). The mean F0 and other parameters pertaining to F0 are frequently used to evaluate speech prosody in the research. F0 has been used to investigate prosody in different clinical populations, including those with autism and Parkinson's disease (e.g. Martens et al., 2011; Quigley, McNally, & Lawson, 2016; Skodda, Gronheit, & Schlegel, 2011). Parameters that measure the variation in F0 are also used to evaluate prosody; these include the F0 range (the difference between the maximum F0 and the minimum F0 in a given speech sample) and the F0 standard deviation (Diehl & Paul, 2012). In regard to prosody, the F0 range can indicate something about the type of intonation a speaker exhibits in their speech. A low F0 range, for example, can be associated with monotonous speech (Loeb & Allen, 1993). Finally, two acoustic parameters relating to amplitude, the mean amplitude and amplitude range, are also frequently used in the evaluation of spoken prosody. A

low amplitude range can indicate monoloudness and impaired prosody (Duffy, 2020). Analysis that has examined duration or timing features of prosody have usually measured speaking rate. Speaking rate refers to the number of syllables or words produced divided by the time taken (Robb & Gillon, 2009). A slow speaking rate is common in those with motor speech difficulties, for example, dysarthria (Kent & Kim, 2003).

For this study, fluency was included under the component of prosody because it relates to features of speech that are larger than the phone (Kent & Vorperian, 2013). Fluency refers to the smoothness or rhythmicity of speech and impaired fluency is observed when a listener judges speech to have more dysfluency than would be expected for a typical speaker (Leddy, 1999). Fluency can be perceptually evaluated using a rating scale or by a less impressionistic method of calculating the frequency of dysfluent occurrences. The number of dysfluency events in a speech sample are tallied and expressed as a percentage of the entire speech sample (e.g. Guitar, 2019; Karimi, O'Brian, Onslow, & Jones, 2014). Frequency of the dysfluent events can be calculated in terms of the percentage of syllables stuttered, the percentage of words stuttered, and the percentage of stuttering-like dysfluencies (%SLD). SLD are typically syllable or part-word repetitions, prolongations and blocks (Bloom & Cooperman, 1999). A study by O'Brian, Packman, Onslow, and O'Brian (2004) compared the use of frequency analysis and a rating scale for the evaluation of fluency in adults who stuttered. They found high intra- and inter-rater reliability for both measures. They also found that the frequency analysis scores and rating scores were strongly positively correlated with each other. Frequency analysis can be carried out perceptually or using acoustic methods. Acoustic analysis software can be used to analyse a speech sample by annotating

dysfluencies and calculating the duration of fluent and dysfluent sections (Hasseltine et al., 2016; Rezai et al., 2017). Most formal assessments of fluency incorporate the use of frequency analysis. For example, the Stuttering Severity Instrument-4<sup>th</sup> Edition (Riley, 2009) evaluates the percentage of syllables stuttered as part of its test battery.

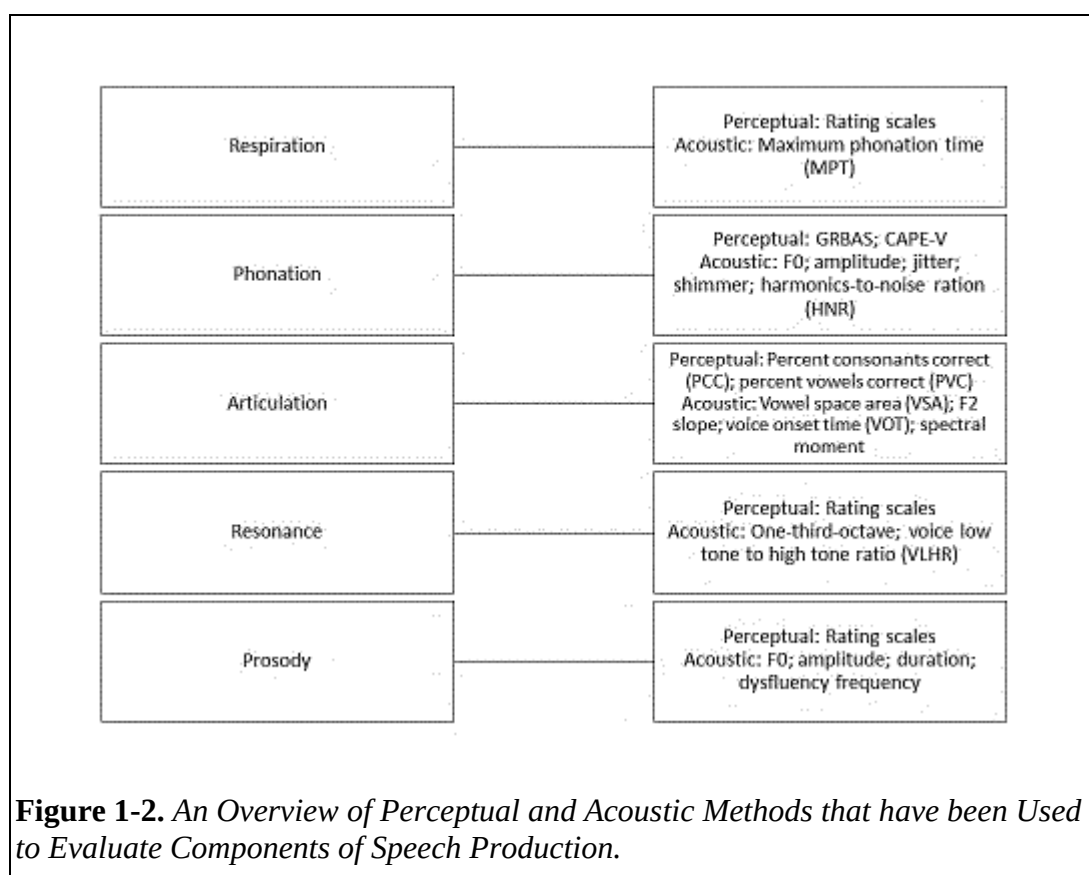
Atypical prosodic features of speech can impact on how a listener decodes the acoustic signal. For example, incorrect use of pauses could impact on how listener perceives boundaries between words which could negatively impact on their perception of intelligibility (Hammen & Yorkston, 1996). An atypical speaking rate and dysfluency can also negatively impact on speech intelligibility (Feenaughty, Tjaden, & Sussman, 2014). One study by De Bodt et al. (2002) found that when compared to articulation, resonance, and phonation, prosody was the second strongest contributor to speech intelligibility in speakers with dysarthria.

### **1.3.6 Summary**

The above sections have provided an overview of the components of speech production and how they can be evaluated in the clinic using both perceptual and acoustic analysis methods. This overview was provided in order to offer a rationale for the methods that were used in the current study. In summary, the main perceptual methods that can be used to evaluate the components of speech production are the completion of some form of rating scale or frequency calculation. Regarding acoustic analysis of speech production, MPT is the main acoustic parameter that can be employed to examine respiratory function and F0, amplitude and HNR are the main acoustic parameters used to evaluate phonation. For articulation, several acoustic parameters have been used for assessing both vowels and consonants: the main parameters are VSA, F2 slope, VOT and spectral moment analysis. One-third-

octave analysis is a valid method for evaluation of resonance and for prosody, acoustic parameters pertaining to F0, amplitude, and duration are the most frequently used. Figure 1-2 provides a summary of the evaluation methods that were discussed.

The above sections also discussed how an impairment to the function of any speech production component might impact on speech intelligibility. In general, however, a limited number of studies have examined how the components contribute to intelligibility when more than one of the components are evaluated and compared. The few studies that did compare more than one component all found articulation to be the strongest contributor to listener judgement of speech intelligibility. Nevertheless, no study has included all five components of speech production in the analysis.



## **1.4 Speech production in Down syndrome**

As this study mainly concerns speech production and speech intelligibility in individuals with DS, a brief overview of DS and the features of the syndrome relevant to the current study is provided in the following sections.

The following sections will summarise the research evidence relating to each component of speech production in DS (see Figure 1-3 for a summary).

### **1.4.1 Respiration in Down syndrome**

Difficulties with respiration in people with DS are investigated frequently in the medical literature; however, respiration for the support of speech production and intelligibility has received considerably less attention for this group. Different types of respiratory problems can occur for individuals with DS; these include sleep apnoea, chronic infections, (Jacobs, Gray, & Todd, 1996), reduced vital capacity (Dichter, Darbee, Effgen, & Palisano, 1993), reduced respiratory muscle strength (Costa et al., 2015) and various structural abnormalities such as laryngomalacia, and a smaller trachea (Bertrand, Navarro, Caussade, Holmgren, & Sánchez, 2003). Laryngomalacia is a softening or flaccidity of the laryngeal cartilages (Colton et al., 2011). The flaccid cartilages prolapse over the airway and partially obstruct it, disrupting the airflow from the lungs. However, studies that have investigated respiration for speech production in DS have only done so by including a minor evaluation as part of their larger study protocol. One study did find children and adults with DS, aged 10-20 years, to have significantly less respiratory support compared to a control group, as judged by two SLTs (Roger, 2009). However, respiratory support was rated on a binary scale, as either being present or absent and

the study did not provide a full explanation as to how respiratory support was defined.

A recent study by Jones et al. (2019) adapted the perceptual parameters from the Darley et al. (1969a) protocol and used a 5-point EAI scale to analyse connected speech samples for 26 children with DS. The listeners were three experienced SLTs who received training prior to carrying out the evaluation. Jones et al. (2019) used 47 perceptual parameters to analyse speech production which included three parameters pertaining to respiration. Results showed that one parameter, audible inspiration or expiration, was present in 23 out of the 26 speakers with DS.

Studies that have used the MPT to assess respiration in DS have reported mixed findings. Lee, Thorpe, and Verhoeven (2009b) found no difference in MPT between a group of nine adults with DS and a control group matched for age and gender. However, it must be noted that Lee et al.'s speakers were all members of a theatre group. Although none had reportedly received any formal voice training; being exposed to a theatre environment may have made the speakers more aware of their own breathing patterns and voice production which could have impacted on the MPT. Moreover, only those without breathing and voice problems would be more likely to join a theatre group. Hence, it is possible that those particular speakers with DS may not have been representative of the population as a whole. Contrastingly, another study that measured MPT in adult speakers with DS found a shorter MPT compared to a typical group matched for age (Seifpanahi, Bakhtiar, & Salmalian, 2011).

In general, people with DS can experience difficulties with respiration as measured by both perceptual and acoustic analysis. However, the contribution of respiration to speech intelligibility has not yet been investigated. Moreover, as is the



case with other clinical populations, no study has compared the contribution of respiration to the speech intelligibility profile in those with DS when compared to the other components of speech production.

#### **1.4.2 Phonation in Down syndrome**

Difficulties with phonation in speakers with DS are frequently reported in the literature. The main reported causes of atypical phonation are related to anatomical features of the syndrome and excessive voice use (Leddy, 1999). Several earlier studies give anecdotal reports about reduced voice quality in speakers with DS but do not provide empirical evidence to support the claims; these problems were mainly a lower than typical pitch, breathiness, and strain (Montague & Hollien, 1973; Moran & Gilbert, 1982). Other descriptions such as “rough” and “raucous” have also been mentioned in the literature when describing voice quality in people with DS (Price, 1994). One study by Pentz and Gilbert (1983) recruited a group of listeners to rate the voice quality of speakers with DS. Listeners rated the voice of the speakers with DS as significantly different to a control group in terms of overall voice quality. However, the listeners could not identify if the different voice quality of the group with DS was due to a specific feature such as pitch or breathiness. Another study by Moura et al. (2008) recruited two SLTs to evaluate voice quality in 66 children with DS and a control group matched on age using the GRBAS scale. Findings showed that the group with DS were rated as significantly more severe across all areas on the GRBAS scale: general severity, roughness, breathiness, asthenia, and strain. The study by Jones et al. (2019), mentioned in section 1.4.1 above, showed that hoarseness was one of the most common perceptual features relating to voice in the speech of 26 children with DS. In relation to loudness, one study by Roger (2009)

found loudness to be rated as significantly lower in 22 children and young adults with DS compared to a control group.

Acoustic analysis of phonation in DS has received a significant amount of attention in the literature, particularly in comparison to respiration, resonance, and prosody. As explained in section 1.3.2, acoustic analysis of phonation usually involves measuring parameters including F0, amplitude, jitter, shimmer, and HNR. Studies investigating mean F0 in speakers with DS have yielded variable findings. Weinberg and Zlatin (1970) found a higher mean F0 in a group of 5- to 7-year-old children with DS compared to a control group matched for age. On the other hand, Moura et al. (2008) found a lower mean F0 for a group of children aged 5-6 years. For older children, Michel and Carney (1964) and Hollien and Copeland (1965) found no difference in mean F0 between groups of boys and girls with DS aged 8-10 years and respective control groups. These two studies also measured speakers' height and found the group with DS to be at least one and-a-half years behind age expectations. Authors suggested that this could be a possible reason for the perceived lower pitch in DS, in that people would see a person with DS and perceive age-appropriate pitch as low in comparison to immature physical size. Other studies have also found no difference in mean F0 between children with DS and those who are typically developing (Albertini et al., 2010; Montague Jr, Brown Jr, & Hollien, 1974; Pentz & Gilbert, 1983). These findings highlight that there are inconsistent findings regarding mean F0 in children with DS. The variable results may also be due to differences in methodological design between the studies; these features will be discussed later in this section.

In relation to adults with DS, most studies that examined mean F0 have found a higher mean F0 in groups with DS compared to their respective control

groups (Albertini et al., 2010; Lee et al., 2009b; Moran & Gilbert, 1978; Seifpanahi et al., 2011). Findings of an increased mean F0 contradict the perceived lower pitch that has been historically reported when discussing voice quality in DS (Blanchard, 1964; Moran & Gilbert, 1982). Montague Jr, Hollien, Hollien, and Wold (1978) directly examined this discrepancy between perceptual and acoustic evaluation findings relating to pitch and mean F0. They used speech samples gathered from 20 individuals with DS and 20 age-matched typical speakers (Montague Jr et al., 1974). The initial study showed no difference in mean F0 between the two groups. The follow-up study recruited 16 untrained listeners to judge the speaker's pitch. Listeners were played speech samples from each speaker and were asked to indicate if they perceived abnormal pitch. Then if abnormal pitch was judged to be present, listeners rated the severity on a 7-point rating scale. The listeners did not know that the speakers had DS. Findings showed that the majority of the speakers with DS were perceived to have a significantly lower pitch compared to the control group. This finding contradicts the acoustic findings where a similar mean F0 was obtained for both groups on the same speech sample.

The group with DS were also found to have significantly more variability in their pitch levels. The authors suggested that it was this variability that may be responsible for the perceived lower pitch in speakers with DS even though acoustic analysis showed a typical mean F0. However, it may also be that when listeners are judging the voice of someone with DS, they hear what they think is a lower pitch, when in fact, they are hearing an interaction of other aspects of voice quality, such as hoarseness or roughness (Michel & Carney, 1964). Limited research has used acoustic analysis to evaluate amplitude relating to phonation in the speech of individuals with DS; however, one study found that adult speakers with DS had

significantly lower levels of amplitude compared to typical adults matched on age and gender (Albertini et al., 2010).

Acoustic studies have also reported difficulties with voice quality in DS. In addition to perceptually rating aspects of voice quality in adults with DS, Pentz and Gilbert (1983) and Moura et al. (2008) carried out acoustic analysis in order to identify differences between speakers with DS and typical speakers. They obtained measures of jitter and shimmer and found significantly higher levels of both in the group with DS compared to the control groups. Kent and Vorperian (2013) suggest that the generally higher levels of jitter and shimmer in speakers with DS are possibly due to hypotonia of the larynx and inconsistent motor control during speech production, which in turn, impacts on phonation. However, other research findings relating to jitter and shimmer have varied considerably in DS. Albertini et al. (2010) found no difference between a group of children and adults with DS, and a group of typical speakers. Somewhat surprisingly, two studies that investigated jitter in adults with DS, Lee et al. (2009b) and Seifpanahi et al. (2011), found lower levels of jitter compared to a control group matched for age and gender. Lower levels of jitter would indicate more stability in the voice which is an unexpected finding in speakers with DS. However, as mentioned previously, the speakers in Lee et al.'s study were members of a theatre group; hence it is possible that being part of a theatre group involving singing and acting may have had an impact on speakers' voices, hence influencing jitter and shimmer outcomes. Another possible reason for the speakers with DS having lower jitter levels may be the characteristics of the speaker control group. However, Seifpanahi et al. (2011) report that their typical speakers were selected by a laryngologist and SLT, therefore, they are confident that the typical speakers in their study were indeed typical speakers.

Another acoustic parameter of voice quality, HNR, has been found to be generally lower in speakers with DS compared to typical populations. A lower HNR indicates more noise in the acoustic signal, which can correlate with breathiness and hoarseness (Javadipour, Moradi, Soltani, Noori, & RezaeeRad, 2013; Moran & Gilbert, 1982). Pentz and Gilbert (1983) found reduced HNRs for a group of 14 children with DS compared to a control group. Moura et al. (2008) also found a lower HNR in children with DS. Moran and Gilbert (1982) found slightly more mixed results for their group of adults with DS, in that some of the 16 adults with DS had lower HNRs while others did not. The authors interpreted this finding as voice difficulties affecting some but not all individuals with DS.

In general, perceptual studies report some degree of voice difficulty in DS. However, the acoustic studies showed mixed results for mean F0 in children but a generally higher mean F0 in adults. Mixed results were also found for jitter and shimmer with two studies finding lower jitter in adults with DS compared to a control group. However, there are a number of methodological aspects regarding the above studies that should be highlighted and considered when interpreting results. Methodological aspects can be discussed in terms of two areas: speaker characteristics and testing procedures. Albertini et al. (2010) and Michel and Carney (1964) did not match their group with DS and the control group for age. In fact, the mean age of the control group in Albertini et al.'s was considerably older than the group with DS: 46 years and 26 years respectively. Age can affect voice quality (Lortie, Thibeault, Guitton, & Tremblay, 2015). Hence, comparing the voice quality of two groups with different age ranges would not be appropriate. The hearing ability of the speakers also differed across studies. Some studies deliberately excluded those with hearing loss. The authors argued that hearing loss impacts on self-monitoring of

speech production, which could influence voice quality. However, as Roger (2009) stated, including only those with DS who have normal hearing may not be representative of the population as a whole. Hearing loss has been reported to occur in 80% of individual with DS (Blaser et al., 2006). In addition, some of the earlier studies included speakers with DS who were institutionalised. Being institutionalised may have impacted on the frequency of speakers' voice use or the quality of external voice models which could also have impacted on voice quality (Pentz & Gilbert, 1983). Secondly, the speech stimuli used for acoustic analysis differed across most of the studies. The more common stimulus of sustained vowel phonation was used in some studies; however, other studies analysed production of single words and extracted vowels from connected speech (Lee et al., 2009b). Isolated vowels would have different acoustic characteristics compared to both single words and vowels extracted from connected speech, as the latter two can be influenced by articulation and/or prosody (Gerratt, Kreiman, & Garellek, 2016).

Moreover, in Michel and Carney's (1964) study, the speech stimuli differed between the groups in that for the group with DS, spontaneous speech was analysed and for the control group, analysis was carried out from a reading passage. Research has shown that speech that is read aloud can differ to spontaneous speech as people can use a more formal speaking style when reading compared to when speaking naturally (Schuppler, 2017). Additionally, the conditions in which stimuli were recorded were inconsistent across studies, in that different types of microphones and recording environments were used. Lee et al. (2009) used a different recording environment for their group with DS and the control group; the group with DS were recorded in their homes while the control group were tested in a speech laboratory.

These different recording conditions for the two groups may have impacted on acoustic findings.

Despite some inconsistent findings relating to F0 among studies investigating phonation in speakers with DS, this group does have well documented difficulties with phonatory function. However, research comparing the extent of the phonation problem in DS with other aspects of speech production, such as articulation, has not yet been carried out. Moreover, little is known about how much phonation difficulties impact on speech intelligibility in speakers with DS.

### **1.4.3 Articulation in Down syndrome**

Most studies that have examined speech production and speech intelligibility in DS have focused on the area of articulation. The prevalence of impaired articulation is reportedly higher in people with DS compared to those with typical development and also when compared to other populations with cognitive impairment matched on mental age (Leddy, 1999; Rosin, Swift, Bless, & Kluppel Vetter, 1988). Kumin (1994) suggested that impaired articulation is more of a problem for individuals with DS than other areas of speech, such as fluency or phonation. Difficulties with articulation can occur with production of both vowels and/or consonants.

Perceptual measures of articulation, PCC and PVC have been reported to be reduced for speakers with DS (e.g. Brown-Sweeney & Smith, 1997; Wild, Vorperian, Kent, Bolt, & Austin, 2018). As discussed previously in this chapter, Wilson et al. (2019b) analysed aspects of articulation, along with phonation, resonance, and prosody in adolescents with DS using perceptual methods.. They

found that those with lower PCC and PVC scores also had low speech intelligibility scores.

Another study by Bunton, Leddy, and Miller (2007) examined perceptual-phonetic contrasts of articulation in the speech of five adults with DS and the relationship of these contrasts to speech intelligibility. They recruited untrained listeners to judge speech intelligibility through a word identification method. Listeners heard a spoken word and were asked to identify the word they heard from a choice of four written options; one option was the target while the other three were foils. Each foil contrasted to the target word by a specific phonemic feature. For example, for the target word “bad,” the first foil would be “bed” which differs in the vowel, the second foil would be “bat” which differs by voicing of the final consonant, and the third foil would be “pad” which contrasts by voicing of the initial consonant (Kent et al., 1989b). This method allowed for specific error patterns to be identified after listener responses were analysed. The errors that emerged as the most prominent were cluster reduction, imprecise vowel contrasts, deaffrication, gliding, and producing voiced consonants as voiceless or vice-versa. Bunton et al. (2007) proposed that these errors were related to jaw and tongue control, and phonatory function. However, the errors may also be phonological in nature.

Other studies that evaluated articulation in speakers with DS reported that the main sounds that were produced in error were liquids, fricatives and affricates (Crosley & Dowling, 1989; Sommers, Reinhart, & Sistrunk, 1988; Van Borsel, 1996). Findings from instrumental measures using electropalatography and ultrasound have confirmed these observations (Cleland, Timmins, Wood, Hardcastle, & Wishart, 2009; Fawcett, Bacsfalvi, & Bernhardt, 2008). Error types were mainly with cluster reduction, gliding, palatal fronting, stopping, devoicing and deaffrication



(Barnes et al., 2009; Van Borsel, 1996). Distortions and errors with the high-low contrast and front-back contrast for vowels have also been noted (Bunton et al., 2007). Van Borsel (1996) has described articulation in DS as delayed in nature; for example, this research found that errors of adolescents and adults with DS aged 15-28 years were largely similar to that of 2-3 year-old typically developing children. However, other studies have proposed that features of speech in DS are more indicative of a disorder rather than a delay as errors not usually seen in typically developing speech were observed; for example, vowel deletion (Dodd & Thompson, 2001).

In general, acoustic analysis of articulation in speakers with DS has received less attention compared to perceptual methods of evaluation, but studies that have used acoustic analysis have also shown difficulties with articulation. Brown-Sweeney and Smith (1997) reported longer VOTs in children with DS aged 7 and 12 years old compared to age-matched typically developing peers. A longer VOT can reflect slower co-ordination between phonatory and articulatory systems (Ladefoged et al., 2012). For articulation of vowels, a reduced VSA, which as mentioned earlier, can reflect reduced articulatory range, has also been reported for adult speakers with DS (Bunton & Leddy, 2011; Dar, Nazir, & Ahmed, 2020). However, a recent study by Carl, Kent, Levy, and Whalen (2020) measured the VSA in eight young adults with DS and a control group matched on age and gender. They found no significant difference between the VSA of the two groups. However, the speakers' vowel clusters were also examined. A vowel cluster was defined as the distribution of a vowel within the acoustic space and a smaller cluster would indicate more stable and consistent speech production. Carl et al. (2020) found that the speakers with DS had significantly larger clusters which they interpreted as restricted articulatory

efficiency and reduced speech motor control. A study by Rochet-Capellan and Dohen (2015) found a larger VSA for a group of speakers with DS compared to typical speakers which they attributed to increased variability of productions and again, reduced speech motor control.

Another acoustic parameter that has been linked to motor control during speech production is the F2 slope. Although the evidence for measuring the F2 slope of vowels as a strong measure of articulatory performance has been discussed previously, it has not yet been investigated in speakers with DS. Furthermore, even though articulation in DS has received the most attention in the research, the relative contribution of articulation to speech intelligibility when compared to the other components of speech production, has not yet been examined.

#### **1.4.4 Resonance in Down syndrome**

Difficulties with resonance in DS can arise from chronic respiratory infections, which can affect production of some consonants and thus, impact on speech intelligibility (Dodd & Thompson, 2001). Impairment to the function of the velopharyngeal port can arise from anatomical factors such as tonsillectomy and/or adenoidectomy, from hearing loss, or from inaccurate learning of speech sounds (Kavanagh, Kahane, & Kordan, 1986). However, empirical research pertaining to speech resonance in people with DS has yielded mixed findings. Perceptual observations of abnormal nasality have been reported (Rondal & Edwards, 2000), but findings of studies that have specifically examined resonance in this population have not always agreed. Montague and Hollien (1973) evaluated hypernasality in 20 children with DS and a control group matched on age and gender. Listeners with different levels of experience in evaluating speech were recruited to judge hypernasality. Listeners completed an 8-point EAI scale to measure the severity of

hypernasality. The majority of listeners rated the group with DS to have significantly higher levels of hypernasality compared to the control group. However, some of the untrained listeners did not perceive any difference in nasality between the two groups. Rolfe, Montague, Tirman, and Vandergrift (1979) also assessed hypernasality and hyponasality in six adults with DS using EAI rating methods and most speakers were rated as having normal resonance. Kline and Hutchinson (1980) used both perceptual and instrumental analysis to evaluate resonance in young adults. They included three groups of speakers: a typical group, a group with DS, and a group with cognitive impairment of unknown origin. Both perceptual and instrumental analysis methods showed that the group with DS had higher levels of hypernasality compared to the two other groups.

The inconsistent findings across studies may be due to the different experience levels of the listeners who judged resonance. For example, nasality scores obtained from groups of listeners who are more exposed to speech resonance difficulties tend to be lower and have higher inter-rater agreement (e.g. Lewis, Watterson, & Houghton, 2003). These variable findings relating to resonance in speakers DS shows that this component of speech production requires further examination. In addition, the role that resonance plays in the speech intelligibility profile of this group has not been investigated.

#### **1.4.5 Prosody in Down syndrome**

Difficulties pertaining to prosody in individuals with DS have been reported in the literature. Studies that used perceptual analysis methods have reported a lower than typical pitch, difficulties with producing affect and stress, and an atypical speech rate (Pettinato & Verhoeven, 2009; Shriberg & Widder, 1990; Stojanovik, 2011; Zanchi, Zampini, & Panzeri, 2020). Stojanovik (2011) also found that

expressive prosody skills in children with DS were impaired but were generally independent of their language ability. For acoustic analysis of prosody, Zampini et al. (2016) analysed spontaneous speech in children with DS and their analysis showed that most features, such as F0 range, were equivalent to typically developing children. Other studies using acoustic analysis to evaluate prosody in this population also found no difference in F0 range between children with DS and a control group (Hollien & Copeland, 1965; Michel & Carney, 1964; Pentz & Gilbert, 1983). However, for adults with DS, a study by Corrales-Astorgano, Escudero-Mancebo, and González-Ferreras (2018) found a reduced F0 range which was indicative of monotonous speech in adult speakers with DS. In the same study, Corrales-Astorgano et al. (2018) also found higher mean amplitude values in adults with DS compared to a control group matched for age and gender, along with a higher amplitude range. They interpreted these findings as evidence of a prosody difficulty possibly arising from hearing loss and/or reduced motor control during speech production among speakers with DS.

Regarding fluency in DS, similar to other areas of speech production, there is a higher incidence of fluency difficulties reported in this population compared to the general population and other groups with cognitive impairment (Bray, 2003). Kent and Vorperian's (2013) collation of the data pertaining to dysfluency in people with DS shows that stuttering has been reported to occur in the speech of 10-45% of individuals. Incidents of cluttering have also been reported in this group. Cluttering involves breaks in the normal flow of speech production that results from disorganised speech planning, lack of attention or being unsure of what a speaker wants to say (Van Zaalen-Op 't Hof, Wijnen, & De Jonckere, 2009). Van Borsel and Vandermeulen (2008) examined fluency in 76 children and adults with DS using the

Predictive Cluttering Inventory (Daly & Cantrell, 2006). The Predictive Cluttering Inventory evaluates 33 items across four domains: pragmatics, speech/motor, language/cognition, motor co-ordination/writing problems. They found that 60 out of the 76 speakers met the criteria for cluttering compared to only 13 who met the criteria for stuttering.

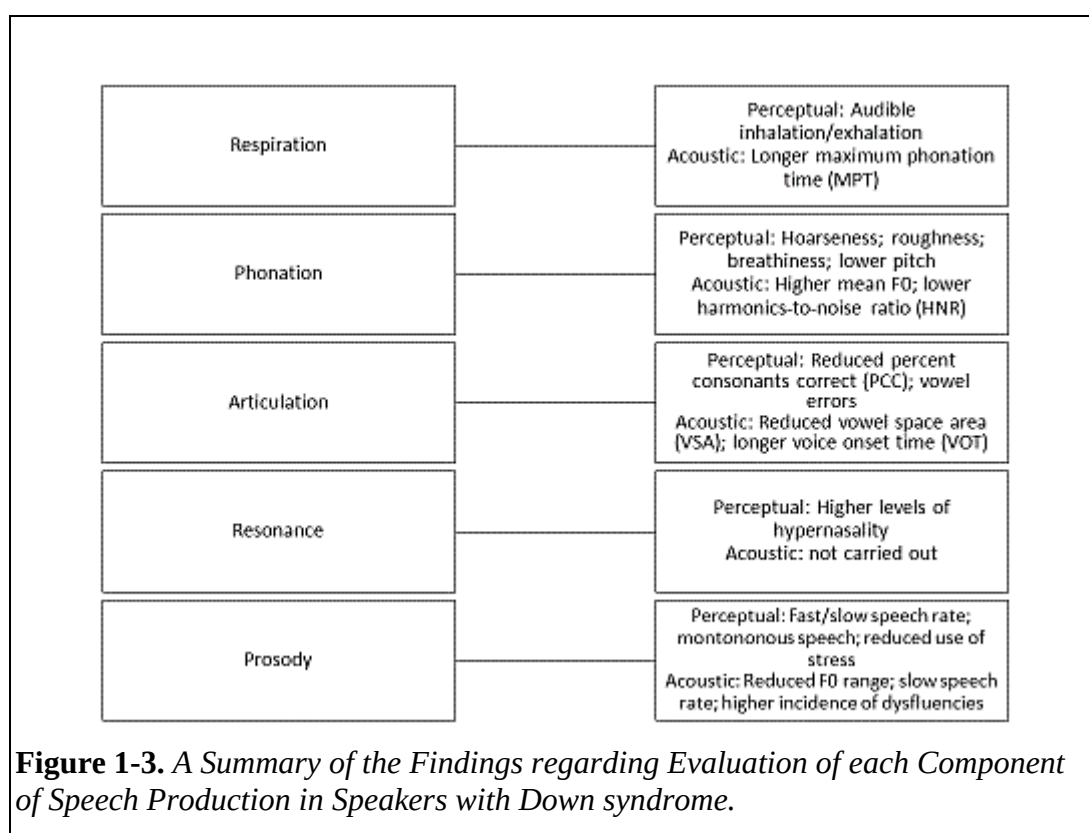
Similar to other populations who can have dysfluent speech, two main theories prevail regarding the nature of fluency difficulties in DS. The neuropsycholinguistic theory describes how dysfluency arises when speech production components and linguistic components are out of sync (Perkins, Kent, & Curlee, 1991). That is, dysfluency can be a product of linguistic impairment, mainly with word finding and utterance formulation (Leddy, 1999; Willcox, 1988). The demands and capacity theory explains how speech fluency can be interrupted when demands exceed the speaker's cognitive, linguistic, motoric or emotional capacities (Adams, 1990). According to Howell (2010), dysfluency in speakers with DS occurs "because the linguistic system has to provide the output at a particular time for the speech sequence to be produced fluently. If the language system does not produce the output to the speech motor system at the required time, speakers hesitate or repeat words until the material is ready" (p. 1).

It is likely that dysfluency, along with the other aspects of prosody discussed in this section, can impact on how a listener perceives the speech signal. Nevertheless, little is known about how prosodic difficulties in speakers with DS can influence their speech intelligibility. Furthermore, to date, how much prosodic difficulties contribute to speech intelligibility compared to other components of speech production in speakers with DS has not been investigated.

#### **1.4.6 Summary**

To summarise the previous sections, individuals with DS can have difficulties with all of the components of speech production. They have been reported to have lower respiratory support for speech and longer MPTs. Individuals with DS have been noted to speak with a lower pitch and have voices which can be rough and hoarse. Acoustic analysis of phonation has reported a higher mean F0, and a lower HNR. Regarding articulation, lower PCC and PVC scores are common, along with a reduced VSA and longer VOTs indicating restricted articulatory precision. However, as mentioned in Chapter 1, reduced PCC can also indicate a difficulty with phonology as well as articulation. For resonance, studies have reported mixed results where some have found higher levels of hypernasality in the speech of individuals with DS while others have found little difference in nasality levels between adults with DS and typical speakers. Prosodic features of speakers with DS can include impaired use of stress and monotonous speech. Incidences of dysfluency are also higher in speakers with DS compared to other populations with cognitive impairment and the general population. Figure 1-3 summarises these main findings regarding speech production in DS. However, as mentioned throughout the previous sections, no study has examined all five components of speech production

in DS as part of a single study, nor has any study compared how each component impacts on speech intelligibility.



### 1.5 Speech intelligibility and its measurement

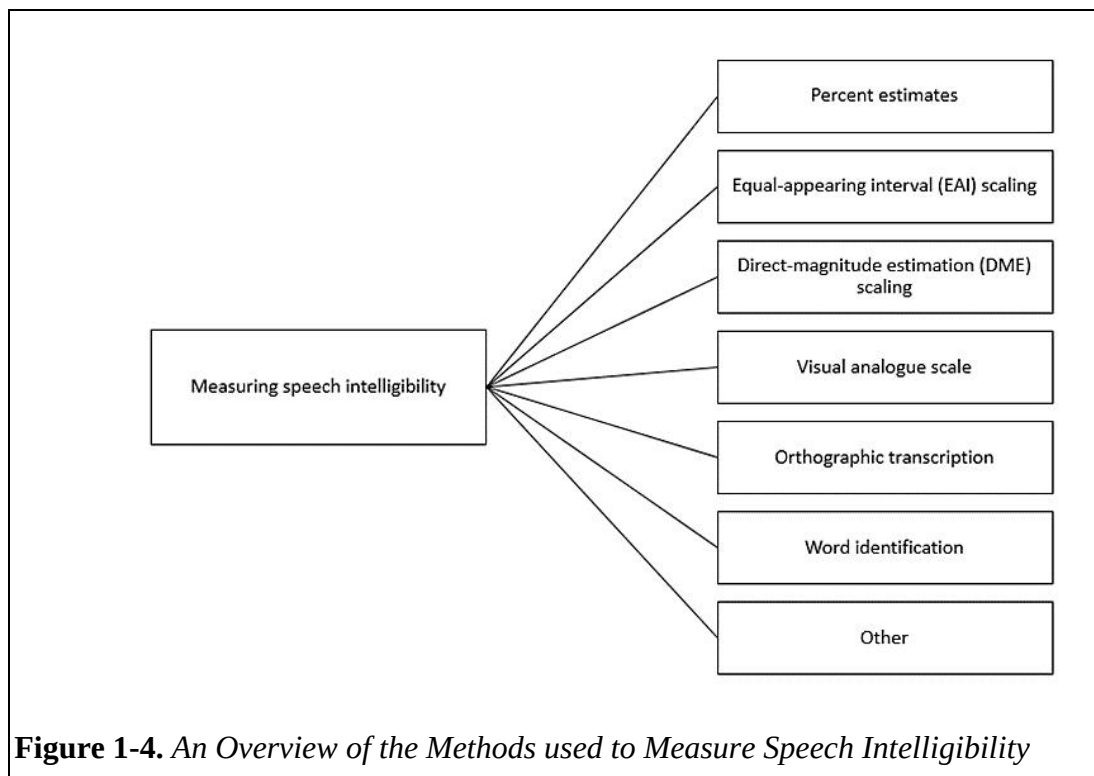
As explained in section 1.1, speech intelligibility refers to the degree to which the acoustic signal, produced by the speaker, is understood by a listener (Yorkston et al., 1996). In order to understand more about speech intelligibility and the nature of difficulties with speech intelligibility in those with DS, it is important to be aware about the various ways in which it can be evaluated. There are a number of methods that have been used to measure speech intelligibility in previous research (see Figure 1-4 for a summary), but in general, there is a lack of consensus regarding the most appropriate method (Barreto & Ortiz, 2008). However, one could argue that this lack of consensus may be due to the many different speech impairments and syndromes that an individual might be presenting with. For example, a speech

intelligibility measure designed for adults with Parkinson's disease may not be appropriate for use with a young child with DS because the child with DS may not have the cognitive or linguistic ability to comprehend the task or read certain speech stimuli.

The challenge regarding the measurement of speech intelligibility is also not helped by the fact that many SLTs and researchers have diverging opinions of what speech intelligibility is and/or how it should be evaluated. For example, in some studies, speech comprehensibility is measured rather than speech intelligibility. While speech intelligibility indicates the degree to which the acoustic signal is understood by the listener, speech comprehensibility accommodates for signal-independent information, including gestures and physical context, that is contextual intelligibility (Hustad, 2008; Yorkston et al., 1996). Comprehensibility is usually measured by having the listener(s) answer questions about the spoken message (Poole, 2011). Other studies have used speech acceptability to determine how the spoken message is perceived. Acceptability is a more subjective measure compared to intelligibility and comprehensibility, that usually assesses the listener's perception of normalcy or naturalness. That is, the speech may be understandable, but may draw attention in a way that reduces its acceptability to the listeners (Poole, 2011). Acceptability is typically measured using a form of rating scale. Each of these measures, intelligibility, comprehensibility and acceptability, evaluate different aspects of listener perception of speech (Dagenais, Adlington, & Evans, 2011).

When it comes to measuring speech intelligibility, there are pros and cons to using each method that should be taken into consideration when determining the assessment protocol. These methods of measurement will be discussed in the following sections.





### 1.5.1 Percent estimates

This subjective method of assessment usually indicates listeners' overall impression and observation of an individual's speech performance. It involves the evaluator listening to a speech stimulus and assigning a percentage between one and 100 that represents their perception of speech intelligibility (Yorkston & Beukelman, 1978). Percent estimates can be an attractive tool for a busy clinician who is under time-constraints and may not be able to complete more time-consuming evaluation methods. However, although using percent estimates can be quick and practical, there is conflicting evidence regarding the reliability of this method as a measure of speech intelligibility when compared to other methods such as orthographic transcription scores (Carter, Yorkston, Strand, & Hammen, 1996).

### 1.5.2 Equal-appearing interval scale

One rating scale that is frequently used to measure speech intelligibility, and has been used to measure intelligibility for speakers with DS, is an EAI scale (e.g.

Valizadeh et al., 2015). EAI scale requires the listener to assign a number to a speech sample that fits a linear partition on the spectrum of the dimension being evaluated (Ludlow et al., 2019). Intervals are expected to be equally distributed and equidistant from each other (Hixon et al., 2020). Typically, when rating speech intelligibility, listeners are presented with a speech stimulus and identify a number on an interval scale (usually 5-, 7- or 10-point scale) to indicate their perception of the speaker's speech intelligibility (Schiavetti, 1981). Each point on the scale is given a number, which may or may not be accompanied by a description. For example, on a 7-point scale, a rating of one may be described as “completely unintelligible speech” and a rating of seven may be described as “fully intelligible speech.” However, the validity of the EAI scale has been questioned due to risks of bias. For example, Kreiman et al. (1993) also found that across the middle range of scores—three to five on a 7-point EAI scale—reliability is reduced, indicating that ratings are only consistent for the more extreme cases as listeners find them more straight-forward to judge.

### **1.5.3 Direct magnitude estimation**

Direct magnitude estimation (DME) has been used frequently in the evaluation of components of speech production (Whitehill, 2002). DME requires the listener to assign a number to a speech stimulus that represents the ratio of that stimulus to a previous stimulus. A modulus may or may not be used when completing DME (Ludlow et al., 2019). A modulus is a speech sample that is used as the reference for which to compare all other speech stimuli. If a modulus is not used, the listener assigns their own rating score to the first speech sample and then rates each subsequent speech sample according to that first sample (Ludlow et al., 2019). Previous research studies have used DME to measure speech intelligibility in several

clinical populations (e.g. Ellis & Fucci, 1991; Weismer & Laures, 2002; Zraick & Liss, 2000).

#### **1.5.4 Visual analogue scale**

A VAS is a perceptual measurement of a certain parameter, for example, pain, mood, or speech intelligibility. It consists of a line usually 100 mm in length, with descriptors on either end indicating the outer extremes of measurement range (Freyd, 1923). When using VAS to evaluate aspects of speech production, the listener listens to a stimulus and makes a mark at a point along the line which reflects their perception of the parameter being measured; then the distance from the left endpoint is measured in mm (Heller, Manuguerra, & Chow, 2016). VAS has been used to measure aspects of speech such as intelligibility and nasality in people with DS, dysarthria, cleft palate, and Parkinson's disease (Keuning, Wieneke, & Dejonckere, 1999; Stipancic, Tjaden, & Wilding, 2016; Whitehill, 2002; Wood, Timmins, & Grayson, 2016). VAS is also employed in the previously discussed CAPE-V protocol (Kempster et al., 2009) for perceptually evaluating phonation.

#### **1.5.5 Factors to consider when choosing a rating scale**

The choice of rating scale depends on the nature of the physical stimulus to be judged. There are two types of perceptual continua: prothetic and metathetic. A prothetic continuum is additive or subtractive and is more quantitative in nature (Schiavetti, 1992). That is, changes in perception occur when a stimulus is added or taken away from what is already present. For example, loudness is a prothetic continuum; if one perceives a noise as louder, it is because a stimulus has been added to the previous stimulus. Likewise, if a sound is perceived as quieter, it is due to a portion of the stimulus being taken away. A metathetic continuum on the other hand, is substitutive and is more of a qualitative phenomenon; that is, a change is perceived

because a new stimulus has replaced the previous stimulus (Stevens, 1975). Stevens (1975) gives pitch as an example of a metathetic continuum in that a higher pitch is perceived when one tone is replaced by a new tone. According to Stevens (1975), listeners judge prothetic and metathetic continua differently. They can easily separate a metathetic continuum into equal intervals; however, when listeners attempt to partition a prothetic continuum into equal intervals, they tend to subdivide the lower end of the continuum into smaller intervals compared to the upper end. Whether a perceptual continuum is prothetic or metathetic can be determined by plotting the EAI ratings against the DME ratings obtained from the same speech samples. If the relationship between the two sets of scores is linear, then it is a metathetic continuum and if the relationship is curvilinear, it is a prothetic continuum (Stevens, 1975). EAI is appropriate for measuring metathetic continua such as voice quality (Yiu & Ng, 2004), whereas DME and VAS are appropriate for evaluating prothetic continua such as nasality (Bettens et al., 2018; Schiavetti, 1981; Whitehill, 2002; Zraick & Liss, 2000).

In a review of assessing speech intelligibility in the speech of those with cleft palate by (Whitehill, 2002), almost half of the studies (47.4%) utilised an EAI scale. However, speech intelligibility is a prothetic continuum (Schiavetti, 1981); therefore, EAI is not an appropriate method for measuring it. While DME can be a viable method to use when measuring speech intelligibility, VAS provides more options for statistical analysis compared to other rating methods (McCormack, Horne, & Sheather, 1988). In addition, VAS is more convenient and easier to carry out. VAS was chosen for use in the current study as the perceptual measure of speech intelligibility due to its advantages over other rating methods and its previous use for

measuring speech intelligibility for those with dysarthria (e.g. Tjaden, Sussman, & Wilding, 2014b).

### **1.5.6 Orthographic transcription**

Although rating methods seem quick and easier to administer, particularly within a busy clinic setting, they do not tell us much about the nature of a speech intelligibility difficulty. Less impressionistic methods such as orthographic transcription can provide additional information about the specific areas of speech production that are challenging for a speaker (Osberger, Maso, & am, 1993).

Orthographic transcription is one of the most widely used methods to measure speech intelligibility both in the clinic and for research and has been used to measure intelligibility for speakers with DS (Skahan et al., 2007; Stipancic et al., 2016; Wilson et al., 2019b). Orthographic transcription involves the listener hearing a speech sample and writing down the words they can understand from the sample. The word-for-word response is then compared to the known target and a speech intelligibility score can be calculated by dividing the total number of words correctly identified by the total number of words produced (Flipsen, Bankson, & Bernthal, 2009). The Assessment of Intelligibility of Dysarthric Speech (ASSIDS, Yorkston & Beukelman, 1984) is a widely used assessment that involves the use of orthographic transcription of words and sentences. For this assessment, words and/or unpredictable sentences are chosen at random from a large pool for a speaker to read or repeat aloud. Recordings of these words and sentences are then played to the listener who orthographically transcribes responses. This method was chosen to measure speech intelligibility in the current study due to its support in the literature as a widely used and reliable approach (Schiavetti, 1992; Yorkston et al., 1992).

### **1.5.7 Word identification**

The word identification method for measuring speech intelligibility was developed by Kent et al. (1989b) and mainly involves two parts. Firstly, a speaker produces a list of words. Then, a judge is presented with the recording of each word one-by-one and is asked to identify the target word from a choice of four words. The three foil words differ to the target word by one phonetic feature. For example, for the target word “feed,” the first foil would be “food” which differs in the vowel, the second foil would be “feet” which differs by voicing of the final consonant, and the third foil would be “fee” which contrasts not having a final consonant (Kent et al., 1989b). Having foils that differ by one specific phonetic feature to the target word allows errors to be analysed in order to identify particular areas of difficulty. For example, if the speaker produced “pad” for the target word “bad,” then a difficulty with prevocalic voicing could be identified. Although word identification has been used to analyse speech intelligibility for speakers with DS (Bunton et al., 2007; Cleland, Wood, Hardcastle, Wishart, & Timmins, 2010), this method was not used in the current study as the aim was to obtain an overall measure of speech intelligibility and not to identify specific errors.

### **1.5.8 Other evaluation methods**

In addition to those discussed in the previous sections, other tools have been developed to evaluate speech intelligibility. These assessments include the Intelligibility in Context Scale (McLeod, Harrison, & McCormack, 2012), the Beginner’s Intelligibility Test (Osberger et al., 1993), and the Children’s Speech Intelligibility Measure (Wilcox & Morris, 1999). However, these assessment tools have mainly applied one of the methods reviewed above and developed their own protocol. For example, the Children’s Speech Intelligibility Measure involves word

identification methods, the Intelligibility in Context Scale employs the completion of an EAI scale to respond to various statements about speech intelligibility, and orthographic transcription is used to evaluate sentences from the Beginner's Intelligibility Test.

### **1.5.9 Summary**

The previous sections have discussed how speech intelligibility can be measured in several ways using both subjective approaches and methods which are more objective in nature. A number of these methods have been used to measure speech intelligibility for speakers with DS in previous studies also. The most frequently used subjective method involves listening to a speech sample and completing some form of rating scale. The use of VAS has some advantages over the other rating methods in relation to reliability and analysis options. One of the most frequently used objective methods of measuring speech intelligibility is where a listener completes an orthographic transcription of words or sentences produced by a speaker. Outcomes of both VAS and orthographic transcription can be presented as a percentage speech intelligibility score and the level of severity can be interpreted. However, when interpreting the results of speech intelligibility assessment, certain factors should be taken into account, based on previous research. These factors will be summarised in the following section.

## **1.6 What can affect speech intelligibility scores?**

An important caveat to be considered when measuring speech intelligibility and interpreting outcome scores is that intelligibility can be a joint product of the speaker, the speech material, the listener, and the measurement method (Barreto & Ortiz, 2010; Ludlow et al., 2019). However, the influence of these factors on the speech intelligibility scores for speakers with DS has not yet been investigated. The

subsequent sections will discuss the most common factors that have been shown to influence speech intelligibility scores for other populations with speech difficulties.

### **1.6.1 Language ability of the speaker**

In addition to the speaker's capability to finely co-ordinate the five components of speech production, another speaker-related factor that may impact on speech intelligibility is their language ability. Castellanos et al. (2014) explained that because both speech production and language utilised the same core information-processing systems, encoding, storage, and retrieval of phonological and lexical representations, it is likely that the two aspects are related to each other. Dromey and Bates (2005) suggest that there is a balance of neural resources that has to be shared between the speech and language processes, hence there must be some form of bidirectional relationship between the two. In general, language ability has been shown to be impaired in people with DS and the aspects that this group have most difficulty with will be discussed later in section 1.7.2. This section will focus on theory and evidence that has explored the relationship between speech and language in typical individuals and clinical populations other than DS.

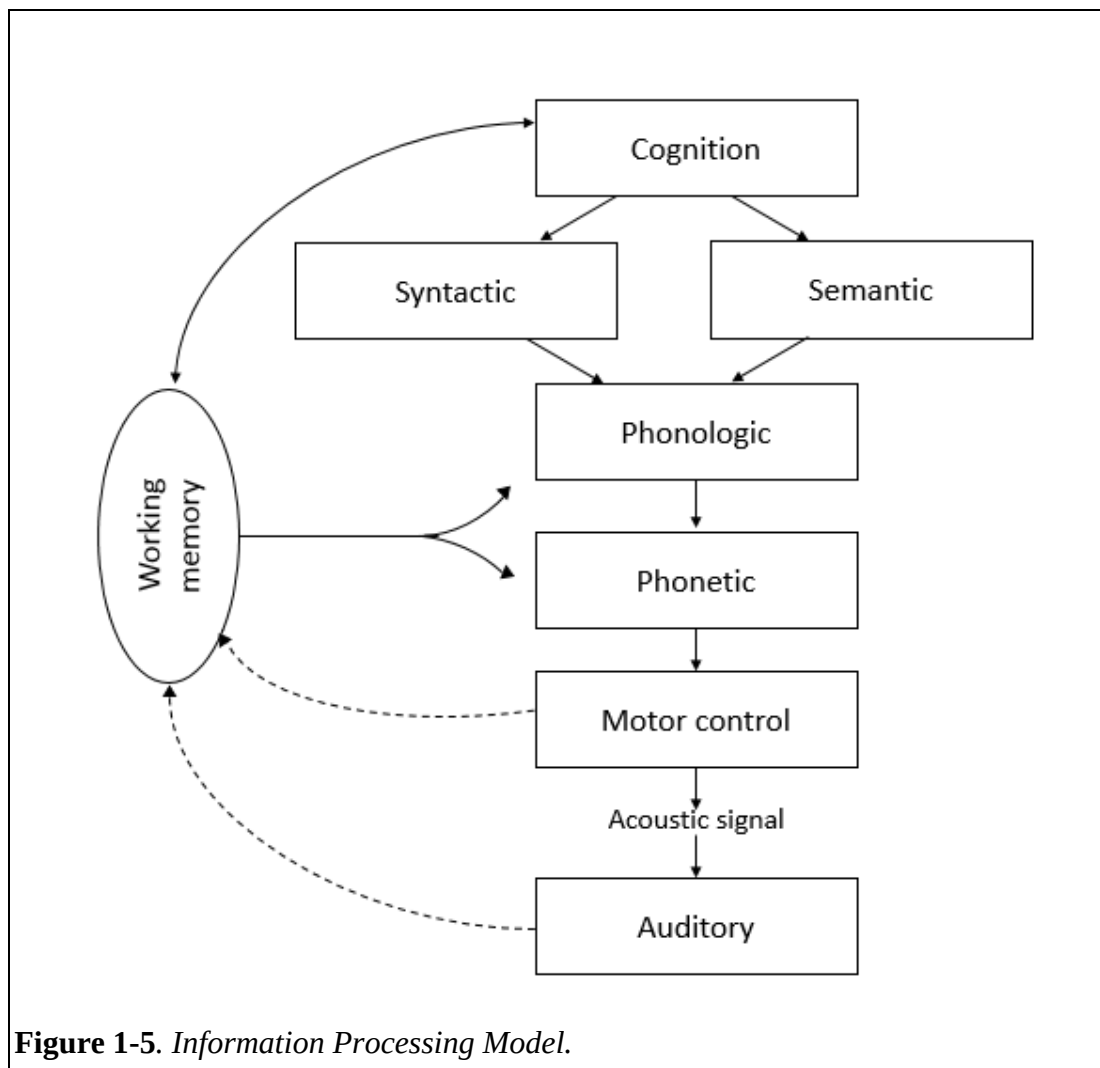
When seeking to explain the relationship between speech and language, a few theories have been proposed. One theory by Levelt (1989) proposed that humans can be active processors of information, employing a number of subsystems to convert a thought or intention into speech output. Kent (2009) summarised what is known about information-processing theory of speech production and devised a model (see **Figure 1-5**). This model represents the top-down theory of utterance production. The model illustrates how semantic, syntactic, and phonologic systems must be engaged before phonetic processes and motor production of speech are initiated. As explained in section 1.3.3, phonology refers to the *function* of speech sounds whereas phonetics



represents the *form* of speech sounds (Bauman-Wängler, 2009).

According to Kent (2009), an utterance is produced as a result of a series of decisions. It begins with a lexical concept decided by the semantic and syntactic systems. Then, the sentence is allocated its phonological components to ensure the sound patterns accurately reflect the semantic and syntactic decisions. This phonological information guides the decisions made at the phonetic level, which then activates the motor instructions required for speech production and influences the acoustic signal. From the information-processing model, Kent (2009) proposes that a breakdown at the syntactic level can impact on the phonological, phonetic, and motor levels which affect the speech signal and also impact on how speech intelligibility is perceived.

Researchers have also proposed that speech production is monitored by a person's comprehension system (Levelt, 1989). That is, the speaker monitors the meaning and accuracy of their speech production to ensure if what they say, is in fact what they intended. The speaker can revise their production or form a new message if needed. Additionally, the information-processing model shows that working memory has a part to play in speech production.



Another aspect of language that can influence a speaker's perceived intelligibility is their use of phonology in that individuals with disordered phonology can be quite unintelligible. Disordered phonology usually involves the presence of one or more atypical phonological processes in an individual's speech. Phonological processes are errors that alter the rules of the phonetic characteristics of target words and operate systematically across sound classes (Hodson & Paden, 1981). One example of a phonological process is final consonant deletion where the last consonant sound is systematically omitted from each word during speech production. That is, "lake" would be pronounced as "lay" and "date" would be pronounced as "day." Research has shown that the presence of phonological processes in a person's

speech can negatively impact on listener judgements of speech intelligibility (Barnes et al., 2009; Hodson & Paden, 1981; Marines & Parsons, 1991). We can also see from the information-processing model that a breakdown at the phonological level can also impact on the subsequent processes in the model and thus, affect speech intelligibility.

In addition to phonology, studies have examined other aspects of language that can contribute to speech intelligibility. For example, Magnus (2011) investigated the contributing variables for speech intelligibility in children with cleft palate. They found that the mean length of response of speakers was a significant contributor to speech intelligibility, where those with a higher mean length of response also obtained higher speech intelligibility scores. The mean length of response, which is the average length of an utterance measured in words, was used by Magnus et al. as a general measure of language ability. The authors explained that the mean length of response (measured in words) was used instead of the more common mean length of utterance (MLU, measured in morphemes) because some morphemes can be difficult to identify in highly unintelligible speech. MLU is a broad measure of expressive language that was first introduced by Brown (1978). It represents the average number of morphemes in an utterance and has been found to be a reliable and valid measure of expressive language ability (Rice, Redmond, & Hoffman, 2006). Magnus (2011) concluded that the speakers with a longer mean length of response were simply more advanced in their overall speech and language skills which facilitated better speech production and as a result, better speech intelligibility.

A speaker's fluency can also affect how listeners perceive the speech signal (Tetnowski, 1998). While for the purpose of this study, fluency has been included

with prosody as an aspect of speech production, some theories suggest that dysfluent speech can stem from linguistic difficulties. As explained in section 1.4.5, the two main theories regarding the cause of dysfluent speech are the demands and capacity theory (Adams, 1990) and the neuropsycholinguistic theory (Perkins et al., 1991). Both of these theories can relate back to the information-processing model (Figure 1-5) in that they involve the interaction of language processes and speech production processes. Studies with typically developing children, children with hearing impairment, and those who stutter have shown that as the complexity of the linguistic message increases, the incidence of dysfluent moments in a speech sample also increases (Kleinow & Smith, 2000; McLaughlin & Cullinan, 1989; Osberger, 1992; Ratner & Sih, 1987; Sawyer, Chon, & Ambrose, 2008). As explained in section 1.6.1, dysfluent speech can disrupt how the listener perceives the speech signal and result in reduced speech intelligibility.

### **1.6.2 Speech material**

The type of speech stimulus that is judged in order to obtain speech intelligibility scores is also an important variable that can influence the results of assessment and how an intelligibility difficulty is understood (Miller, Heise, & Lichten, 1951). Typically, orthographic transcription of single words has been found to yield lower intelligibility scores compared to orthographic transcription of sentences. Yorkston and Buekelman (1981) measured word and sentence intelligibility of speakers with dysarthria using an orthographic transcription task completed by experienced listeners and found that sentence intelligibility scores were higher than word intelligibility scores. Other studies have published similar results (Hustad, 2007; Miller et al., 1951; O'Neill, 1957; Sitler, 1983). Authors suggest that the findings relating to sentence stimuli yielding higher speech

intelligibility scores compared to single word stimuli are due to the syntactic features of sentences helping the listeners to parse the distorted acoustic signal into the appropriate units (Yorkston et al., 1996). When hearing sentences, listeners are also likely to draw on their top-down linguistic knowledge, where context builds from word to word and sentence to sentence (Hustad, 2007; Hustad & Beukelman, 2001; Klasner & Yorkston, 2005). That is, even if speech intelligibility is reduced, the listener can make an “educated” guess based on their knowledge of syntax from other words heard in the sentence. However, the findings of an earlier study by Yorkston and Beukelman (1978) contrasted to the above. They found that while sentences yielded higher speech intelligibility scores compared to words for speakers with mild dysarthria, sentence intelligibility scores were lower than word intelligibility scores for speakers with severe dysarthria. Allison, Annear, Policicchio, and Hustad (2017) reported similar findings for speakers with amyotrophic lateral sclerosis. The authors suggested that the increased number of articulatory transitions in sentence tasks placed an added burden on the speakers with severe dysarthria resulting in lower speech intelligibility scores.

Furthermore, analysis of different types of single word stimuli can yield different speech intelligibility scores. Barreto and Ortiz (2010) studied the influence of using real words, pseudo-words and sentences as stimuli for measuring speech intelligibility of typical adults via orthographic transcription. They found significant differences between speech intelligibility scores for all three types of speech stimuli, with the orthographic transcription of pseudo-words yielding the lowest scores. Again, this may be explained by the lack of context provided by the pseudo-words, hence, the listeners had less knowledge to draw on to help them understand the

spoken message causing them to perceive intelligibility as lowest for this type of stimulus.

Spontaneous speech, while not investigated as extensively as word intelligibility or sentence intelligibility, can also yield different speech intelligibility scores compared to other speech tasks. Measuring speech intelligibility from spontaneous speech is challenging as the target is only known to the speaker. That is, for unintelligible portions of spontaneous speech, it is not possible to ascertain the total number of words produced because it is not known what the speaker intended to say. Hustad (2007) compared speech intelligibility scores when obtained from single words, sentences and a pre-scripted narrative sample for speakers with cerebral palsy, as measured by orthographic transcription. She found that intelligibility scores were highest for the narrative speech samples. Again, this finding aligns with the theory of listener top-down processing. On the other hand, Hustad and Beukelman (2001) did not find any significant differences between speech intelligibility scores obtained from isolated sentences versus narrative discourse. As discussed previously, for speakers with severe dysarthria, stimuli that go beyond the word level may be too challenging to produce due to their increased articulatory transitions (Allison et al., 2017) and may have overridden other influences on speech intelligibility.

### **1.6.3 Listener experience**

When seeking to understand more about the nature of a speech intelligibility difficulty, characteristics of the listener should also be considered. Research has shown that the experience of the listener judging speech intelligibility can impact on outcome scores. The majority of studies have found that intelligibility scores measured by experienced listeners are usually higher compared to those who are inexperienced (DePaul & Kent, 2000; Hustad & Cahill, 2003; Keuning et al., 1999;

McGarr, 1983). For example, McGarr (1983) compared the speech intelligibility scores of children who were profoundly deaf using orthographic transcription completed by inexperienced and experienced listeners. The results showed that the experienced listener group judged speech as more intelligible compared to the inexperienced group for both single words and sentences. McGarr (1983) suggested that the experienced listeners, who had at least one year's experience of listening to the speech of people who are deaf, were familiar with the speech characteristics of this group and were able to compensate for the deviations. Another study by Flipsen (1995) compared the speech intelligibility scores given by parents of children with speech difficulties versus scores given by adults who did not have exposure to hearing unclear speech. Flipsen's results from a word identification test showed that parents, even more so the mothers, were significantly better at identifying the words produced by the children with speech difficulties compared to the group who had no exposure to speech difficulties.

An earlier study by Starr, Moller, Dawson, Graham, and Skaar (1984) compared speech intelligibility scores, as measured by EAI scale, of speakers with cleft palate across six listener groups: clinicians who work and do not work with people who have cleft palate, parents of children with and without cleft palate, and children with and without a cleft palate. Results showed no significant differences between EAI ratings across the six groups. However, as mentioned previously, EAI may not be an appropriate method to measure prosthetic phenomena such as speech intelligibility. Nevertheless, using DME as the method of measurement, Walshe, Miller, Leahy, and Murray (2008) recruited experienced listeners, qualified SLTs, and naive listeners to judge the speech intelligibility of a group of speakers with dysarthria. They also reported no significant difference in how the two listener

groups judged speech intelligibility. Keintz, Bunton, and Hoit (2007) used orthographic transcription to evaluate speech intelligibility of dysarthric speech and also found no difference between outcome scores when judged by experienced and inexperienced listeners. However, it must be noted that the age range of the SLT listener group in the Keintz et al. (2007) study was 27-54 years whereas the age range of the naive listener group was 19-24 years. Previous research has shown that people's judgements of speech intelligibility can differ as they get older, possibly due to decreased auditory acuity and/or cognitive function (Dagenais et al., 2011; Humes et al., 1994). Thus, as the ages between the listener groups differed, the results should be interpreted with caution. Another study by Smith et al. (2019) used orthographic transcription of sentences to compare speech intelligibility scores in speakers with Parkinson's disease when measured by experienced listeners, SLT students, and inexperienced listeners. Results showed no difference between speech intelligibility scores judged by the two listener groups. However, we do not know how much experience the SLT students had with listening to disordered speech. It may be that if the SLT students had more clinical experience, the outcomes could have been different.

The findings of most studies so far show that listeners who are more experienced in listening to people with speech difficulties perceive speech as more intelligible compared to those who are not experienced or exposed to people with speech difficulties. However, researchers have used varying definitions and criteria for "experienced" and "naive" listeners. In particular, when SLT students were recruited to judge speech intelligibility, studies had varying interpretations regarding the experience level of this group; in some studies, they were viewed as experienced or trained and in other studies they were viewed as inexperienced. These



inconsistencies across the studies make interpretation and comparison of results difficult. Nevertheless, the effect of listener experience on judgement of speech intelligibility in speakers with DS has not yet been examined.

#### **1.6.4 Measurement method**

As discussed in section 1.5, several methods for measuring speech intelligibility have been described in the literature. The most common methods include orthographic transcription and scaling procedures, such as EAI, DME and VAS (Barreto & Ortiz, 2008; Walshe et al., 2008). However, the method adopted to measure speech intelligibility affects the results; therefore, the method used to measure speech intelligibility is also an important factor to consider when exploring the nature of reduced intelligibility. In general, orthographic transcription scores tend to be higher than more impressionistic scaling methods. One of the earliest studies to compare speech intelligibility scores across different methods of measurement was by Yorkston and Beukelman (1978). They compared the intelligibility scores based on single words and sentences produced by eight speakers with dysarthria using different evaluation methods: percentage estimates, EAI scale, multiple choice, word and sentence transcriptions, word and sentence completions, and word and sentence multiple choice identification. All tasks ranked the speakers in a similar order in terms of their speech intelligibility. However, the listeners who judged speech intelligibility in the Yorkston and Beukelman (1978) study completed the eight different measurement tasks for each speaker in the same testing session. Exposure to words and/or sentences from each speaker over eight times may have familiarised listeners with the speech material and impacted on their intelligibility judgements (Liss, Spitzer, Caviness, & Adler, 2002). Beijer, Clapham, and Rietveld (2012) recruited ten SLTs to judge the speech intelligibility of speakers with Parkinson's

disease using both orthographic transcription and a 10-point EAI scale. Scores varied across all listeners, but orthographic transcription scores were generally higher than EAI scores.

Stipancic et al. (2016) compared speech intelligibility scores measured using orthographic transcription and VAS was judged by 50 inexperienced listeners. The speakers in this study were three groups of adults with typical speech, Parkinson's disease, and multiple sclerosis and the stimuli were the Harvard sentences, which are a set of phonetically-balanced sentences specifically used to evaluate speech production (Tjaden et al., 2014b). The findings of the Stipancic et al. study showed that the orthographic transcription scores were significantly higher than the VAS scores. However, despite the differences, there was a strong positive correlation between orthographic transcription scores and VAS scores. Moreover, the VAS scores showed slightly higher inter-rater reliability. The authors concluded that a VAS scaling method may be a viable tool for clinicians when evaluating speech intelligibility, as well as orthographic transcription. It should be noted that the listeners who judged intelligibility via orthographic transcription were not the same listeners who completed the VAS measurements. The two different groups of listeners prevent direct comparison of the methods of measurement.

Another study by Tjaden et al. (2014b) also examined the intelligibility of speech in speakers with Parkinson's disease using both orthographic transcription and VAS, with both tasks being completed by the same group of inexperienced listeners. While comparing the two methods was not the aim of their study, the authors reported that orthographic transcription scores were higher than VAS scores. Tjaden et al. did not carry out a correlation analysis between the two measures but they did indicate that both orthographic transcription and VAS measures showed

similar patterns across speakers' intelligibility scores over a period of time. A more recent study by Abur, Enos, and Stepp (2019) used the same group of naive listeners to compare the speech intelligibility scores measured using orthographic transcription and VAS for a group of speakers with Parkinson's disease and typical speakers. The results also showed that orthographic transcription scores were higher than the VAS ratings. Similar to the study by Stipancic et al. (2016), Abur et al. (2019) reported that the speech intelligibility scores obtained using the two methods were highly correlated with each other.

Another factor that has been proven to influence speech intelligibility scores is the context in which the speech stimuli are presented. A study by Hustad (2006) showed that listeners judged speech to be more intelligible when stimuli were presented both visually and aurally compared to when just presented aurally alone. One could argue that when stimuli were presented both visually and aurally, listener perception of comprehensibility was measured, rather than speech intelligibility because more contextual information was available. On the other hand, Hustad and Cahill (2003) found no difference in speech intelligibility scores for five speakers with dysarthria when stimuli were presented aurally only and when accompanied by a visual. However, their sample size of just five speakers limits the generalisability of these findings.

In summary, the research discussed so far shows that the way in which speech intelligibility is measured, and the mode in which speech stimuli are presented to listeners can influence outcome scores. These factors should be considered when interpreting and comparing results of speech intelligibility assessment. In particular, rating methods, such as VAS, seem to evaluate speech intelligibility in different way compared to orthographic transcription. It may be that

when using a rating method to measure speech intelligibility, listeners cannot fully separate speech intelligibility from other features, such as acceptability. Hence, when rating speech intelligibility, listeners' may be capturing other features of speech as well as intelligibility resulting in lower intelligibility scores. However, as rating methods are less time-consuming to administer, it is likely that these methods are employed more often in the clinical setting. The majority of studies that have investigated how the method of measurement affects listener judgement of speech intelligibility have been carried out for speakers with dysarthria. No study has examined how the method of measurement can impact on speech intelligibility scores in speakers with DS.

#### **1.6.5 Summary**

To summarise the previous sections, certain factors have been shown to impact on listener judgement of speech intelligibility scores. It is important to take these factors into account when interpreting the results of speech intelligibility assessment and planning treatment. The language ability of the speaker can impact on speech intelligibility in that if a speaker has a language difficulty, this may have an indirect effect on certain aspects of speech production, and thus impact on speech intelligibility. In regard to the speaking task, factors such as the type of speech material can influence outcome scores in that intelligibility of isolated words is usually lower compared to intelligibility of sentences. The method of measurement should also be considered when interpreting speech intelligibility scores as research has shown that a rating method can yield different outcomes compared to orthographic transcription. Finally, the experience of the listener judging speech intelligibility may also be an influencing factor during assessment. Research has shown that listeners who have more experience in listening to people with speech

difficulties can perceive speech as more intelligible compared to listeners who have little or no experience. This summary supports the suggestion of Ludlow et al. (2019) that speech intelligibility should be considered as a collaborative product of the speaker, speech material, the listener, and the listening task. However, no study to date has examined the role that these factors play in the evaluation of speech intelligibility for speakers with DS. In the current study, a number of these factors were directly investigated in relation to speakers with DS.

### **1.7 /Features of Down syndrome that can impact on speech intelligibility**

As discussed in section 1.4, DS is a complex syndrome that can impact on all aspects of development. Therefore, when one is evaluating speech intelligibility in this population, they should not do so in a vacuum. Speech intelligibility should be considered in terms of other features of DS such as cognitive impairment, language disorder, anatomical differences, hearing loss, and memory impairment. Individually, any one of these factors is likely to have a negative impact on speech production and the presence of more than one may have an even greater effect (Stoel-Gammon, 2003). The main features of DS that can impact on speech intelligibility are discussed in the following sections. However, it should be noted that significant individual differences exist and the features discussed may apply to most but not all individuals in this group (Karmiloff-Smith et al., 2016).

#### **1.7.1 Cognition**

The genetic makeup of DS causes a cognitive impairment. A cognitive impairment can be defined as an intelligence quotient less than 70 on a standardised test of intelligence. Cognitive ability in people with DS varies but the majority of people with DS are reported to lie within the mild to moderate range of cognitive impairment, which is an intelligence quotient between 40-69 (Roberts, Price, &

Malkin, 2007; Roizen & Patterson, 2003). Some studies have directly investigated the relationship between cognition and speech intelligibility in people with DS and found that the speech difficulty is mainly independent of cognition (Cleland et al., 2010; Crosley & Dowling, 1989; Dodd & Thompson, 2001; Stoel-Gammon, 1980). That is, a higher intelligence quotient is not necessarily associated with better speech intelligibility. However, these studies were mainly carried out with children; the association between cognition and speech intelligibility in adults with DS is not fully known.

Cognitive ability in DS has been found to decrease as individuals get older (Neel, 2008; Pennington et al., 2003) and the risk of dementia is higher for this group. A recent Irish study has shown that the prevalence rate of dementia in adults with DS was approximately 36% compared to an incidence rate of about 10% for the general population (McCarron, Haigh, & McCallion, 2017). The cognitive decline that results from both age and the progression of dementia can further impact on speech production and thus decrease speech intelligibility (Roberts et al., 2007).

Impaired cognition can hinder speakers with DS from monitoring their own speech productions and attempting to correct errors and thus, impacting on how the speech signal is perceived by the listeners (Nickels & Howard, 2000). Cognitive ability may also play a role in therapeutic success in that those with better cognition may have more capacity for learning and retention of strategies to increase their speech intelligibility.

### **1.7.2 Language ability**

Difficulties with language are widespread in people with DS. In fact, language difficulties have been found to be more profound for individuals with DS compared to other populations with cognitive impairment matched for mental age

(Abbeduto et al., 2001; Chapman, 2006). People with DS can have difficulties in all areas of language: semantics, syntax, morphology, phonology, and pragmatics (Roberts et al., 2007). Typically, receptive language is better than expressive language for this group and syntax (grammar) is an area of particular difficulty compared to semantics (vocabulary, Chapman, Schwartz, & Bird, 1991; Chapman et al., 1998). Infants with DS usually produce their first word between 18-36 months and their language development continues to proceed at a slower pace compared to typically developing peers (Berglund, Eriksson, & Johansson, 2001). When they reach adolescence and adulthood, individuals with DS have considerably less-developed language skills compared to typical individuals of the same age.

Researchers have used a variety of approaches to evaluate language ability in DS. For adults with DS, numerous studies have used versions of the Test for Auditory Comprehension of Language (TACL, Carrow-Woolfolk, 2014; Chapman, 2006; Miolo, Chapman, & Sindberg, 2005; Price, Roberts, Vandergrift, & Martin, 2007a). This assessment evaluates comprehension of vocabulary, grammatical morphemes, and elaborated sentences and has been frequently used to evaluate receptive language for people with DS (Chapman, 2006; Miolo et al., 2005; Price, Roberts, Vandergrift, & Martin, 2007b). This test will be described in more detail in Chapter 4 as it was used to evaluate the receptive language of the speakers with DS in the current study.

To evaluate expressive language in individuals with DS, one method that researchers have used is conversational analysis. Software such as Computerised Language Analysis (CLAN, McWhinney, 2000) or Systematic Analysis of Language Transcripts (SALT, Miller et al., 2016) have been used to analyse language samples and automatically calculate a number of expressive language measures. For

individuals with DS, the most common measures that have been obtained include MLU (explained in section 1.6.1) and the type-token ratio (TTR). The TTR represents the diversity of vocabulary in relation to the number of words in a speech sample (Richards, 1987). In theory, the larger the TTR, the more diverse the use of vocabulary. In the expressive language of people with DS, MLU and TTR have been found to be considerably lower compared to typical populations, those matched for mental age, and other groups with cognitive impairment (Chapman et al., 1998; Laws & Bishop, 2004; Miles & Chapman, 2002; Rondal & Comblain, 1996). Studies using language analysis software have also shown that children and adolescents with DS use fewer grammatical markers and more basic sentence structures compared to typically developing children matched on mental age (Vicari, Caselli, & Tonucci, 2000).

In the current study, the MLU and a measure known as vocabulary diversity (vocD) was used to evaluate the expressive language ability for those with DS. In recent times, the reliability of the TTR as a measure of lexical diversity has been questioned due to its dependency on the size of the speech sample; hence, the vocD measure was created by Malvern, Richards, Chipere, and Durán (2008) to overcome this challenge. The TTR was strongly influenced by sample size, in that the larger the number of words in a sample, the lower the TTR. However, vocD is not a function of the number of words in a sample and reflects the variation in TTR over a range of sample sizes (Malvern et al., 2008). VocD is based on a mathematical model which analyses the probability of new vocabulary being introduced as speech samples increase in length. This measure has been found to have strong validity and correlate with other measures of lexical diversity (Malvern et al., 2008; McKee, Malvern, & Richards, 2000). Until the present study, no study had used the vocD to



analyse expressive language ability in those with DS. However, the vocD has been used to analyse language in other populations including those who stutter, those with aphasia, and those who speak English as a second language (Harris Wright, Silverman, & Newhoff, 2003; Malvern & Richards, 2012; Silverman & Ratner, 2002).

In addition to semantics and syntax, some researchers have proposed that a disorder relating to phonology can also occur in individuals with DS (Barnes et al., 2009; Cleland et al., 2010). These researchers propose that anatomical differences and motor impairments do not fully account for the speech difficulties experienced by those with DS and that a phonological disorder may also be influencing speech production. For example, Dodd and Thompson (2001) carried out a study that compared the phonological skills of children with DS to children with inconsistent phonological disorder. Both groups performed similarly in terms of the type and consistency of errors leading Dodd and Thompson to conclude that children with DS have under-developed phonological representations leading to unclear speech production.

The relationship or interaction between speech intelligibility and language ability in individuals with DS is somewhat unclear. Some researchers have argued that speech intelligibility can impact on language ability. That is, if an individual with DS has reduced intelligibility, they may be less encouraged to make speaking attempts, hence limiting opportunities to practice expressive language (Miller & Leddy, 1999). Moreover, to compensate for reduced speech intelligibility, people with DS may shorten their utterances and reduce the complexity of their utterances (Miller & Leddy, 1999). Chapman et al. (1998) argues that without improved speech intelligibility, gains in expressive language would not contribute to overall

communicative effectiveness for individuals with DS. This view of speech and/or language impacting on the other is supported by the findings of a study by Ní Cholmain (1994). Ní Cholmain found that a structured treatment programme targeting speech production for a group of children with DS not only resulted in increased speech intelligibility, but also resulted in improved expressive syntax skills.

When viewing the relationship between speech intelligibility and language ability from the other direction, that is how language ability can impact on speech intelligibility, various theories have been proposed. Drawing on the information-processing theory of speech production (Figure 1-5, p. 50), it has been suggested that difficulties at the linguistic level (which are common in people with DS) would impact on the phonetic level, hence, affecting the speech signal and impacting on perceived speech intelligibility (Kent, 2009). Language ability may also impact on speech intelligibility in that those with DS who have stronger language skills may respond better to therapy targeting increased speech intelligibility as they would be better able to comprehend instructions (Nickels & Howard, 2000). However, to date, only two studies have examined how aspects of language ability can contribute to speech intelligibility in people with DS.

Chapman, Seung, Schwartz, and Bird (2000) investigated the impact of comprehension along with other variables, on speech intelligibility in children and adolescents with DS. Out of hearing acuity, chronological age, cognition level, maternal education, and comprehension, they found that comprehension as measured by the TACL-4, was the strongest contributor to intelligibility scores from regression analysis. The authors suggested that comprehension was a driving force behind both expressive language and speech production for those with DS. However, this study

did not examine how expressive language contributed to speech intelligibility in the speakers with DS.

Cleland et al. (2010) investigated the relationship between aspects of both receptive and expressive language and speech intelligibility in 15 children and adolescents with DS. Cleland and colleagues found no correlation between receptive and expressive scores on the Clinical Evaluation of Language Fundamentals-Preschool 2nd Edition (Wiig, Secord, & Semel, 2006) and the Children's Speech Intelligibility Measure (Wilcox & Morris, 1999). The authors concluded that difficulties with speech production in DS are likely to be due to some factor(s) other than language, possibly motor speech impairments. However, the Children's Speech Intelligibility Measure uses single words as the stimuli from which to measure speech intelligibility. It may be that the relationship between language ability and speech intelligibility becomes more established when additional complex linguistic processes, such as spoken sentences, are involved.

Studies of those with language disorder have proposed that memory, specifically phonological short-term memory, is integral to language development. Phonological short-term memory can be important for "mediating the development of long-term representations as the lexicon grows" (Laws & Bishop, 2004, p. 435). It can also be important for the acquisition of grammar (Baddeley, Gathercole, & Papagno, 1998) and assists in "maintaining auditory input and planning speech movements" (Nip, Green, & Marx, 2011, p. 157). Research has shown a marked difficulty with phonological short-term memory in individuals with DS relative to their non-verbal abilities, and independent of hearing abilities (Conners, 2003; Jarrold & Baddeley, 2001). Children with Developmental Language Disorder also have a marked difficulty with phonological short-term memory which some

researchers suggest may be the reason for the two groups having similar language characteristics (Laws & Bishop, 2004). Impaired phonological memory in people with DS, means that they have difficulty establishing accurate representations in their lexicons, formulating grammatically correct utterances, and monitoring output during speech production, hence reducing listener judgements of speech intelligibility (Acheson & MacDonald, 2009).

### **1.7.3 Anatomical and physiological features**

Anatomical differences can be found in all individuals who have DS. A number of anatomical differences in this group have already been mentioned in previous sections, but this section serves to draw these differences together. Some individuals can accommodate for these differences and they may not impact significantly on speech production and speech intelligibility. However, those with more severe anatomical differences may find compensating for these differences more of a challenge. Therefore, the anatomical features of DS should be taken into account when evaluating the nature of speech intelligibility for this group. Firstly, people with DS are physically smaller in height compared to their typical age-matched peers (Myrelid, Gustafsson, Ollars, & Anneren, 2002). They can also have a smaller skull and jaw structures, which is likely to be due to reduced bone growth (Miller & Leddy, 1999; Vorperian & Kent, 2004). As these differences relate to the head and face, they can impact on the structures and muscles needed for speech production which can affect how the speech signal is perceived by listeners and thus, affect speech intelligibility.

One of the most frequently reported features of DS is a smaller mouth compared to typical individuals (Leddy, 1999). Early research initially reported macroglossia, which is a larger than average tongue, in people with DS (e.g.

Olbrisch, 1982). However, more recent studies have shown that people with DS do not have macroglossia; it is more that the tongue is large in relation to the small oral cavity which can restrict lingual movement (Guimaraes, Donnelly, Shott, Amin, & Kalra, 2008).

People with DS can also have enlarged tonsils and a narrow airway (Arumugam et al., 2016). They are also more prone to upper respiratory tract infections which can lead to blockage of the airway and nasal cavity impacting on speech breathing and also resonance (Rondal & Edwards, 2000; Venail, Gardiner, & Mondain, 2004). They have also been reported to have laryngomalacia, which can result in a stridor voice (Bertrand et al., 2003) and can have a narrower and shorter palate and smaller larynx compared to typical individuals (Dellavia et al., 2007; Leddy, 1999). These differences could change the configuration of the vocal tract and also limit tongue movement which can impact on articulation of speech sounds and how the speech signal is perceived by the listener (Beckman, Wold, & Montague, 1983; Leddy, 1999).

#### **1.7.4 Hearing**

Hearing difficulties are widespread in people who have DS with prevalence rates reported to be as high as 80% in this population (Blaser et al., 2006). Hearing loss can be conductive, due to otitis media, and/or permanent, due to sensorineural hearing loss. Otitis media is the most common cause of hearing difficulties in people with DS (Kumin, 1994). A five-year longitudinal study by Shott, Joseph, and Heithaus (2001) followed the hearing development of 48 young children with DS and found that 96% had at least one ear infection and 83% had pneumatic tube placement to treat otitis media. Stoel-Gammon (2001) suggests that hearing loss can compromise the learning environment for individuals with DS and is likely to be

associated with poorer outcomes on both speech and language measures. People with DS who are already more vulnerable to impaired speech intelligibility may have this difficulty exacerbated due to hearing loss (Roberts, Stoel-Gammon, & Barnes, 2008). Hearing loss can result in difficulties with auditory discrimination, which can make it more difficult for speakers to hear the subtle phonetic differences between speech sounds. If a speaker cannot hear the acoustic differences between certain sounds, they may not be able to produce these differences, thus impacting negatively on their speech intelligibility (Kumin, 2006). A study by Chapman et al. (2000) found that hearing acuity directly impacted on speech intelligibility in children and adolescents with DS. Hence, studies investigating the nature of reduced speech intelligibility in this group should consider hearing acuity as a possible influential factor.

#### **1.7.5 Neurological factors**

In addition to structural differences, people with DS show differences with the central and peripheral nervous system. They have a smaller brain-size and weight, fewer cerebral sulci, fewer cortical neurons, and less neuronal density (Leddy, 1999). Stoel-Gammon (2001) suggests that these cerebral features may be related to the restricted accuracy, speed, and consistency of speech movements in individuals with DS. If speech movements are not carried out accurately, this would distort the acoustic signal and directly impact on speech intelligibility. Another neurological problem in DS that is widely cited throughout the literature is low muscle tone, which is also known hypotonia (Almeida et al., 2000). Hypotonia can affect the function and synchronicity of all of the muscles used for speech

production. For example, it can restrict lip movement, affecting production of labial consonants and rounded vowels (Roberts et al., 2008).

Several researchers propose that neurological differences in DS result in a major problem with *speech motor control* that can impact on speech intelligibility. Indeed, some researchers have proposed that motor speech could be the main cause of speech difficulties for this group (Kumin, 2001; Miller et al., 1951). Impairments with motor speech can impact on the precision of speech production and an individual's ability to adapt to their unique speech structures, that is, skeletal or muscular differences (Bunton & Leddy, 2011). This assumption has arisen from observations of planning and programming deficits, impaired movement of the tongue, and hypotonia (Coêlho, Delgado, Rosa, & Alves, 2020; Wilson et al., 2019a). Individuals with DS have been reported to have a greater involvement of motor speech component compared to others with cognitive impairment and it can be independent of cognitive level (Henderson, Morris, & Frith, 1981). Difficulties with oro-motor control, including tongue, lip and jaw movement, have been reported in speakers with DS (Barnes, Roberts, Mirrett, Sideris, & Misenheimer, 2006; Bunton & Leddy, 2011; Spano et al., 1999; Spender et al., 1995). Oro-motor function has also been found to significantly correlate with speech intelligibility for this group (Cleland et al., 2010). That is, difficulties with combining and sequencing phonemes was strongly associated with reduced speech intelligibility.

Reports of motor speech features consistent with both dysarthria and apraxia of speech have been reported for people with DS (Barnes et al., 2006; Coêlho et al., 2020; Hamilton, 1993; Kumin, 2006). A study of motor speech performance in DS by Rupela, Velleman, and Andrianopoulos (2016) showed that children with DS can show symptoms of dysarthria (e.g. speech sound distortion), apraxia of speech (e.g.

groping), and motor speech problems that are not otherwise specified. However, many symptoms of each difficulty can overlap with each other making the motor speech profile difficult to establish for some of the speakers with DS. Another study by Wilson et al. (2019a) had comparable findings to Rupela et al. (2016) in that they too found that speakers with DS can exhibit signs of dysarthria, apraxia, or both in their speech. From their analysis they found that the most common type of dysarthria in the adult speakers with DS was of the ataxic type (Wilson et al., 2019a). Ataxic dysarthria results from an impairment at the cerebellum resulting in inaccurate timing, reduced speed of movement, and low muscle tone (Ackermann, 2008; Fiez, 2016; Roth & Worthington, 2011). This type of dysarthria mainly affects articulation, phonation, and prosody by interfering with co-ordinated movement of the laryngeal and articulatory muscles used during speech production (Kent et al., 2000; Murdoch, 2010). If the co-ordination and timing of the muscles involved in speech production are impaired, atypical speech production is likely to result, impacting on perception of speech intelligibility.

#### **1.7.6 Summary**

The previous sections have given an overview of the factors that can impact on speech production and speech intelligibility in speakers with DS. Factors such as cognition, hearing, anatomical and neurological features of the syndrome, and memory may impact on the control and co-ordination of the components involved in speech production and thus, impact on listener judgement of intelligibility. Furthermore, difficulties with receptive and expressive language are common in people with DS. The information-processing model (Figure 1-5, p. 50) depicts how impairment at the linguistic level can have a knock-on effect at the motor level which could affect how the speech signal is produced by the speaker and perceived



by the listener. These specific aspects of DS should be taken into account when seeking to understand the speech intelligibility profile for this group.

### **1.8 Research aims and hypotheses**

As discussed throughout this introductory chapter, difficulties with speech intelligibility in both children and adults with DS are reported in many previous studies (Buckley, 1999; Cleland et al., 2010; Kumin, 1994, 1996). Reduced speech intelligibility in people with DS can persist into adulthood and may be a lifelong difficulty (Coppens-Hoffman, 2012). Poor speech intelligibility also reduces communication between people with DS and their families (Pueschel & Hopman, 1993). Abbeduto and Murphy (2004) assessed speech intelligibility in people with DS and those with cognitive impairment of other origins and they found that even when these groups with disabilities were matched for mental age, speakers with DS still had significantly reduced speech intelligibility.

As also discussed in Chapter 1, reduced speech intelligibility can arise from an impairment to any one of the components involved in speech production and people with DS can have difficulty with all of these components. However, no study has specifically examined all of these components of speech production in one single study nor has any study investigated which components contribute most to reduced speech intelligibility for this population. Furthermore, as mentioned previously, other factors can also impact on speech production and assessment outcomes for this group. Some research has shown that language ability can impact on speech production and that features of intelligibility assessment, such as the method of measurement and the experience of the person judging speech, should also be considered when interpreting assessment results. Although these factors have been shown to influence speech intelligibility outcomes in other populations, limited

research exists that has investigated these factors in DS. This research consisted of four studies which sought to address the gaps in knowledge and understand more about speech intelligibility in individuals with DS by achieving the following aims (summarised in Figure 1-6).

**Aim of Study 1:** To investigate which speech components contribute to speech intelligibility in adolescents and adults with DS using perceptual analysis (Chapter 2).

Reduced speech intelligibility scores on their own do not tell us about the nature of a speech problem, only that one exists. This study examined which components of speech production contributed most to intelligibility scores in DS according to perceptual analysis. It is important for SLTs to be aware of aspects of speech production that may be influencing speech intelligibility in those with DS so that they can plan and implement appropriate therapy for this group. For this study, several methods were chosen to perceptually evaluate the components of speech production for the speakers with DS. These methods were selected on the basis of their advantages over other methods, and their frequent use by both clinicians and researchers in the perceptual evaluation of speech, including those with DS (Baker & McLeod, 2011; Bates & Titterton, 2017; Baylis, Chapman, Whitehill, & Group, 2015; de Almeida et al., 2019; Duffy & Folger, 1996; Evitts et al., 2016; Jones et al., 2019; Simmons & Mayo, 1997). It was hypothesised that the speech of those with DS would be perceived to be atypical across the majority of perceptual parameters. It was also expected that parameters pertaining to articulation would be the main contributors to speech intelligibility.

**Aim of Study 2:** To investigate which speech components contribute to speech intelligibility in adolescents and adults with DS using acoustic analysis (Chapter 3).

Similar to the first study, this second study investigated which aspects of speech production contributed to speech intelligibility for the speakers with DS; however, in this case, acoustic analysis methods were used. Acoustic analysis may help SLTs to understand more about the contributing factors to unintelligible speech in DS by supplementing the perceptual analysis findings. The acoustic parameters chosen for evaluation of the speech production components were chosen based on their support in the literature and their proven association with speech intelligibility in other speaker populations (Diehl & Paul, 2012; Ferrand, 2002; Forrest et al., 1988; Kent et al., 1989a; Levy et al., 2015; Liu et al., 2007; Peppé, 2009; Roy et al., 2013; Vogel et al., 2009). When considering the literature around acoustic analysis of speech production in DS, it was hypothesised that the speakers with DS would show differences with a number of acoustic features of speech compared to the typical speakers. Again, parameters related to articulation were predicted to be the main factors that would contribute to speech intelligibility scores based on previous research. However, the extent of this association could not be predicted.

**Aim of Study 3:** To investigate which aspects of language ability contribute to speech intelligibility in adolescents and adults with DS (Chapter 4).

In addition to aspects of speech production, it is also important for SLTs to consider other possible factors that may influence speech intelligibility in those with DS. The relationship between language ability and speech intelligibility in this population is unclear and requires further investigation; it may be that the language level of individuals with DS can impact on their intelligibility scores. The third study

examined aspects of both receptive and expressive language skills in the speakers with DS and how they related to speech intelligibility scores. Although the current evidence regarding the relationship between language ability and speech intelligibility in DS is varied, due to the information-processing model (Figure 1-5, p. 50), it was hypothesised that language ability would impact on speech intelligibility scores, in that those with higher language ability scores were also expected to have higher speech intelligibility scores.

**Aim of Study 4:** To examine the differences between speech intelligibility scores in people with DS when (a) measured using a rating versus orthographic transcription task and (b) when judged by experienced versus naive listeners (Chapter 5).

When evaluating speech intelligibility, SLTs need to consider how the measurement method they use might impact on outcome scores. They may also need to be aware about how they, as being frequently exposed to atypical speech, may judge intelligibility differently compared to someone who has been less exposed. The fourth study used two types of measurement method, orthographic transcription (as used in the previous three studies) and VAS, to measure speech intelligibility for the speakers with DS and investigated if they yielded different outcome scores. This study also investigated if experienced listeners perceived speech intelligibility differently to inexperienced (or naive) listeners. Drawing on studies that investigated intelligibility in other clinical populations, it was hypothesised that speech intelligibility scores would significantly differ depending on the method of measurement used and also on the experience of the people who judged speech intelligibility. Orthographic transcription scores were predicted to be higher than

VAS scores and the experienced listener group were expected to provide higher speech intelligibility scores compared to the naive listener group.

Results of these four studies aimed to provide new knowledge about the nature of reduced speech intelligibility in individuals with DS and provide insight around factors that may influence its measurement. The first two studies used a methodology that had not yet been used to investigate speech in those with DS. In previous studies, the components of speech production were mainly examined in isolation, whereas Study 1 and Study 2 evaluated all five of the components of speech production and examined their relative contribution to the speakers' intelligibility. The third study sought to add to the limited knowledge around the impact of language ability on speech intelligibility in those with DS. Lastly, Study 4 explored aspects of intelligibility assessment that had not yet been examined in this group. The findings from each of the four studies will initially be discussed separately in their relevant chapters. Then, in Chapter 6, the four sets of findings will be amalgamated and discussed in terms of key themes that emerged. Chapter 6 will also discuss the clinical implications of the study findings along with limitations and direction for future research.

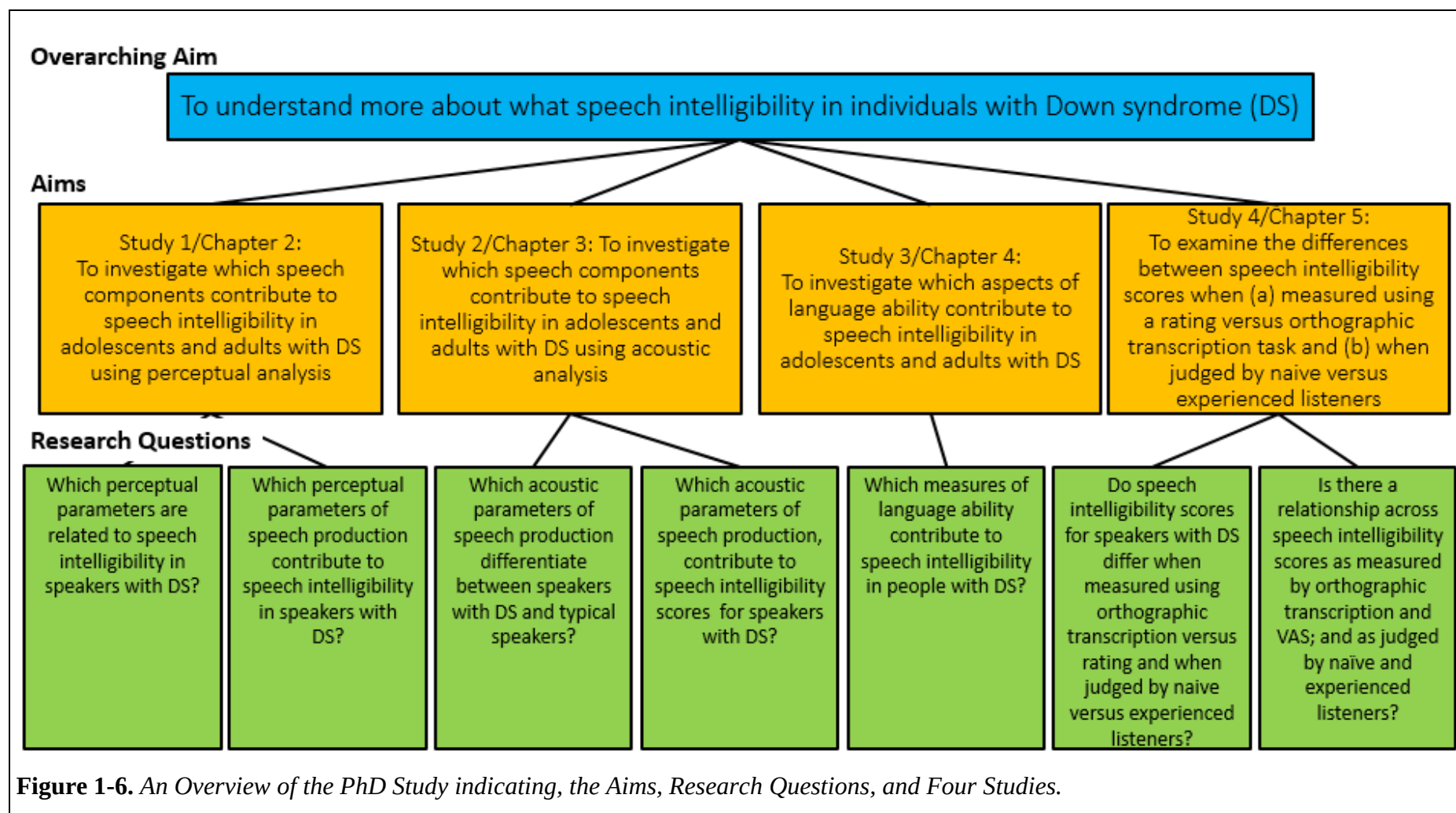


**Figure 1-6.** An Overview of the PhD Study indicating, the Aims, Research Questions, and Four Studies.

## Chapter 2

# PERCEPTUAL FEATURES OF SPEECH IN INDIVIDUALS WITH DOWN SYNDROME, AND THEIR IMPACT ON SPEECH INTELLIGIBILITY

### 2.1 Introduction

As discussed in Chapter 1, reduced speech intelligibility is a common feature among people with Down syndrome (DS) and is associated with difficulties in the areas of *respiration*, *articulation*, *phonation*, *resonance*, and *prosody* (Kent & Vorperian, 2013). Difficulties with these components of speech production are usually due to the anatomical and neurological impairments of the syndrome (Kent & Vorperian, 2013; Wilson et al., 2019a). Reduced speech intelligibility can exert a considerable influence on a person's life as it can impact on other people's perceptions, decisions around education, literacy skills, personal relationships, and job opportunities (McCormack, McLeod, McAllister, & Harrison, 2009). Hence, it is not surprising that increased speech intelligibility is a frequent goal for people with DS in speech and language therapy (SLT). However, there is still much to learn about the nature of speech intelligibility difficulties in this group.

When evaluating different aspects of speech production, perceptual evaluation is considered as the gold-standard (e.g. Ludlow et al., 2019). During perceptual assessment, different types of speech tasks are used to elicit speech samples from the speaker; then the assessor listens for the presence or absence of atypical speech features and judges the severity level of each atypical feature. Some specific protocols for perceptual assessment of speech production have been developed and one that has been widely used is the classic work by Darley et al. (1969a) for perceptually judging the speech of adults with different types of dysarthria. In Darley et al.'s (1969a) protocol, speech production is judged according

to 38 dimensions related to respiration, phonation, articulation, resonance, and prosody using a 7-point equal-appearing interval scale (EAI, see section 1.3.1 in Chapter 1 for more information on the Darley et al. (1969a) protocol and section 1.5 for a discussion of scaling methods). Another frequently used perceptual protocol that has been specifically developed for evaluating phonation is the Consensus Auditory-Perceptual Evaluation of Voice (CAPE-V, Kempster et al., 2009). This protocol includes assessment of the most common atypical voice features (overall dysphonia rating, roughness, breathiness, strain, pitch and loudness) and the severity level is rated using VAS (Nemr et al., 2012).

As previously mentioned, research has shown that all five of the components of speech production can be affected in people with DS, with most studies reporting problems with articulation and voice quality using perceptual judgements (Bunton et al., 2007; Price, 1994; Van Borsel, 1996). As discussed in Chapter 1, articulatory difficulties such as imprecise consonants, reduced percent consonants correct (PCC), and reduced percent vowels correct (PVC) have been reported in this group (e.g. Jones et al., 2019; Wild et al., 2018; Wilson et al., 2019b). For phonation, observations such as roughness, hoarseness, and breathiness have been noted (e.g. Jones et al., 2019; Moura et al., 2008).

Some studies have also highlighted difficulties with prosody and resonance for speakers with DS, although findings are inconsistent in relation to the latter (Jones et al., 2019; Kline & Hutchinson, 1980; Montague & Hollien, 1973; Pettinato & Verhoeven, 2009; Rolfe et al., 1979; Stojanovik, 2011). However, most studies that have investigated the components of speech production in individuals with DS have done so by examining just one or two components in a single study. Little research has examined all five components of speech production for individuals with



DS, particularly adolescents and adults, in one single study. Furthermore, no research has compared the relative contribution of all five speech components to speech intelligibility in DS. The examination of all components allows for a profile of speech intelligibility to be identified for adolescents and adults with DS.

This current study aimed to address this gap in knowledge by investigating the contribution of each speech component to speech intelligibility in adolescents and adults with DS using perceptual analysis. A number of methods were used to perceptually evaluate each of the five major components of speech production and investigate their contribution to speech intelligibility. Due to the high number of studies evaluating articulation in DS and linking articulation with speech intelligibility, it was hypothesised that parameters pertaining to articulation would be strong contributors to speech intelligibility scores for the speakers with DS. The research questions for this study were as follows:

1. Which perceptual parameters are related to speech intelligibility in speakers with DS?
2. Which perceptual parameters of respiration, phonation, articulation, resonance, and prosody contribute to speech intelligibility in speakers with DS?

## **2.2 Method**

### **2.2.1 Participants**

Ethical approval was obtained from the Clinical Research Ethics Committee of the Cork Teaching Hospitals for this PhD project and all subsequent studies (Appendix A). Two groups of participants, speakers with DS and listeners who completed the judgement of speech intelligibility of the speakers, were involved in this study. The speakers were 30 adolescents and adults with DS aged 16 years and

over (14 males, 16 females, age range 16-47 years, mean age: 23;05 years). A sample size of 30 was chosen for this study as it is reflective of the sample sizes used in previous studies investigating speech production in individuals with DS (e.g. Barnes et al., 2009). All speakers had DS as the only diagnosis (i.e. no other diagnosis such as autism or attention deficit hyperactivity disorder); had no obvious structural abnormality as evaluated by an oro-motor exam (see section 2.2.6 for more information regarding oro-motor exam); and were within the mild-moderate range of cognitive impairment based on parent report and the records that they had. The speakers with DS were also monolingual Irish-English speakers and were able to communicate in spoken sentences. Furthermore, a background history regarding medical issues, schooling and previous SLT input was obtained from parents and/or carers for each speaker (see Appendix B for full details).

The listeners were 16 typical adults who were recruited to judge speech intelligibility for the group with DS. This sample size is comparable to previous studies that recruited a panel of listeners to judge speech intelligibility (e.g. Ellis & Fucci, 1991). The listeners were professionals (including SLTs, occupational therapists, and carers) working full-time with individuals who have speech difficulties, for a minimum of three years. Additionally, the listeners were monolingual Irish-English speakers and passed a hearing screen at 25 dBHL at 1000, 2000, and 4000 Hz in both ears.

### **2.2.2 Collection of speech data from the speakers with Down syndrome**

Informed consent was obtained for each speaker with DS prior to testing (see Appendix C). The entire protocol of perceptual evaluation of speech production was carried out by the investigator, an SLT experienced in the evaluation of speech disorders. Testing took place across two sessions lasting approximately 45 minutes

each. Session one involved a hearing test and administration of speech elicitation tasks which was carried out for all speakers in a sound-attenuated room in Brookfield Health Sciences Building, University College Cork. Testing for session two, which involved administration of various formal assessments, was carried out within speakers' local clinics or in the Brookfield Speech and Language Therapy Clinic in University College Cork. The speakers with DS received a voucher of €15 upon completion and the speakers and their parents were provided with a detailed summary report about their performance on all tasks. The research protocol was piloted in an earlier study (O'Leary, Lee, O'Toole, & Gibbon, 2019).

### **2.2.3 Perceptual analysis of speech components**

The materials, stimuli, and procedures for perceptually evaluating each of the five components of speech production are described in the following sections. See Figure 2-2 for a summary of the parameters used for perceptual analysis across each speech component, along with the speech elicitation tasks.

#### **2.2.3.1 *Respiration***

The perceptual evaluation of respiratory function for speech production was assessed using parameters from Darley et al.'s (1969a) protocol for evaluating respiration in dysarthric speech. The stimulus used was spontaneous speech which was elicited from each speaker by asking them to talk about a selection of daily life topics, including friends, families, school, and hobbies (Wilson et al., 2019b). The three parameters evaluated for respiration were forced inspiration/expiration, audible inspiration, and grunt at end of expiration. VAS was used for rating the severity level of each of the three parameters. As explained in Chapter 1, the VAS is a 100 mm line with descriptors on each end, in this case the left end represented "normal" and

the right end represented “severe.” A copy of the record form for the entire perceptual analysis is included in Appendix D.

#### **2.2.3.2 *Phonation***

The general procedure from the CAPE-V protocol (Kempster et al., 2009) was used to perceptually evaluate phonation. The protocol consisted of three speech tasks: the first was prolonged phonation of the vowel /a/, the second was repetition of six sentences containing various phonetic contrasts, and the third was spontaneous speech (Kempster et al., 2009). For the third task, the usual elicitation question “tell me about your voice problem” was not used as it was not deemed suitable for the speakers with DS. They may not have understood the question or it may not have been applicable to the speakers who did not have a voice difficulty. Hence, this was replaced by the spontaneous speech task described in section 2.2.3.1 above. The speakers’ voices were judged during the three tasks and the CAPE-V record form was completed. Using a VAS ranging from mildly deviant to severely deviant, a rating for five voice parameters—roughness, breathiness, strain, pitch and loudness—was given. The “overall dysphonia” parameter was not rated as it was viewed as too broad a measure that would not have contributed to identifying the specific parameters that contributed to speech intelligibility.

#### **2.2.3.3 *Articulation***

The “sounds-in-words” subtest from the Goldman-Fristoe Test of Articulation-3<sup>rd</sup> Edition (GFTA-3, Goldman & Fristoe, 2015) was used as the stimulus to evaluate the speakers’ articulation in order to obtain two measurements, PCC and PVC. This subtest consists of a single word picture naming task, which elicits all of the English speech sounds in each word position (word-initial, word-medial, and word-final). In line with the standard PCC calculation method and the

GFTA-3 manual, a production was considered inaccurate when the target sound was distorted, deleted, or substituted (Goldman & Fristoe, 2015; Shriberg, 1997a); see Table 2.1 for examples of these three error types.

The GFTA-3 record form was used to document speakers' productions of consonants and vowels for use in PCC and PVC calculation. Correct productions were not marked on the record form, that is, they were left blank. Any consonant produced in error was marked on the record form by striking through the target sound in the "IPA Transcription" column; and the type of error was then recorded in the "Initial," "Medial," and "Final" columns depending on the position of the sound within the target word. Substitutions were recorded by writing in the sound produced, omissions were recorded by writing in a dash (–), and distortions were recorded by transcribing the production using broad phonetic transcription.

A consonant cluster was counted as one item; hence, a cluster reduction event (e.g. the word "queen" /kwɪn/ produced as /kɪn/) would be counted as one error. If a speaker did not attempt to produce a target word, "NR" (no response) was recorded next to that target word. The number of target sounds not elicited was subtracted from the figure representing the total number of consonants produced. If a word was modelled by the examiner and the speaker repeated it, an "(i)" was recorded next to the word indicating that it was produced on imitation. The total number of errors marked in the "Initial," "Medial," and "Final" columns were added together and recorded in the box labelled "Total Raw Score.". This figure was subtracted from the total number of target consonants produced in the elicitation sample to obtain the total number of consonants produced correctly. The PCC was then calculated by

dividing the total number of consonants which were produced accurately by the total number of consonants produced (Shriberg & Kwiatkowski, 1982).

Vowel errors were documented by striking through the target sound in the “IPA Transcription” column of the record form and recording the productions in the “Response” column. The total number of vowel errors in the speech sample was recorded on the record sheet. The same method used for PCC was used for calculating the PVC except with consonants being replaced by vowels in the analysis. See Figure 2-1 for a full example of how the speech stimuli were marked and used to calculate the PCC and PVC for one speaker with DS (see Appendix E for the PCC and PVC calculations for all 30 speakers).

**Table 2.1.** *Examples of Error Types*

|                 | Target | Production | Error Classification   |
|-----------------|--------|------------|------------------------|
| <b>yellow</b>   | jɛlo   | lɛlo       | consonant substitution |
|                 |        | jælo       | vowel substitution     |
| <b>brushing</b> | bɪʌʃɪŋ | bʌʃɪŋ      | omission               |
| <b>house</b>    | haʊs   | haʊb       | distortion             |

# Sounds-in-Words (Ages 2:0-21:11)

| Item                               | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|------------------------------------|-------------|-------------------|----------|---------|--------|-------|
| 1                                  | house       | haʊs              |          | h       |        | /     |
| 2                                  | door        | dɔː               |          | d       |        | r     |
| 3                                  | pig         | pɪg               |          | p       |        | g     |
| 4                                  | cup         | kʌp               |          | k       |        | p     |
| 5                                  | boy         | bɔɪ               |          | b       |        |       |
| 6                                  | apple       | æpəl              |          |         | p      | l     |
| 7                                  | go          | go                |          | g       |        |       |
| 8                                  | duck        | dʌk               |          | /g      |        | k     |
| 9                                  | quack       | kʷæk              |          | /k      |        | k     |
| 10                                 | table       | tebəl             |          | t       | b      | l     |
| 11                                 | monkey      | mʌŋki             |          | m       | ŋ k    |       |
| 12                                 | hammer      | hæmə              |          | h       | m      | ə     |
| 13                                 | fish        | fɪʃ               |          | f       |        | ʃ     |
| 14                                 | watch       | wɒʃ               |          | w       |        | /b    |
| 15                                 | spider      | spaidə            |          | sp      | d      | ə     |
| 16                                 | web         | wɛb               |          | w       |        | b     |
| 17                                 | drum        | dʁʌm              |          | /d      |        | m     |
| 18                                 | plate       | plet              |          | pl      |        | t     |
| 19                                 | knife       | naɪf              |          | /n      |        | f     |
| 20                                 | shoe        | ʃu                |          | ʃ       |        |       |
| 21                                 | slide       | slaɪd             |          | sl      |        | d     |
| 22                                 | swing       | swɪŋ              |          | /s      |        | ŋ     |
| 23                                 | guitar      | ɡeɪtər            |          | /k      | t      | r     |
| 24                                 | lion        | laɪən             |          | l       |        | n     |
| 25                                 | chair       | tʃeə              |          | /t      |        | r     |
| 26                                 | soap        | sɒp               |          | s       |        | p     |
| 27                                 | glasses     | ɡlæsɪz            |          | /g      | s      | z     |
| 28                                 | tiger       | taɪgə             |          | /t      | g      | ə     |
| 29                                 | puzzle      | pʌzəl             |          | /p      | z      | l     |
| Items 1-29 Subtotals               |             |                   |          | 10      | 0      | 2     |
| 30                                 | finger      | ˈfɪŋɡə            |          | /b      | ŋ g    | ə     |
| 31                                 | ring        | rɪŋ               |          | r       |        | ŋ     |
| 32                                 | thumb       | θʌm               |          | θ       |        | /     |
| 33                                 | elephant    | ələˈfənt          | æ        |         | l f    | nt    |
| 34                                 | vacuum      | ˈvækjuəm          | (i)      | v       | /      | m     |
| 35                                 | shovel      | ˈʃʌvəl            | /s       | v       | l      |       |
| 36                                 | teacher     | ˈti:tʃə           |          | t       | tʃ     | ə     |
| 37                                 | zebra       | ˈzeɪbrə           |          | z       | br     |       |
| 38                                 | giraffe     | ˈdʒɪræf           | /d       | r       | f      |       |
| 39                                 | vegetable   | ˈvedʒtəbəl        | /b       | s t     | l      |       |
| 40                                 | brushing    | ˈbrʌʃɪŋ           |          | br      | ʃ      | ŋ     |
| 41                                 | blue        | blu               |          | bl      |        |       |
| 42                                 | yellow      | ˈjeləʊ            | /l       | l       |        |       |
| 43                                 | brother     | ˈbrʌðə            |          | br      | ð      | ə     |
| 44                                 | frog        | fɹɒɡ              | /f       |         | g      |       |
| 45                                 | green       | ɡriːn             | /g       |         | n      |       |
| 46                                 | that        | ðæt               | (i)      | ð       | t      |       |
| 47                                 | leaf        | liːf              |          | l       | f      |       |
| 48                                 | cookie      | ˈkʊki             |          | k       | k      |       |
| 49                                 | cheese      | tʃiːz             | /t       |         | z      |       |
| 50                                 | pajamas     | ˈpædʒəmeɪz        | /b       | a m     | z      |       |
| 51                                 | teeth       | tiːθ              |          | t       | θ      |       |
| 52                                 | princess    | ˈprɪnsɪs          | /p       | n       | s      |       |
| 53                                 | crown       | kraʊn             |          | kr      |        | n     |
| 54                                 | truck       | trʌk              | /t       |         | k      |       |
| 55                                 | red         | red               |          | r       | d      |       |
| 56                                 | juice       | dʒʊːs             | /d       |         | s      |       |
| 57                                 | zoo         | zuː               | /s       |         |        |       |
| 58                                 | star        | stɑː              |          | st      | r      |       |
| 59                                 | five        | faɪv              |          | f       | v      |       |
| 60                                 | seven       | ˈsevn             | /s       | v       | n      |       |
| Items 30-60 Subtotals              |             |                   |          | 15      | 6      | 1     |
| Transfer Items 1-29 Subtotals here |             |                   |          | 10      | 0      | 2     |
| Total Raw Score                    |             |                   |          | 34      |        |       |

3 vowel errors.

|                                                   |            |
|---------------------------------------------------|------------|
| Percent Consonants Correct (PCC)                  |            |
| (a) Total number of target consonants             | <b>141</b> |
| (a) Number of consonants not elicited             | 0          |
| (b) Total number of consonants elicited (a) – (b) | 141        |
| (c) Total number of consonants in error           | 34         |
| (d) Total consonants correct (c) – (d)            | 107        |
| (e) PCC: (e) ÷ (c) x 100                          | 76         |
| Percent Vowels Correct (PVC)                      |            |
| (a) Total number of target vowels                 | <b>88</b>  |
| (b) Number of vowels not elicited                 | 0          |
| (c) Total number of vowels elicited (a) – (b)     | 88         |
| (d) Total number of vowels in error               | 3          |
| (e) Total vowels correct (c) – (d)                | 85         |
| (f) PVC: (e) ÷ (c) x 100                          | 97         |

**Figure 2-1.** Example of a Completed Record Form (from GFTA-3) for Consonant and Vowel Evaluation with PCC and PVC Calculation.

#### 2.2.3.4 Resonance

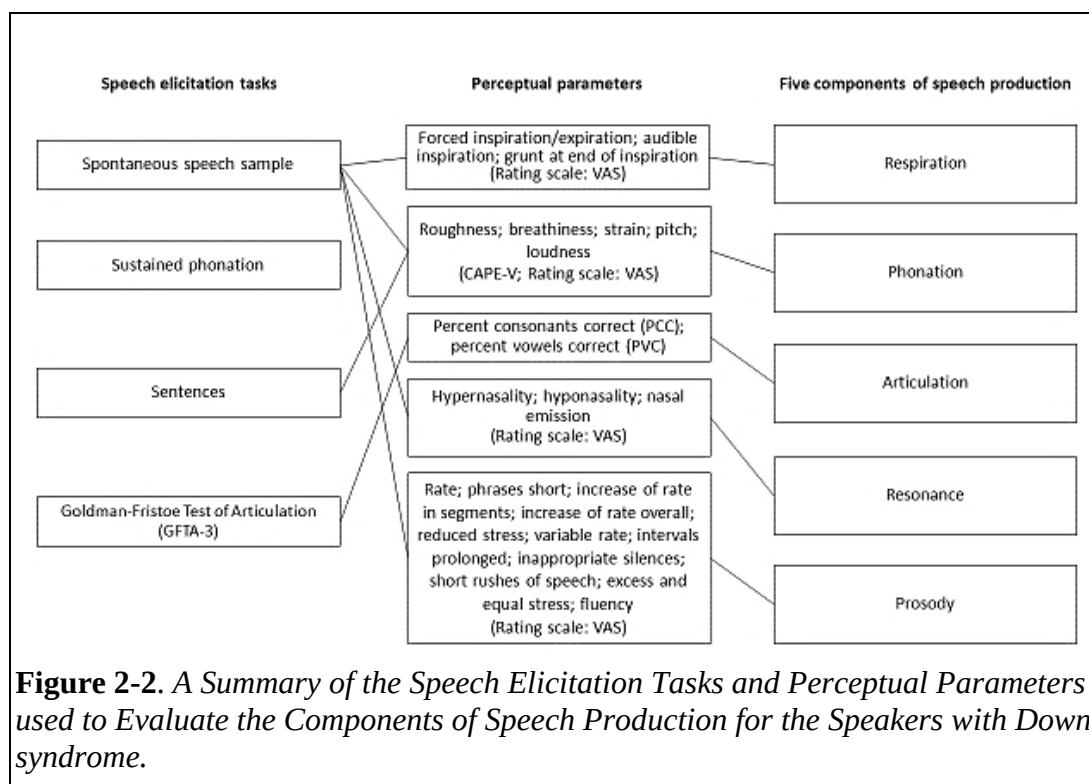
Similar to respiration, the Darley et al. (1969a) protocol was employed to evaluate resonance from a spontaneous speech sample. The parameters evaluated were hypernasality, hyponasality, and nasal emissions and VAS was employed to perceptually evaluate the severity of each. Also similar to respiration, the left end of the VAS represented “normal” and the right end represented “severe.”

#### 2.2.3.5 Prosody

Darley et al.’s (1969a) protocol was also used for analysing prosody of spontaneous speech. Ten aspects of prosody pertaining to pitch, loudness, speech rate and stress were evaluated using VAS. As a general measure of fluency, an additional VAS was completed to give a broad indication of the speakers’ fluency.



Similar to the method used for evaluating respiration and resonance, the left end of each VAS evaluating prosody was labelled as “normal” and the right end as “severe.” Figure 2-2 summarises the parameters used for perceptual analysis across each speech component.



#### 2.2.4 Elicitation of sentences for measuring speech intelligibility

In order to measure speech intelligibility, the speakers with DS repeated sentences taken from the Assessment of Intelligibility of Dysarthric Speech (ASSIDS, Yorkston & Beukelman, 1984). The general procedure for administering the assessment was followed according to the test manual. Typically, in the ASSIDS, sentences up to 15 words in length are elicited but, for this study, sentences over 10 words in length were deemed too lengthy for the speakers with DS to repeat. Hence, twelve sentences were recorded by each speaker: two sentences five words in length, two sentences six words in length, up to two sentences ten words long. Sentences

that the speakers had difficulty repeating were replaced by another one of the same sentence length randomly selected from the sentence pool according to the manual.

### **2.2.5 Procedure for measuring hearing acuity**

As discussed in Chapter 1, there is a high prevalence rate of hearing difficulties in DS. Hence, the hearing level of each speaker was obtained to gain a general indication of hearing acuity on the same day as completing the speech elicitation tasks. Hearing acuity was also used in analyses to examine if hearing difficulties impacted on their speech intelligibility. An experienced audiologist obtained speakers' pure tone average for each ear in decibel hearing levels (dBHL) for frequencies 500, 1000, 2000, 4000 and 8000 Hz. The speakers who regularly wore hearing aids were tested in the free field while wearing their hearing aids in order to obtain a measure of hearing acuity reflective of their everyday life. The hearing acuity of each speaker was calculated by obtaining the mean dBHL across both ears.

### **2.2.6 Procedure for measuring oro-motor function**

In addition to hearing difficulties, people with DS can also have impaired oro-motor skills (see section 1.7.5 in Chapter 1). Therefore, the speakers' oro-motor structure was examined to eliminate any structural abnormality such as cleft palate in accordance with the study inclusionary criteria; and their oro-motor function was evaluated in order to gain an idea of the speakers' oro-motor ability at the time of testing. Oro-motor structure and function was assessed using the Oral Speech Motor Protocol (Robbins & Klee, 1987). This assessment has been used to evaluate oro-motor function for those with DS in previous studies (e.g. Barnes et al., 2006; Cleland et al., 2010). It evaluates the structure and function of the lips, mandible, maxilla, teeth, tongue, velopharynx, and larynx through a variety of tasks. The Oral

Speech Motor Protocol also assesses the accuracy and precision of co-ordinated speech movements along with aspects of prosody and voice. The assessment allows for verbal, visual, and auditory cues to be given to the person being tested, as well as allowing up to three attempts for tasks to be completed. For scoring oro-motor function, items were given a score of 2 for “adult-like,” 1 for “emerging,” and 0 for “absent.” Speakers’ total oro-motor function scores out of a possible 112 were calculated.

### **2.2.7 Preparation of sound files for listening task**

The speech samples of the speakers with DS were edited using Praat software version 6.1.04 (Boersma & Weenink, 2019) and each sentence produced by each speaker was saved as a single sound file. Hence, 12 sentences from each of the 30 speakers resulted in 360 sentences in total. As it would be impractical for each listener to judge that amount of audio files, the sentence stimuli were pooled and divided into eight lists. Each of the eight sentence lists contained three sentences controlled for sentence length from half of the 30 speakers, making up 45 sentences. See Figure 2-3 for the procedure that was used to allocate the sentences from each speaker into eight sentence lists. PowerPoint presentation was used for presenting the sentence lists. Eight PowerPoint files, one for each sentence list, were created with each presentation containing the task instructions and each audio file embedded in a single slide.

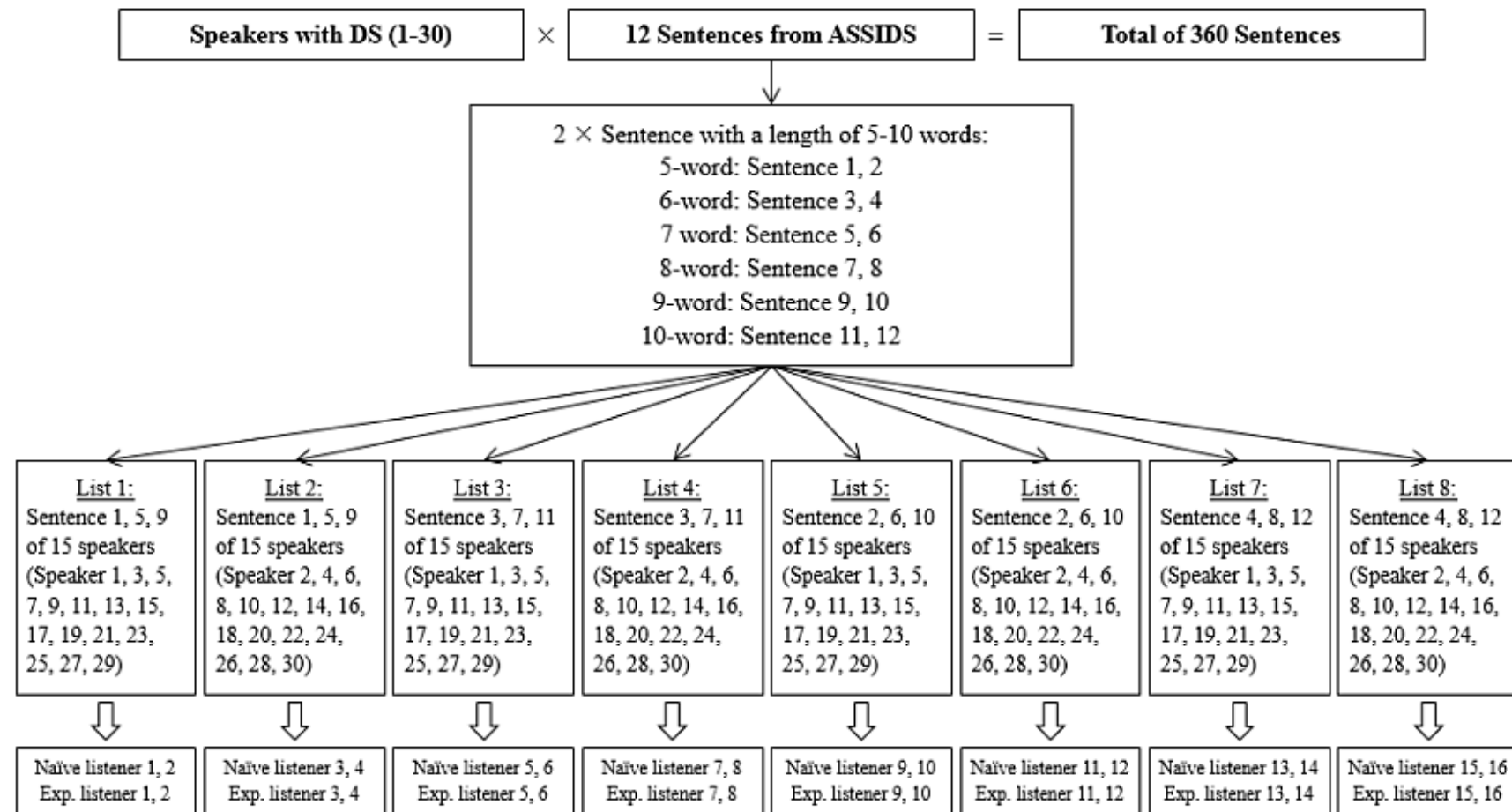


**Figure 2-3.** An Overview of the Procedure used for Allocating Speakers' Sentences into Eight Lists for the Listening Task.

### **2.2.8 Procedure for listeners**

Each of the 16 listeners was randomly assigned a sentence list to judge. Hence, each sentence list was judged by two listeners and each speaker was heard by eight listeners (Figure 2-3). For this study, the speech intelligibility score for each speaker was obtained based on an orthographic transcription task. The listening task was administered in a quiet room within the Department of Speech and Hearing Sciences or in the listener's place of work. Sentences were presented via a laptop and headphones. The listeners were instructed to listen to each sentence and write down what they thought they had heard. The listeners were encouraged to guess if they were unsure and could choose to listen to each sentence one more time before moving on to the next item (Yorkston & Buekelman, 1981). The investigator was present with each listener at all times to ensure that they followed the listening task instructions and in case there were any issues.

### **2.2.9 Data analysis**

In order to obtain the scores for each perceptual parameter across each speaker, a ruler was used to measure the distance from the left end of the VAS to the mark made by the investigator. A second investigator, who was an SLT experienced in listening to speech impairments and was not familiar with the study, listened to the speech samples from three speakers (10%) who were randomly selected. The second investigator evaluated the speech samples according to all of the perceptual analysis methods described above in section 2.2.3. To measure inter-rater reliability, the percentage agreement score for each parameter was calculated by dividing the smaller rating score from one judge by the larger rating from the other judge, and multiplying by 100 (e.g. Karimi et al., 2014).

To calculate the speech intelligibility scores, a similar scoring system to that of

Stipancic et al. (2016) was used to score the listeners' orthographic transcriptions. Homophones (e.g. "right" for "write") and phonetically correct errors (e.g. "tyes" for "ties") were scored as correct. Incorrect plurals (e.g. "cat" for "cats") and tense markers (e.g. "stays" for "stayed") were scored as incorrect. A single speech intelligibility score was derived for each speaker. The score was calculated by dividing the number of correctly transcribed words by the total number of target words.

Using the Statistical Package for the Social Sciences (version 26), a number of analyses were carried out with the collected data. Histograms and Q-Q plots were visually inspected to determine if normal distribution of the data could be assumed. Scatterplots and regression with quadratic curve estimation were utilised to determine if the relationship between speech intelligibility and each perceptual parameter was linear. Spearman rank-order correlations analysis was carried out to examine the relationship between each perceptual parameter and speech intelligibility scores. In addition, stepwise multiple regression analysis with blockwise entry methods was carried out to investigate the perceptual parameters that contributed to speech intelligibility. Correlation analysis was carried out first to identify the parameters that were related to speech intelligibility because it was possible that not all of the parameters that were related to speech intelligibility would get into a final regression model (Field, 2018). For the regression, the dependent variable was the speech intelligibility score and the independent variables were all of the perceptual parameters that have been outlined above. As hearing loss is common in people with DS and can impact on speech production, it was adjusted for by inserting the speakers' hearing acuity scores into the first block of the regression model. All independent variables were then inserted into the second block of the

regression model where stepwise selection was performed. When the model was devised, diagnostic tests were carried out to ensure that the data met the following assumptions for stepwise regression (Cohen, Cohen, West, & Aiken, 2003; Field, 2018):

1. There must be a linear relationship between the dependent variable and each of the independent variables. Linearity was checked by examining the residual plots of the regression model.
2. There should be a lack of autocorrelation among the model residuals. That is, the residuals of the regression model should be independent of each other. Autocorrelation was checked by means of the Durbin-Watson test.
3. The variance of the regression model residuals cannot differ across the independent variables; this is known as heteroscedasticity. The Breusch-Pagan test was used to check for this assumption.
4. The residuals of the regression model must be normally distributed. Normality was checked for by plotting the predicted residual values of the model on the x-axis against the standardised residuals on the y-axis.
5. The independent variables cannot be highly correlated with each other, or a single independent variable cannot be predicted by a linear combination of other independent variables; this is referred to as multicollinearity. The presence of multicollinearity was checked for by examining the variance inflation factors (VIF) for each independent variable that emerged from the regression model.

## **2.3 Results**

### **2.3.1 Analysis of perceptual parameters**

Table 2.2 outlines the number of speakers for which each parameter was observed in their speech and the severity range for each parameter. The most common features were PCC less than 100 (93%), roughness (77%), atypical pitch (70%), and problems with fluency (70%). In terms of severity, the features that certain speakers had most difficulty with were fluency (maximum severity: 88 out of 100), breathiness (maximum severity: 80 out of 100), roughness (maximum severity: 77 out of 100), and strain (maximum severity: 76 out of 100). Fourteen parameters were found to have mostly zero scores across speakers (for PVC, most speakers had scores of 100). That is, these 14 parameters were judged to be normal for the majority of speakers. These were forced inspiration/expiration, audible inspiration, grunt at end of expiration, hypernasality, hyponasality, nasal emission, excess and equal stress, reduced stress, rate slow/fast, short phrases, increased rate overall, variable rate, prolonged intervals, and inappropriate silences.



**Table 2.2.** *The Frequency of the Presence of Each Parameter along with Severity Range across the Speakers with Down syndrome as Rated by the Investigator*

| Perceptual parameter           | Number of speakers | Percentage of speakers (%) | Severity range |
|--------------------------------|--------------------|----------------------------|----------------|
| Respiration                    |                    |                            |                |
| Forced inspiration/ expiration | 2                  | 7                          | 0-34           |
| Audible inspiration            | 9                  | 30                         | 0-38           |
| Grunt at end of expiration     | 0                  | 0                          | 0              |
| Phonation                      |                    |                            |                |
| Breathiness                    | 14                 | 47                         | 0-80           |
| Roughness                      | 23                 | 77                         | 0-77           |
| Strain                         | 14                 | 47                         | 0-76           |
| Pitch                          | 21                 | 70                         | 0-69           |
| Loudness                       | 8                  | 27                         | 0-44           |
| Articulation                   |                    |                            |                |
| PCC < 100                      | 28                 | 93                         | 76-99          |
| PVC < 100                      | 6                  | 20                         | 96-100         |
| Resonance                      |                    |                            |                |
| Hypernasality                  | 4                  | 13                         | 0-54           |
| Hyponasality                   | 7                  | 23                         | 0-68           |
| Nasal emission                 | 6                  | 20                         | 0-39           |
| Prosody                        |                    |                            |                |
| Excess and equal stress        | 3                  | 10                         | 0-51           |
| Reduced stress                 | 10                 | 33                         | 0-61           |
| Rate slow/fast                 | 9                  | 30                         | 0-74           |
| Short phrases                  | 6                  | 20                         | 0-54           |
| Increased rate in segments     | 13                 | 43                         | 0-74           |
| Increased rate overall         | 2                  | 7                          | 0-29           |
| Variable rate                  | 7                  | 23                         | 0-64           |
| Prolonged intervals            | 4                  | 13                         | 0-44           |
| Inappropriate silences         | 3                  | 10                         | 0-74           |
| Short rushes of speech         | 14                 | 47                         | 0-74           |
| Fluency                        | 21                 | 70                         | 0-88           |

*Note.* PCC = percent consonants correct; PVC = percent vowels correct.

### 2.3.2 Speech intelligibility, hearing acuity and oro-motor function for the speakers with Down syndrome

The speech intelligibility scores, as measured by orthographic transcription, ranged from 21-98%, with over half of the speakers having scores above 80%.

Hearing acuity scores ranged from 5-47 dBHL, indicating that some speakers had no difficulty with hearing, while others had mild to moderate hearing loss. Table 2.3 presents the speakers' intelligibility scores and hearing acuity. Table 2.4 summarises the oro-motor function scores for each speaker with DS. Total oro-motor function scores ranged from 89-111 out of a possible 112, indicating that all the speakers had some difficulty with oro-motor function. The main areas of difficulty were with co-ordinated speech movements.

**Table 2.3.** *Speech Intelligibility Scores and Hearing Acuity for Speakers with Down syndrome (DS)*

| Speaker with DS | Speech intelligibility score | Hearing acuity (dBHL) |
|-----------------|------------------------------|-----------------------|
| 1               | 68%                          | 38                    |
| 2               | 94%                          | 13                    |
| 3               | 84%                          | 33                    |
| 4               | 97%                          | 47                    |
| 5               | 91%                          | 20                    |
| 6               | 45%                          | 13                    |
| 7               | 66%                          | 30                    |
| 8               | 48%                          | 36                    |
| 9               | 27%                          | 33                    |
| 10              | 58%                          | 25                    |
| 11              | 44%                          | 30                    |
| 12              | 71%                          | 32                    |
| 13              | 98%                          | 16                    |
| 14              | 88%                          | 33                    |
| 15              | 93%                          | 17                    |
| 16              | 32%                          | 20                    |
| 17              | 90%                          | 22                    |
| 18              | 93%                          | 38                    |
| 19              | 40%                          | 23                    |
| 20              | 87%                          | 28                    |
| 21              | 81%                          | 24                    |
| 22              | 86%                          | 31                    |
| 23              | 85%                          | 24                    |
| 24              | 88%                          | 33                    |
| 25              | 87%                          | 26                    |
| 26              | 87%                          | 9                     |
| 27              | 98%                          | 18                    |
| 28              | 73%                          | 14                    |
| 29              | 41%                          | 5                     |
| 30              | 88%                          | 15                    |

*Note.* dBHL = decibels hearing level.

**Table 2.4.** *Oro-motor Function Scores for the Speakers with Down syndrome as Measured by the Robbins and Klee Oral Speech Motor Protocol*

| Speaker | Lips<br>(28, 24-28) | Mandible<br>(2, 1-2) | Tongue<br>(16, 14-16) | Velopharynx<br>(8, 7-8) | Larynx<br>(8, 4-8) | Co-ordinated<br>speech<br>(38, 21-38) | Speech<br>sample<br>(12, 5-12) | Total oro-motor<br>function<br>(112, 89-111) |
|---------|---------------------|----------------------|-----------------------|-------------------------|--------------------|---------------------------------------|--------------------------------|----------------------------------------------|
| 1       | 27                  | 2                    | 16                    | 8                       | 8                  | 35                                    | 10                             | 106                                          |
| 2       | 28                  | 2                    | 16                    | 8                       | 6                  | 36                                    | 9                              | 105                                          |
| 3       | 28                  | 2                    | 16                    | 8                       | 8                  | 34                                    | 11                             | 107                                          |
| 4       | 27                  | 2                    | 16                    | 8                       | 8                  | 31                                    | 12                             | 104                                          |
| 5       | 25                  | 2                    | 14                    | 8                       | 8                  | 32                                    | 9                              | 98                                           |
| 6       | 27                  | 2                    | 15                    | 8                       | 6                  | 21                                    | 8                              | 97                                           |
| 7       | 26                  | 2                    | 16                    | 8                       | 8                  | 32                                    | 9                              | 99                                           |
| 8       | 27                  | 2                    | 16                    | 8                       | 6                  | 31                                    | 9                              | 90                                           |
| 9       | 26                  | 2                    | 15                    | 7                       | 4                  | 33                                    | 5                              | 90                                           |
| 10      | 27                  | 2                    | 14                    | 8                       | 7                  | 37                                    | 8                              | 95                                           |
| 11      | 25                  | 1                    | 14                    | 8                       | 7                  | 23                                    | 11                             | 89                                           |
| 12      | 28                  | 2                    | 16                    | 8                       | 8                  | 36                                    | 11                             | 106                                          |
| 13      | 28                  | 2                    | 16                    | 8                       | 8                  | 36                                    | 9                              | 107                                          |
| 14      | 27                  | 2                    | 15                    | 8                       | 8                  | 35                                    | 11                             | 106                                          |
| 15      | 26                  | 2                    | 16                    | 8                       | 8                  | 37                                    | 12                             | 107                                          |
| 16      | 27                  | 2                    | 16                    | 8                       | 8                  | 36                                    | 11                             | 108                                          |
| 17      | 28                  | 2                    | 16                    | 8                       | 8                  | 35                                    | 12                             | 109                                          |
| 18      | 24                  | 2                    | 16                    | 8                       | 8                  | 37                                    | 12                             | 107                                          |
| 19      | 24                  | 2                    | 14                    | 8                       | 8                  | 33                                    | 10                             | 99                                           |
| 20      | 26                  | 2                    | 15                    | 8                       | 7                  | 36                                    | 10                             | 105                                          |

|    |    |   |    |   |   |    |    |     |
|----|----|---|----|---|---|----|----|-----|
| 21 | 27 | 2 | 15 | 8 | 8 | 35 | 11 | 106 |
| 22 | 28 | 2 | 15 | 8 | 7 | 36 | 10 | 106 |
| 23 | 25 | 2 | 15 | 8 | 6 | 36 | 10 | 102 |
| 24 | 26 | 2 | 16 | 8 | 7 | 37 | 9  | 105 |
| 25 | 24 | 2 | 16 | 8 | 7 | 37 | 9  | 103 |
| 26 | 25 | 2 | 15 | 8 | 8 | 35 | 10 | 103 |
| 27 | 28 | 2 | 16 | 8 | 8 | 37 | 12 | 111 |
| 28 | 26 | 2 | 15 | 8 | 7 | 35 | 10 | 103 |
| 29 | 26 | 2 | 14 | 8 | 8 | 35 | 11 | 104 |
| 30 | 24 | 2 | 16 | 8 | 5 | 38 | 5  | 98  |

*Note.* Numbers in brackets represent total possible score and range of speaker scores respectively for each test component.

### **2.3.3 Perceptual parameters that are related to speech intelligibility in speakers with Down syndrome**

Visual inspection of the histograms and Q-Q plots for each perceptual parameter showed that the ratings were not normally distributed (Appendix F); hence, Spearman rank-order correlations was used to examine the relationship between the perceptual parameters and speech intelligibility. Table 2.5 shows the results of the correlation analysis. Three parameters, PCC, breathiness, and short phrases, were found to be significantly related to speech intelligibility scores for the speakers with DS.

**Table 2.5.** *Spearman Rank-order Correlation Results for the Relationship between Each Perceptual Parameter and Speech Intelligibility*

| Perceptual parameter          | Spearman $r_s$ |
|-------------------------------|----------------|
| Forced inspiration/expiration | −0.06          |
| Audible inspiration           | 0.23           |
| Breathiness                   | −0.53**        |
| Roughness                     | −0.09          |
| Strain                        | −0.08          |
| Pitch                         | 0.04           |
| Loudness                      | −0.21          |
| PCC < 100                     | 0.63***        |
| PVC < 100                     | −0.09          |
| Hypernasality                 | 0.09           |
| Hyponasality                  | −0.13          |
| Nasal emission                | −0.09          |
| Excess and equal stress       | −0.23          |
| Reduced stress                | −0.20          |
| Rate slow/fast                | −0.24          |
| Short phrases                 | −0.47**        |
| Increased rate - segments     | −0.27          |
| Increased rate - overall      | −0.09          |
| Variable rate                 | −0.06          |
| Prolonged intervals           | −0.26          |
| Inappropriate silences        | −0.33          |
| Short rushes of speech        | −0.29          |
| Fluency                       | −0.29          |

*Note.* PCC = percent consonants correct; PVC = percent vowels correct.

\*\* $p < .01$ . \*\*\* $p < .001$ .

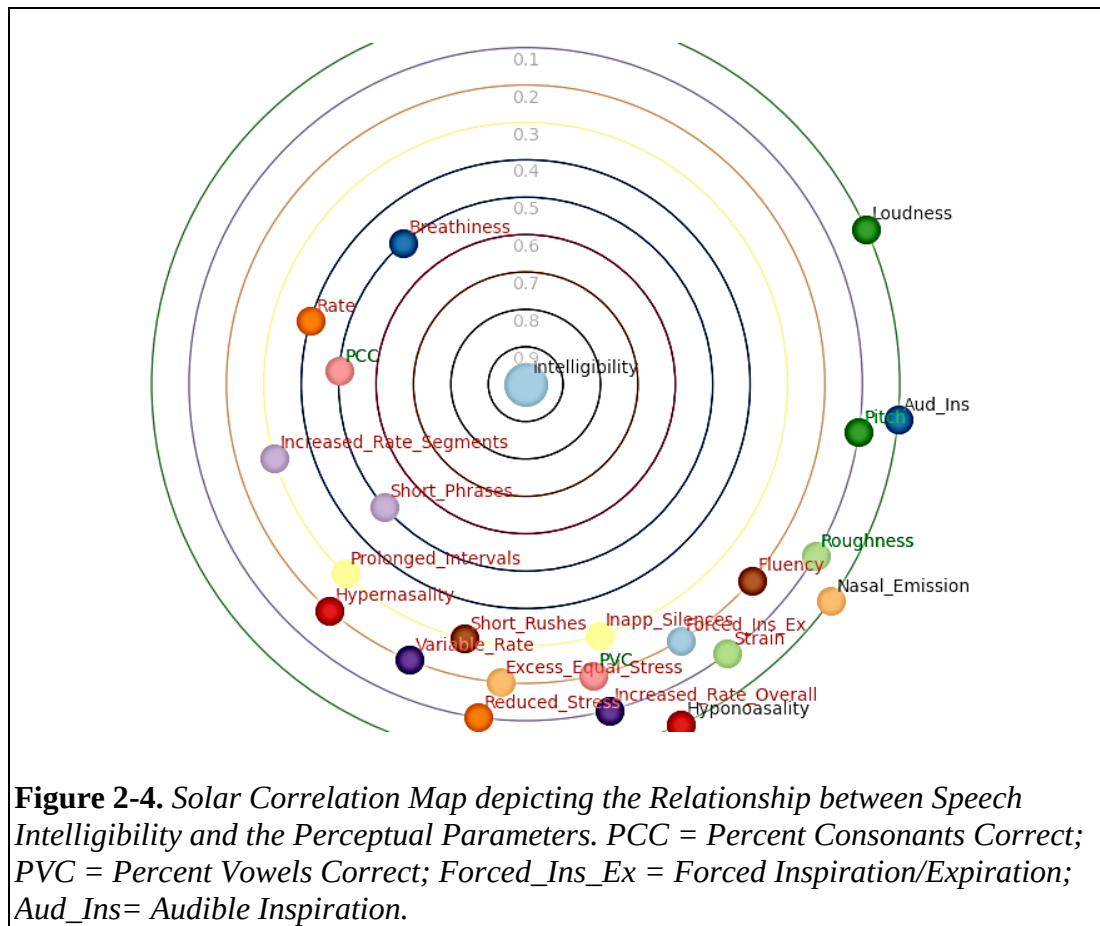


Figure 2-4 depicts a visual representation of the relationship between speech intelligibility and the perceptual parameters via a solar correlation map. In the solar correlation map, speech intelligibility is at the centre of the solar system and the perceptual parameters are depicted as planets in various orbits around speech intelligibility. Each orbit represents a Spearman  $r_s$  coefficient (e.g. 0.1, 0.2, 0.3, etc.). The closer the perceptual parameter is to the centre (the closer the orbit), the higher the Spearman  $r_s$  coefficient and the stronger its relationship to the speech intelligibility. The parameters labelled in green text represent a positive relationship with the speech intelligibility and those in red text represent a negative relationship. The correlation map shows that breathiness, PCC, and short phrases were most strongly associated with speech intelligibility scores as they are in orbit closest to the centre. PCC is labelled in green which indicates a positive relationship with speech



intelligibility in that as PCC scores increased, so did speech intelligibility scores. Breathiness and short phrases are labelled in red which indicates a negative relationship with speech intelligibility. That is, as scores for breathiness and short phrases increased (i.e. were perceived as more severe), speech intelligibility scores decreased.

The proximity of perceptual parameters to each other in orbit represents their correlation with each other. That is, if an inter-correlation greater than 0.8 is present among two parameters, the parameter with the strongest correlation to speech intelligibility becomes a planet and the other becomes its moon. However, in this case, there was no inter-correlation greater than 0.8 among the perceptual parameters in this study, hence, there are no moons (see Appendix G for correlation results).

#### **2.3.4 Perceptual parameters of speech production that contributed to speech intelligibility in the speakers with Down syndrome**

Stepwise multiple regression was carried out to examine which perceptual parameters (independent variables) contributed to speech intelligibility (dependent variable) for the speakers with DS. As reported in section 2.3.1 above, most of the speakers had a score of zero for 14 of the perceptual parameters (forced inspiration/expiration, audible inspiration, grunt at end of expiration, hypernasality, hyponasality, nasal emission, excess and equal stress, reduced stress, rate slow/fast, short phrases, increased rate overall, variable rate, prolonged intervals, and inappropriate silences). Therefore, these parameters were recoded into binary variables: “0” to indicate if the feature was absent and “1” to indicate if the feature was present (Lavrakas, 2008). The parameter “grunt at end of expiration” was given a rating score of zero for all of the 30 speakers; hence, it was excluded from further analysis. Examination of scatterplots and regression with quadratic curve estimation

showed that the relationship between most independent variables and the dependent variable was roughly linear (Appendix H). However, a significant negative quadratic relationship was found for breathiness and a significant positive quadratic relationship for PCC. Hence, these variables were entered with a quadratic term into the regression model to represent the changing slope of the relationship over the range of speech intelligibility scores (Hair, 2019). The quadratic term was obtained by squaring the original variable. Points of high leverage were also-checked for validity and no changes were made to the data after examination. Table 2.6 and Table 2.7 summarise the results of the regression.

**Table 2.6.** *Summary of Regression Model for Study 1*

| Model | Variables                                                                            | $R^2$ | Adjusted $R^2$ | $R^2$ Change | $F$ Change | Sig  |
|-------|--------------------------------------------------------------------------------------|-------|----------------|--------------|------------|------|
| 1     | Hearing acuity                                                                       | 0.01  | -0.03          | 0.01         | 0.16       | 0.69 |
| 2     | Hearing acuity<br>Breathiness<br>Breathiness <sup>2</sup>                            | 0.38  | 0.30           | 0.37         | 7.67       | 0.00 |
| 3     | Hearing acuity<br>Breathiness<br>Breathiness <sup>2</sup><br>PCC<br>PCC <sup>2</sup> | 0.69  | 0.64           | 25.49        | 0.00       | 0.00 |

*Note.* Sig = significance level; PCC = percent consonants correct.

**Table 2.7.** *Coefficients of Regression Model for Study 1*

| Variable                 | $B$   | Standard error | $T$   | Sig  | VIF  |
|--------------------------|-------|----------------|-------|------|------|
| Hearing acuity           | 0.08  | 0.41           | 0.40  | 0.74 | 1.11 |
| Breathiness <sup>2</sup> | -0.01 | 0.00           | -5.87 | 0.00 | 1.04 |
| PCC <sup>2</sup>         | 0.01  | 0.00           | 5.13  | 0.00 | 1.07 |

*Note.* Sig = significance level; VIF = variance inflation factor; PCC<sup>2</sup> = percent consonants correct squared.

The results of the regression indicated that hearing acuity and two independent variables, breathiness and PCC, together explained 64% of the variance in speech intelligibility scores (adjusted  $R^2 = 0.64$ ,  $F(5, 29) = 11.32$ ,  $p = 0.00$ ). These

results indicate that, due to the quadratic effect of breathiness, there was little or no change in speech intelligibility scores when breathiness scores were low, but a larger decrease in intelligibility scores occurred when breathiness scores increased by 20-60. For PCC, there was little or no change in speech intelligibility scores when PCC scores were greater than 97, but a larger decrease in intelligibility scores when PCC scores decreased below 95. Hearing did not significantly contribute to intelligibility scores; in fact, the *R*-square value was zero. When hearing was removed from the model, breathiness and PCC were still the main contributors to intelligibility scores: adjusted  $R^2 = 0.67$ .

### **2.3.5 Inter-rater reliability**

A mean percentage agreement score of 93% was obtained across the perceptual parameters between the first and second investigator (see Appendix I for a full summary of the percentage agreement scores).

### **2.3.6 Diagnostic tests for regression model**

**Assumption 1:** The scatterplots in Figure 2-5 show the residuals on the y-axis plotted against each of the contributing variables (hearing acuity, breathiness, and PCC) on the x-axis. The scatterplots show that there is no clear pattern among the residuals; hence, a linear relationship can be assumed between the dependent variables and the contributing independent variables.

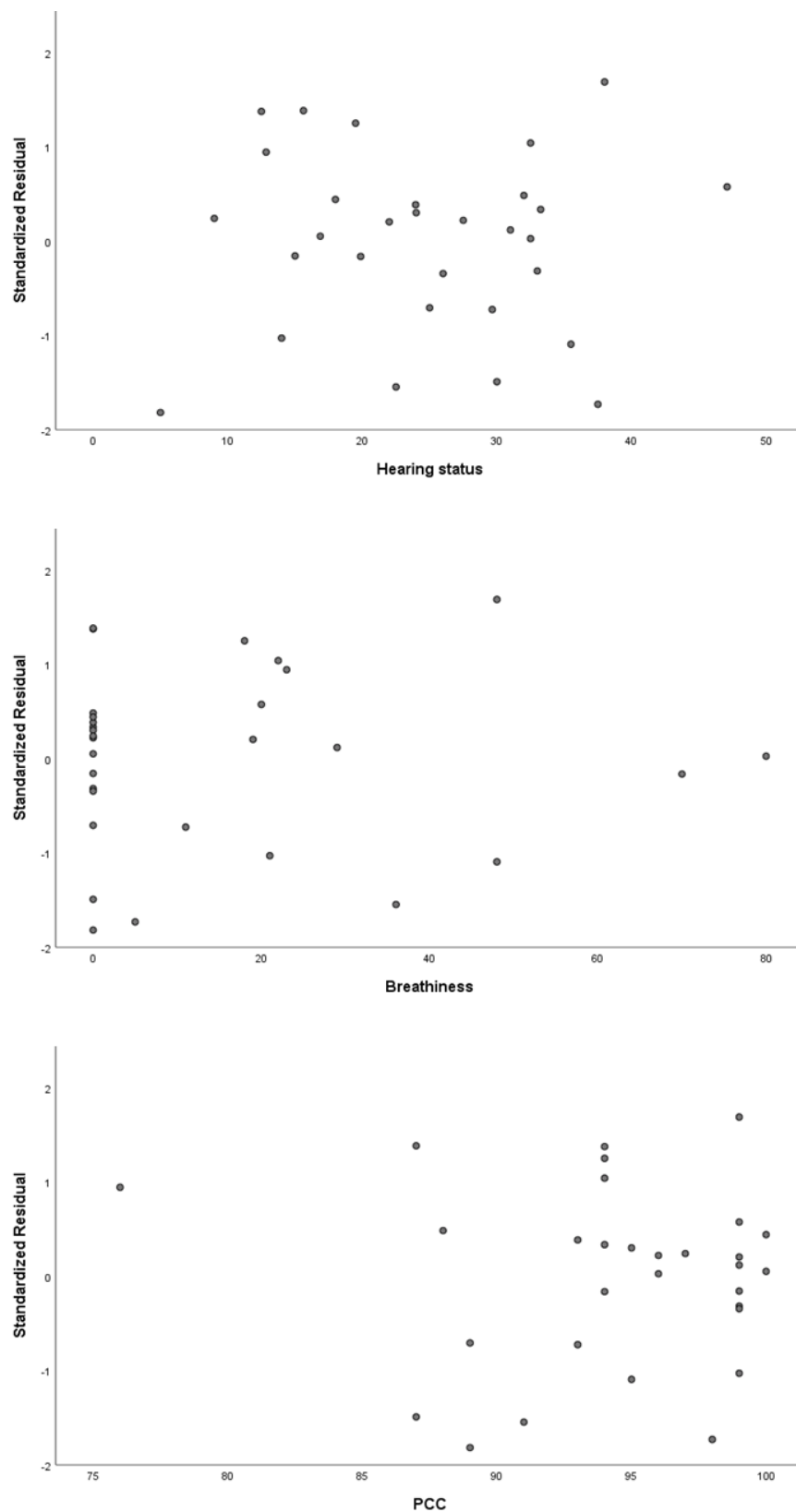


**Figure 2-5.** Scatterplots of the Standardised Residuals as a Function of the Contributor Variables for Study 1. PCC = Percent Consonants Correct.

**Assumption 2:** The result of the Durbin-Watson test was 1.75. As this value is close to 2, we can assume that the residuals of the regression model are not highly correlated with each other (Field, 2018).

**Assumption 3:** The Breusch-Pagan test for heteroscedasticity resulted in a chi-square value of 0.86,  $p = 0.35$ . As this is above the significance level of 0.05, we can reject the null hypothesis that heteroscedasticity exists in the residual of the regression model.

**Assumption 4:** Figure 2-6 plots the predicted residual values on the x-axis against the standardised residuals on the y-axis. The scatterplot follows a straight line which indicates that the residuals of the model are normally distributed.

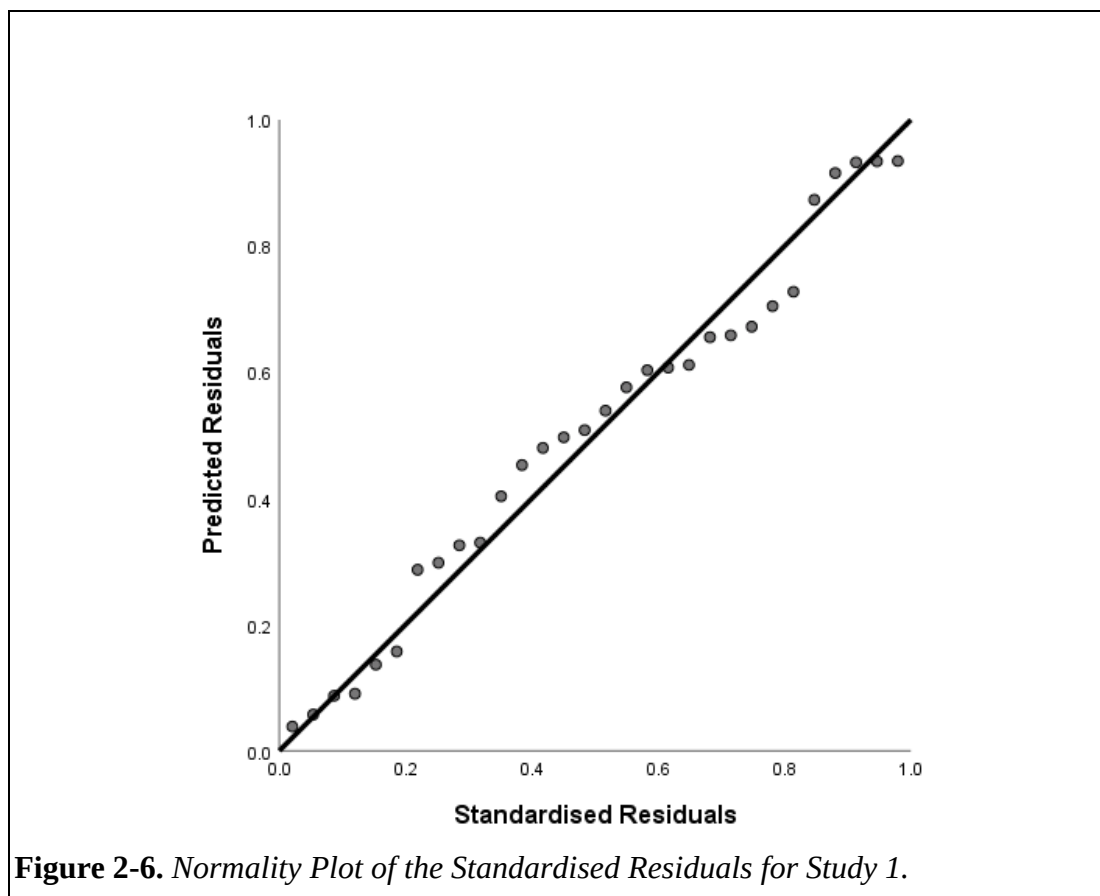


**Figure 2-6.** *Normality Plot of the Standardised Residuals for Study 1.*

**Assumption 5:** The VIFs for each independent variable are well below 10 (see Table 2.6) which indicates a low risk of multicollinearity within the data (Hair, 2019).

### **2.3.7 Summary of results**

The results of the study show that out of the perceptual parameters representing each of the five components of speech production, breathiness and PCC strongly contributed to speech intelligibility for the speakers with DS. Hearing acuity did not contribute to speech intelligibility. Furthermore, there was a quadratic relationship between both speech intelligibility and breathiness, and speech intelligibility and PCC scores. This indicates that the relationship changed over a range of scores. When breathiness scores were low, speech intelligibility scores did not change, however, once breathiness scores reached 20 out of 100 or over (i.e. more breathiness was observed), speech intelligibility scores began to decrease. The opposite was true for PCC scores. When PCC scores were high, approximately 95% or more, speech intelligibility scores remained constant. But, when PCC scores decreased below 95%, intelligibility scores also decreased. One other perceptual parameter relating to prosody—short phrases—was found to correlate with speech intelligibility but it did not emerge from the regression model.

## **2.4 Discussion**

This study aimed to examine which perceptual features of speech production contributed to speech intelligibility in adolescents and adult speakers with DS. The findings showed that breathiness, as measured by VAS from the CAPE-V, and PCC of single words, were the features of speech that contributed the most to the speakers' speech intelligibility. Correlation analysis also showed that short phrases, as measured by VAS from spontaneous speech, was significantly associated with

speech intelligibility. These findings will be discussed in the following sections according to the study's research questions.

#### **2.4.1 Perceptual parameters that related to speech intelligibility in speakers with Down syndrome**

In addition to breathiness and PCC (which will be discussed in the next section), the parameter “short phrases” was found to be significantly negatively correlated with speech intelligibility. That is, if a speaker was perceived to be frequently using short phrases in their spontaneous speech, the person would be perceived as less intelligible. One reason, perhaps, why speakers with DS often give people an impression of poor speech intelligibility is their use of short phrases or shorter utterances as compared to typical speakers (Chapman et al., 1998).

Alternatively, a speaker's use of short phrases may result in breaks at inappropriate parts of a spoken utterance which could hamper listeners' understanding of the verbal message and impact on speech intelligibility. Difficulties with appropriate use of word and phrase boundaries have been previously reported in people with DS (Heselwood, Bray, & Crookston, 1995; Stojanovik, 2011). The atypical use of short phrases was noted to be present in the speech of nearly half of the speakers. The fact that this feature was so common in the speech of the speakers with DS may be as a result of difficulties related to language rather than speech. The relationship between language ability and speech intelligibility will be explored in Study 3 (Chapter 4).

#### **2.4.2 Perceptual parameters of speech production that impacted on speech intelligibility for the speakers with Down syndrome**

Out of all the perceptual parameters across the five components of speech production, breathiness and PCC emerged as the strongest contributors to speech

intelligibility for the speakers with DS. Breathiness, a perceptual phonatory measure, was the strongest contributor and independently accounted for 36% of the variance in speech intelligibility scores. A breathy voice, which results from an increase of airflow from the larynx causing noisy turbulence of air, can be due to impaired function or control of the vocal folds (Hartl, Hans, Vaissiere, & Brasnu, 2003; Klatt & Klatt, 1990). An observation of breathiness usually indicates the presence of relatively larger proportions of noise or aperiodic energy in the voice (Ludlow et al., 2019). It could be that this source of noise reduces the clarity of the speech which in turn affects the auditory perception of the listeners and their ability to perceive contrasts between sounds (Porcaro et al., 2019).

There are a number of possible reasons to explain the presence of breathiness in the speech of those with DS. As discussed in section 1.7.5 of Chapter 1, a common neurological disruption that can occur in people with DS is hypotonia. Hypotonia results in low muscle tone which may impact on the laryngeal muscles that control the movement of the vocal folds. If the vocal folds do not adduct and abduct in an appropriate manner, increased levels of air can escape through the glottis resulting in a breathy voice. Breathiness may also be caused by vocal abuse (Hillenbrand, Cleveland, & Erickson, 1994; Monsen, 1983). Vocal abuse encompasses behaviours and habits that can strain or injure the vocal folds (Boone, McFarlane, Von Berg, & Zraick, 2014). Speakers with DS may use their voice excessively by frequent throat clearing, coughing, and shouting, which can put pressure on the vocal folds and trigger the development of nodules. The nodules then prevent the vocal folds from adducting completely, allowing air to flow through the glottis and cause a breathy voice (Radish Kumar, Bhat, & Prasad, 2010). Another possible reason for the perception of breathiness may be due to the nature of the



speech task. In the current study, the speakers' voice quality was evaluated based on sustained phonation, production of sentences, and spontaneous speech. During the spontaneous speech task, there may have been increased demands on breath support impacting on the co-ordination between respiration and phonation resulting in the speakers producing a breathy voice (Allison & Hustad, 2018).

Previous studies that have perceptually examined phonation in people with DSs have also reported problems with voice quality. For example, Moran and Gilbert (1982) also found that breathiness was a notable difficulty in speakers with DS and Wilson et al. (2019b) found "roughness" to be the main aspect of phonation to differentiate between those with DS who had low and high speech intelligibility. Therefore, along with articulation, phonation plays a pertinent role in the speech intelligibility profile for people with DS.

In addition to breathiness, PCC was also a significant contributor to speech intelligibility scores for the speakers with DS. The finding that PCC, which was a measure of articulatory precision of consonants, emerged as a contributor to speech intelligibility indicates that accurate production of speech sounds plays an important role in the listener judgement of intelligibility. The imprecise or distorted production of consonants can impact on the acoustic signal and negatively affect what is understood by the listener. Difficulties with articulation can be due to the anatomical features of DS, such as a large tongue in a small oral cavity, and a narrower shorter palate (see section 0 in Chapter 1). Difficulties can also be due to motor skills which will be discussed in section 1.7.5. As well as a measure of articulation, the PCC can also be a marker of phonological development and does not identify if errors are articulatory or phonological in nature. Impaired phonology can result in error

patterns that impact on consonant production, which can then affect listener perception of the acoustic signal.

The finding that PCC was a strong contributor to speech intelligibility was not surprising as it has also been reported in previous studies that have examined the contribution of articulation to speech intelligibility in those with dysarthria (e.g. De Bodt et al., 2002). This finding is also consistent with those from Wild et al. (2018) and Cleland et al. (2010) who found a significant relationship between PCC scores and speech intelligibility in speakers with DS. Wilson et al. (2019b) also found that PCC scores were significantly lower in a group of speakers with DS who had low speech intelligibility compared to a group with high speech intelligibility. Moreover, while they did not measure PCC, Jones et al. (2019) found that, out of 47 perceptual parameters, “imprecise consonants” was the second most prominent speech production difficulty among children with DS behind “naturalness.” The current study also showed that the speakers had most difficulty with articulation of fricative and affricate sounds, a finding which is consistent with previous studies who have evaluated articulation in DS (Van Borsel, 1996). Articulation of fricatives and affricates require more refined control of the tongue and other motoric aspects which may explain why these types of sounds are more difficult for speakers with DS (Kent et al., 1992; Kim, Martin, Hasegawa-Johnson, & Perlman, 2010).

### **2.4.3 Other findings**

As explained in the method section of this study, hearing acuity was controlled for in the regression model to eliminate the effects of hearing loss on the study’s results. However, the analysis still allowed for examination of the impact of the speakers’ hearing acuity on their speech intelligibility. Somewhat surprisingly, no relationship between hearing acuity and speech intelligibility was found. This is

unusual as the influence of hearing ability on speech production and speech intelligibility has been well documented (e.g. Cupples et al., 2018; Flipsen, 2008; Laws & Hall, 2014; Osberger et al., 1993). However, Chapman, Seung, Schwartz, and Bird (2000) also used regression analysis to investigate certain parameters, including hearing acuity, that contributed to speech intelligibility in speakers with DS and found that hearing acuity was not a significant contributor to speech intelligibility. It should be noted that many of the speakers with DS in the current study were within the normal range of hearing or had a mild hearing loss. It may be that hearing loss had to be more severe among the speakers with DS to have an impact on analyses in the current study.

As commonly reported in this population, there was considerable heterogeneity across the speakers with DS. For example, no one perceptual parameter was observed in all 30 speakers. Moreover, the range of severity observed for certain parameters was broad across speakers; for example, difficulties with fluency were rated between 0 (indicating no difficulty) and 88 (indicating severe difficulty). The fact that perceptual features differed greatly across speakers and the severity of these features also varied shows that interspeaker variability, as judged by perceptual analysis, was high.

To reiterate, perceptual analysis was the primary tool that was used for assessing speech production in this study. However, as pointed out previously, perceptual judgement can be influenced by the type of speech material used for analysis and the type of rating scale, along with the variable internal standards of the listener (De Bodt et al., 1997). That is why researchers recommend supplementing perceptual judgements with instrumental measures in order to obtain the most accurate measurement of speech production and intelligibility (e.g. Kent et al.,

1999). The next study will use acoustic analysis, which is a type of instrumental evaluation, to examine the same components of speech production for the speakers with DS and examine their impact on speech intelligibility.

## **2.5 Conclusion**

This study allowed for a perceptual profile of speech intelligibility for speakers with DS to be established. The findings showed that aspects of articulation and phonation, particularly consonant production and voice quality, were significant contributors to speech intelligibility for the speakers with DS. The use of short phrases was also associated with reduced speech intelligibility however, hearing acuity did not have any impact. The implications of these findings will be discussed further in the general discussion chapter (Chapter 6).

## **Chapter 3**

# **ACOUSTIC FEATURES OF SPEECH IN INDIVIDUALS WITH DOWN SYNDROME, AND THEIR IMPACT ON SPEECH INTELLIGIBILITY**

### **3.1 Introduction**

While the previous study reported in Chapter 2 applied perceptual judgements of speech, this study used acoustic analysis to investigate how much each of the components of speech production contributed to speech intelligibility for the same speakers with Down syndrome (DS). Acoustic analysis was chosen as it is the one type of instrumental analysis that can provide insight into the function of all five of the speech components and is less invasive compared to other types of instrumental analyses. The present study also compared the acoustic parameters of speech production in speakers with DS to typical speech. As stated in Chapter 1, the components involved in speech production modify the acoustic properties which results in the speech signal. By investigating the acoustic properties of the speech (via acoustic analysis), one can infer the difficulties that occurred in the processes that are involved. There has been an increased application of acoustic analysis to investigate the speech production of individuals with DS, particularly, articulation of consonants and vowels, and voice quality (Kent & Vorperian, 2013). Section 1.4 in Chapter 1 discusses the research regarding acoustic analysis of speech in those with DS; the main findings will be summarised in the following paragraphs.

Acoustic analysis of respiration during speech in DS has received the least attention in the research. As reviewed in Chapter 1, one acoustic parameter, maximum phonation time (MPT), can be obtained as a general measure of respiration. However, in speakers with DS, measurements of MPT have yielded conflicting findings; one study found no difference in MPT between a group of

adults with DS and a control group (Lee et al., 2009b) while another study found that MPT was shorter in adults with DS compared to a typical group (Seifpanahi et al., 2011).

Acoustic analysis of phonation in DS has received the most focus among the components of speech production. As discussed in Chapter 1, studies using acoustic analysis of phonation in DS have also had variable findings. For adults with DS, most studies found a higher mean fundamental frequency (F0, the acoustic correlate of vocal pitch) compared to their respective control groups (Albertini et al., 2010; Lee et al., 2009b; Moran & Gilbert, 1978; Seifpanahi et al., 2011). In regard to voice quality, harmonics-to-noise ratio (HNR) has been found to be lower in speakers with DS compared to typical populations (Moura et al., 2008; Pentz & Gilbert, 1983). A lower HNR indicates more noise in the acoustic signal and reduced voice quality, possibly relating to perceptual observations of hoarseness (e.g. Muñoz et al., 2003).

In regard to articulation, two studies examining vowel production have found the vowel space area (VSA) to be reduced in two adults with DS compared to a control group (Bunton & Leddy, 2011; Dar et al., 2020). A smaller VSA can represent “reduced acoustic contrast among vowels and a loss in perceptual distinctiveness” (Bunton & Leddy, 2011, p. 7). On the other hand, a recent study by Carl et al. (2020) found no difference in VSA between eight young adults with DS and a group of typical speakers matched on age and gender. For articulation of consonants, one acoustic parameter, voice onset time (VOT), has been found to be longer for stop sounds in children with DS compared to typically developing children indicating reduced co-ordination between articulation and phonation (Brown-Sweeney & Smith, 1997). However, no research has examined VOT in adults with DS.

To date, no study has evaluated resonance in speakers with DS using acoustic methods and limited research also exists for prosody in speakers with DS. One study by Corrales-Astorgano et al. (2018) did find higher mean amplitude levels but a lower amplitude range among sentences spoken by adults with DS compared to a control group. These findings indicate that people with DS speak louder during speech production but do not use as much variation in loudness levels. Restricted variation in loudness may prevent speakers with DS from using stress to augment their spoken message. As discussed in Chapter 1, fluency is included as an aspect of prosody because both areas pertain to features of speech production that can be expressed in units beyond the phone (Kent & Vorperian, 2013). Studies have shown that, similar to other areas of speech production in speakers with DS, there is a higher incidence of fluency problems for this group compared to typical populations and those with other cognitive impairments (Bray, 2003).

To summarise the acoustic analysis findings so far, problems with phonation and articulation are common in speakers with DS. Difficulties with other aspects of speech production including respiration, resonance, and prosody seem less clear; but, this is likely due to the fact that fewer studies have been carried out to investigate these components in the speech of those with DS. Nonetheless, similar to the gap identified in the previous study using perceptual analysis of speech, to date no study has acoustically analysed all five components of speech production in speakers with DS and examined their contribution to speech intelligibility.

An acoustic profile of speech intelligibility can be an important tool in order to identify the nature of an intelligibility problem for a certain clinical population (Kent & Read, 2010). While an acoustic profile of speech intelligibility has not yet been examined for speakers with DS, previous studies have attempted to establish an

acoustic profile for those with hearing loss and dysarthria. From these studies, certain acoustic parameters emerge most frequently as strong contributors to speech intelligibility. For example, a study on speakers with hearing impairment showed that VOT accounted for over 60% of the variance in speech intelligibility scores (Metz et al., 1985). VOT contributes to the listener's perception of voiced and voiceless phonemes; if a speaker's VOT is atypical or inconsistent, the listener's perception of the spoken message can be interrupted, thus reducing speech intelligibility. Other studies on children and adults with cerebral palsy found that the F2 slope strongly contributed to speech intelligibility for this group (Ansel & Kent, 1992; Lee et al., 2014). F2 slope has been found to be strongly associated with speech intelligibility scores for other groups with dysarthria also (Kent et al., 1989b; Kim et al., 2009). F2 slope is linked to the rate of vocal tract change from movement of the tongue during speech production (Kent et al., 1989a; Weismer, Yunusova, & Bunton, 2012).

As mentioned above, there has not been any study that has investigated the extent to which the five components of speech production impact on speech intelligibility in speakers with DS based on acoustic analysis. Therefore, this second study aimed to investigate the contribution of each speech component to speech intelligibility in adolescents and adults with DS using acoustic evaluation methods. The five components of speech production were evaluated for the speakers with DS using acoustic parameters that have been used to evaluate speech production in previous research studies. A group of typical speakers matched for age and gender to the speakers with DS was also included to serve as a comparison for the acoustic analysis. Based on the current evidence, it was hypothesised that parameters related



to articulation would be the main contributors to speech intelligibility scores. The research questions were as follows:

1. Which acoustic parameters of speech production differentiate between speakers with DS and typical speakers?
2. Which acoustic parameters of speech production contribute to speech intelligibility scores for speakers with DS?

## **3.2 Method**

### **3.2.1 Participants**

As detailed in Chapter 2, the 30 adolescents and adults with DS and 16 listeners (described in section 2.2.1) were included in this study. In addition, 30 age-matched (in years) and gender-matched typical speakers were also recruited to serve as a control group. Similar to the speakers with DS, the typical speakers were monolingual Irish-English speakers and were native to Cork, Ireland. They also passed a pure tone hearing screen at 25 dBHL for frequencies 1000, 2000, and 4000 Hz in both ears (the hearing screen was administered before speech data collection commenced).

### **3.2.2 Collection of speech data**

The materials and procedures for collecting speech data from the typical speakers were essentially the same as those for the speakers with DS (see section 2.2.2 in Chapter 2). The only procedural differences were that the speech data was collected within a single session that lasted approximately 45 minutes, the typical speakers did not complete the formal assessments and the typical speakers completed a hearing screening rather than undergoing full audiological testing. Speech material was recorded using a digital recording device (Zoom H1) with a sampling rate of 48 kHz and 16-bit quantisation. The recording device was placed at a 30 cm distance at

mouth level for each speaker. The collected speech samples were acoustically analysed using Praat software version 6.1.04 (Boersma & Weenink, 2019). Similar to Study 1, the research protocol was piloted in a previous study (O'Leary et al., 2019).

### **3.2.3 Acoustic analysis of speech data**

The following sections describe the acoustic parameters, corresponding speech stimuli, and elicitation methods for the evaluation of each of the major components of speech production (see for Figure 3-7 for a summary).

#### **3.2.3.1 Respiration**

The MPT for each speaker was obtained as an acoustic measure of respiration. It is acknowledged that the MPT can also be influenced by phonatory function but for the purpose of this study, it was used a measure of respiratory function (Maslan et al., 2011). The speakers were instructed to take a deep breath and sustain vowel /a/, at a comfortable level, for as long as they could. The investigator demonstrated the task and the speakers then made three attempts. The onset and offset of vowel /a/ were identified based on the waveform where the onset was the start of the first regular glottal pulse of the vowel and the offset was the end of the last glottal pulse (Kent et al., 1999, Figure 3-1). The average duration across the three productions was calculated for each speaker (Hirano & McCormick, 1986).

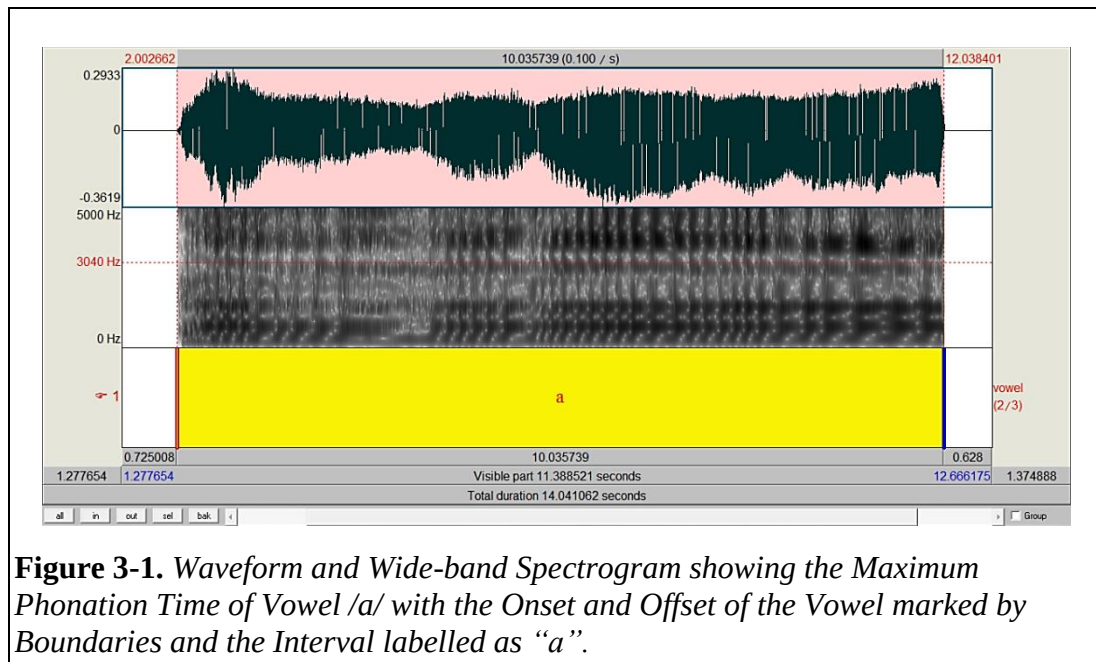


**Figure 3-1.** Waveform and Wide-band Spectrogram showing the Maximum Phonation Time of Vowel /a/ with the Onset and Offset of the Vowel marked by Boundaries and the Interval labelled as “a”.

### 3.2.3.2 Phonation

Three of the most frequently used acoustic parameters for evaluating phonatory function were used in this study, namely mean F0, mean amplitude and HNR. These parameters were chosen as they have been found to be the voice parameters highlighted as deviant in speakers with DS (Lee et al., 2009b; Moura et al., 2008; Seifpanahi et al., 2011). The three parameters were measured based on sustained phonation of /a/, the same stimulus that was used to calculate MPT. In order to analyse the most stable part of the vowel, the middle 3-second section of each production was selected for analysis (Felippe, Grillo, & Grechi, 2006; see Figure 3-2). The mean value for each parameter across the three productions was then calculated for each speaker.

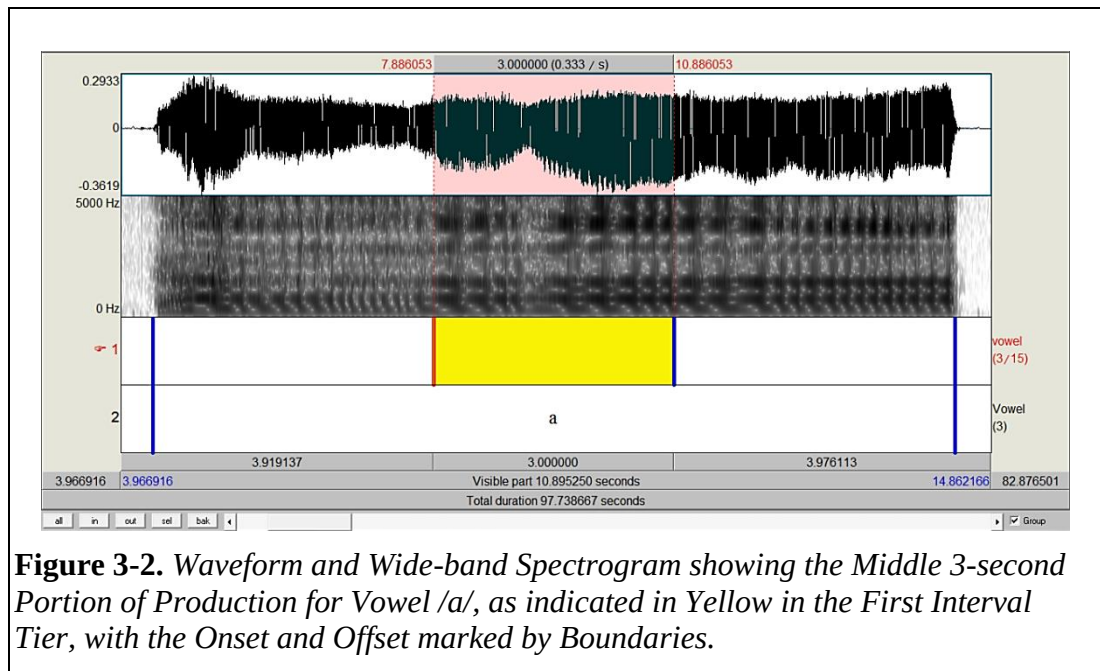


**Figure 3-2.** Waveform and Wide-band Spectrogram showing the Middle 3-second Portion of Production for Vowel /a/, as indicated in Yellow in the First Interval Tier, with the Onset and Offset marked by Boundaries.

### 3.2.3.3 Articulation

Four acoustic parameters were applied to evaluate articulation: VSA and F2 slope for vowels, and spectral analysis of the first moment (M1) along with VOT for consonants. The VSA was measured according to the method used by Vorperian and Kent (2014) where F1 represents the first formant and F2 represents the second formant of each vowel:  $VSA = 0.5 \times [(/i/F2 \times /æ/F1 + /æ/F2 \times /a/F1 + /a/F2 \times /u/F1 + /u/F2 \times /i/F1) - (/i/F2 \times /æ/F2 + /æ/F1 \times /a/F2 + /a/F1 \times /u/F2 + /u/F1 \times /i/F2)]$ . The corner vowels were elicited using the speakers' productions of four single-syllable words taken from the Peterson and Barney (1952) frequently used word list (heed, had, who'd, hod). The vowels were elicited using the /hVd/ syllabic structure embedded in a carrier phrase "I say hVd again" to eliminate the effects of co-articulation (Aylett & Turk, 2006). All speech stimuli for articulation were presented to the speakers on a card, typed in large font and with an accompanying visual cue (e.g. Derdemezis et al., 2016). For example, the target sentence "I say who'd again" was accompanied by a picture of an ear and a picture of food items, indicating that

the target word sounded like “food” (see Appendix J for an outline of the visual cues). The speakers were familiarised with the stimuli before recording commenced. Five productions of each sentence were elicited and the order of eliciting the 20 sentences (four vowels  $\times$  five productions each) was randomised for each speaker. The vowel segments were identified based on the signal in the wide-band spectrogram; the onset of each vowel segment was defined as the point where both F1 and F2 became visible and the offset was identified at the point where F2 and F1 were no longer visible (Liu, Tsao, & Kuhl, 2005). The frequencies of F1 and F2 for /i, æ, u, ɑ/ were then obtained at 50% vowel duration (i.e. the temporal midpoint of the vowel) for each production (Bunton & Leddy, 2011). Figure 3-3 shows annotation of vowel /i/ and the identification of the temporal midpoint of the vowel (marked by the boundary in red). The mean values for F1 and F2 across the five productions were computed for each corner vowel and the VSA was calculated using the above formula.

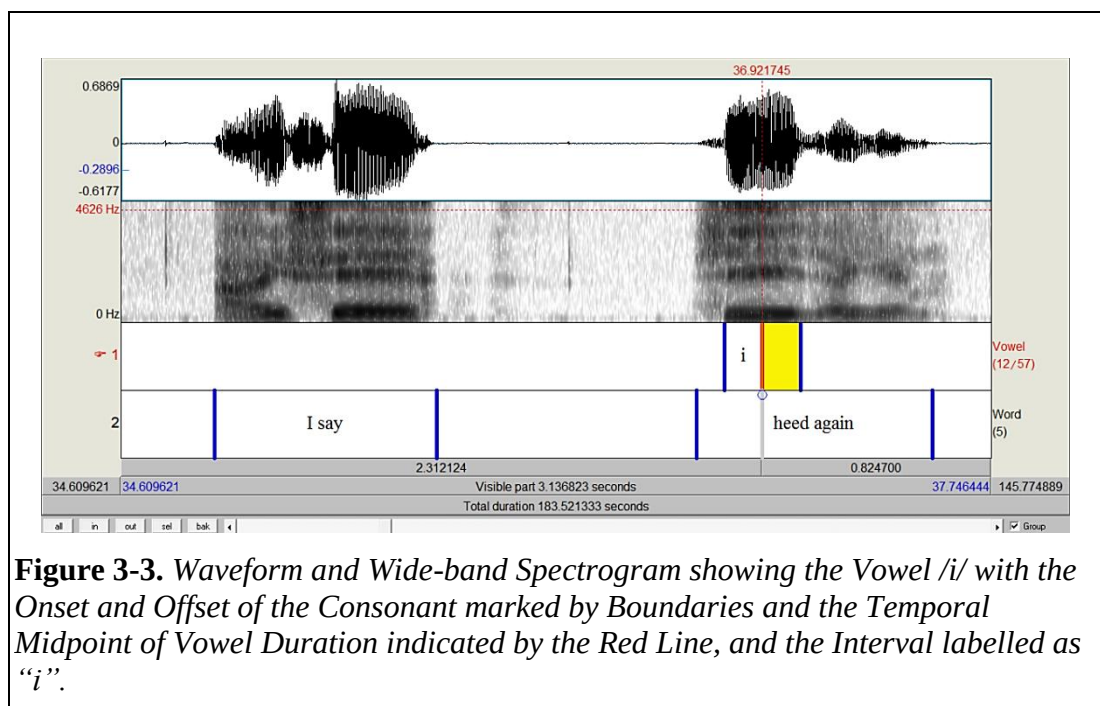
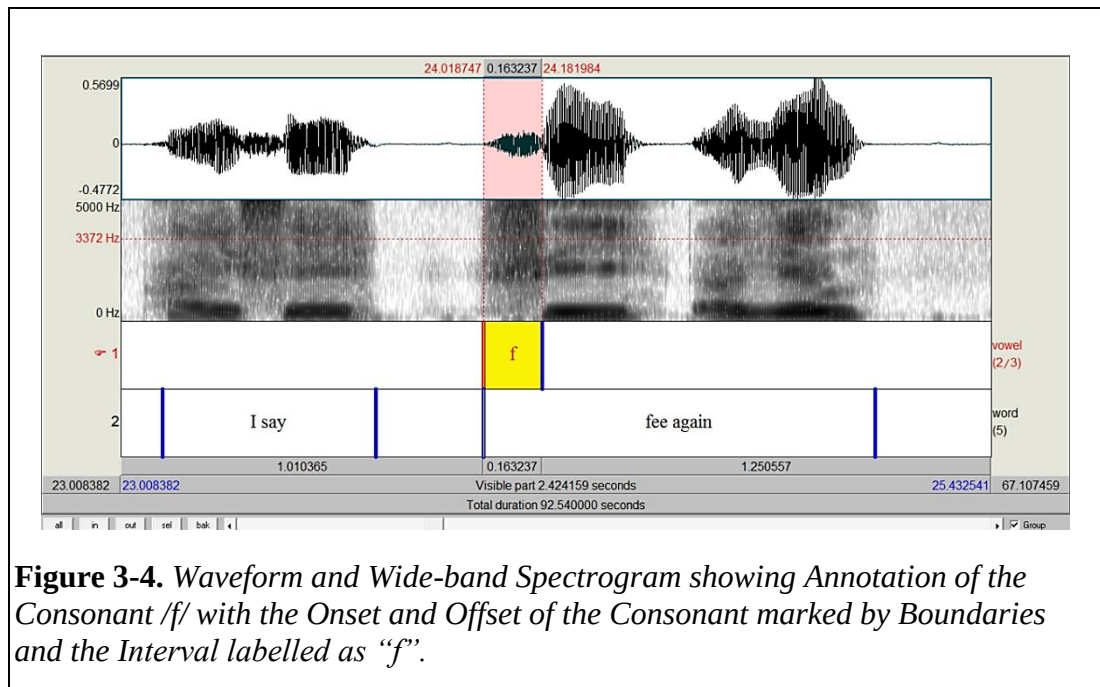


**Figure 3-3.** Waveform and Wide-band Spectrogram showing the Vowel /i/ with the Onset and Offset of the Consonant marked by Boundaries and the Temporal Midpoint of Vowel Duration indicated by the Red Line, and the Interval labelled as “i”.

The second acoustic parameter for evaluating articulation of vowels was F2 slope, which was also measured for each of the four corner vowels. The F2 slope for each vowel was calculated by using the following formula  $(F2 \text{ offset} - F2 \text{ onset}) \div \text{duration}$  (Lansford & Liss, 2014). F2 onset was defined as the F2 at 20% vowel duration and F2 offset was defined as the F2 at 80% of vowel duration. The F2 slope was calculated for each vowel and then the mean F2 slope value was obtained across the five productions for /i/, /æ/, /u/, and /ɑ/.

For articulation of consonants, M1 and VOT were measured. The procedure for obtaining the M1 (centre of gravity) used in the study by Karlsson, Shriberg, Scheer, and Nadler (2003) was also used in this study. Analysis was carried out with three fricative sounds, /s/, /f/, and /ʃ/. The fricative /θ/ was not included for analysis as this sound is often not present in Southern Irish-English, which was the language of the speakers (Hickey, 2007). The fricative sounds were elicited by the speakers repeating or reading aloud three words “see,” “fee,” and “she” in the same phonetic context. Each fricative was elicited five times each in random order as part of the “I say \_\_\_\_\_ again” carrier phrase (McAuliffe, Robb, & Murdoch, 2007). The M1 was obtained from the full duration of the fricative sound. The onset of the fricative was defined as the first appearance of strong aperiodic energy in the waveform and spectrogram and the offset was identified as the end of aperiodic energy (see Figure 3-4). The M1 was obtained for the production of each fricative produced and then the mean M1 was calculated across the five productions.



The VOT was measured for /p/, /b/, /t/, /d/, /k/ and /g/. The stimuli were six words, /pi/, /bi/, /ti/, /di/, /ki/, and /gi/ (spelt as “pee,” “bee,” “tee,” “dee,” “kee,” and “gee”), embedded in the same carrier phrase “I say \_\_\_\_\_ again.” The six target sentences were repeated or read aloud five times each in random order. The start of the VOT was defined as the onset of the burst of the plosive, indicated by the dark vertical striation on the wide-band spectrogram coinciding with a short increase in amplitude. The end selection of VOT was defined as the start of the first glottal cycle of the following vowel, which is depicted by dark vertical striation on the wide-band spectrogram (Cole, Kim, Choi, & Hasegawa-Johnson, 2007). Figure 3-5 shows the VOT for /k/ identified in the waveform and wide-band spectrogram. The mean VOT for each consonant across the five productions was then calculated for each speaker.

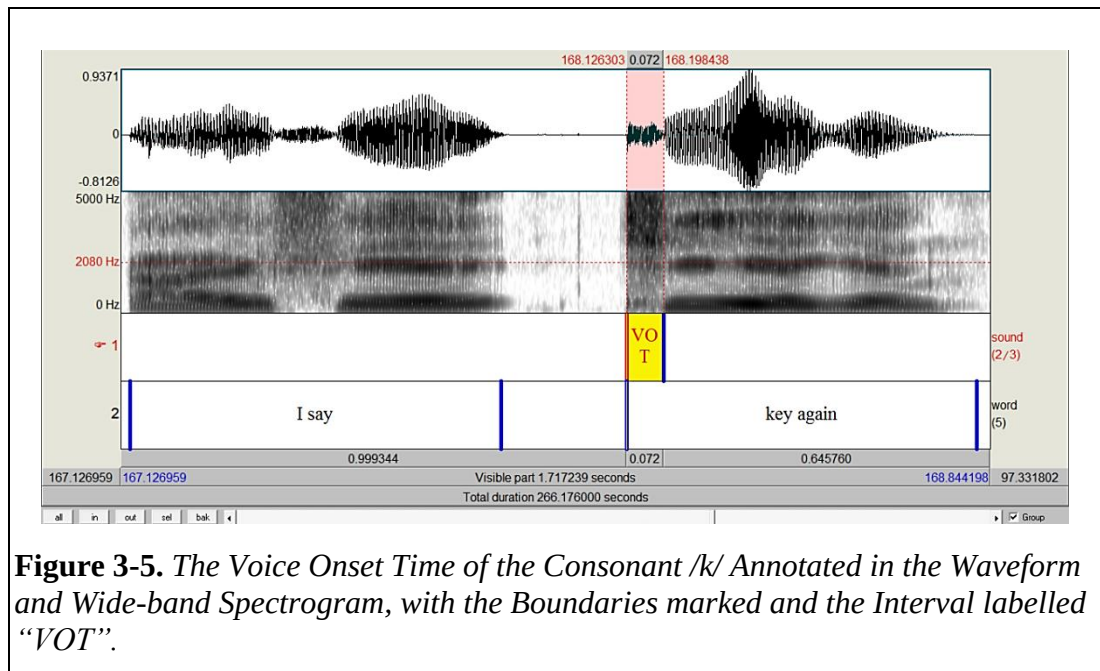


**Figure 3-5.** *The Voice Onset Time of the Consonant /k/ Annotated in the Waveform and Wide-band Spectrogram, with the Boundaries marked and the Interval labelled “VOT”.*

### 3.2.3.4 Resonance

One-third-octave analysis was employed to acoustically evaluate resonance. The procedure for carrying out one-third-octave analysis used by Kataoka et al. (1996) was used. The stimuli used for this parameter was the middle 50ms portion from three productions of the prolonged vowel /i/ (Lee, Ciocca, & Whitehill, 2009a). Normalisation of the spectrum was done to eliminate external influences such as a loud voice (Yoshida et al., 2000). In order to normalise the spectrum, for each production of /i/, the amplitude value of the 1/3-octave band where the F0 of the speaker fell was subtracted from the amplitude value of each of the 1/3-octave bands. One-third octave analysis was conducted on all three productions of the vowel /i/ and the mean values were calculated for each frequency range.

### 3.2.3.5 Prosody

The six parameters used to acoustically analyse prosody were mean F0, F0 range, mean amplitude, amplitude range, speaking rate, and percentage of stuttering-like dysfluencies (%SLD). The stimulus for analysing prosody was the entire



discourse of the speakers' spontaneous speech sample. The onset of the first word and the offset of the last word in each utterance of the speech sample were identified in the wide-band spectrogram. The onset was defined as the beginning of acoustic energy and the offset point was defined by the termination of acoustic energy of speech, and the annotation was verified by careful listening to the audio signal. To be included in analysis, each section of speech had to contain complete utterances consisting of a minimum of three consecutive words; unintelligible sections and parts where two people were talking at the same time were excluded (Chon, Sawyer, & Ambrose, 2012).

The F0, F0 range, amplitude and amplitude range were obtained across each speech section and the average for each parameter was obtained. The total duration and total number of words across the speech sections were tallied and the speaking rate was calculated. The speaking rate was calculated by dividing the total number of words produced in the speech sample by the total duration in minutes; hence, the unit of measurement was words per minute. Figure 3-6 shows an example of a complete utterance annotated in the waveform and wide-band spectrogram in terms of the words spoken and the number of words.

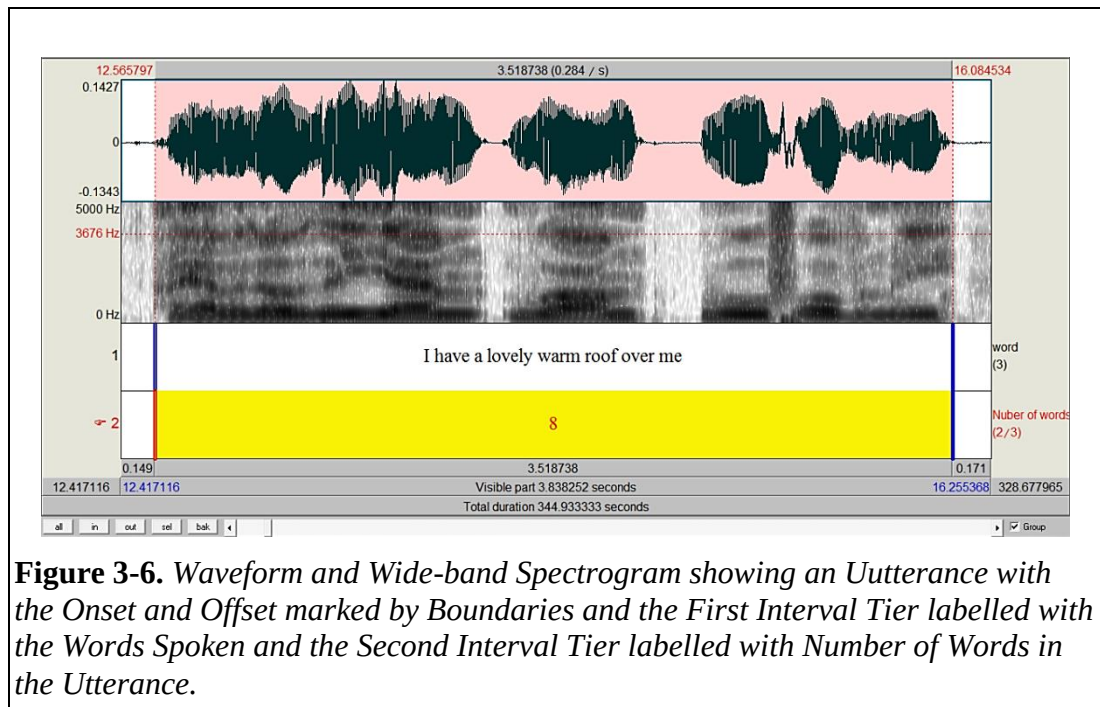
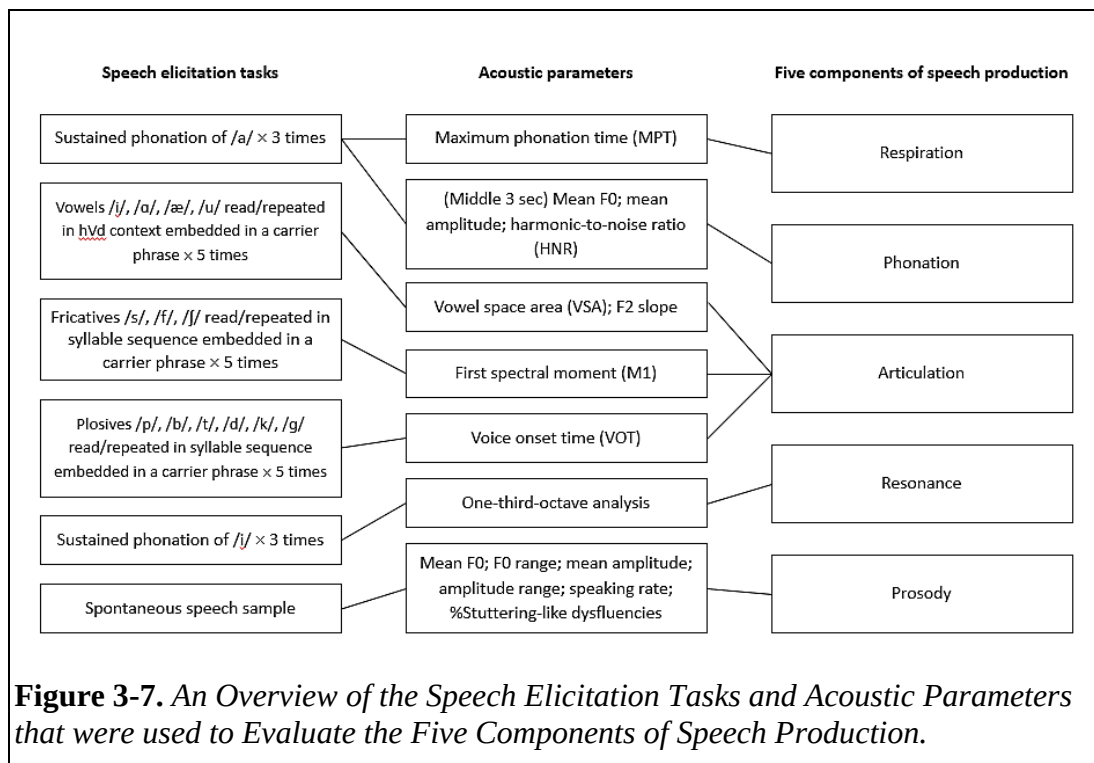


**Figure 3-6.** Waveform and Wide-band Spectrogram showing an Utterance with the Onset and Offset marked by Boundaries and the First Interval Tier labelled with the Words Spoken and the Second Interval Tier labelled with Number of Words in the Utterance.

As a measure of fluency, the %SLD was also calculated from the spontaneous speech sample. The Bloom and Cooperman (1999) procedure was used for identifying dysfluencies. Dysfluencies included syllable or part-word repetitions, phoneme prolongations, and blocks. The %SLD was calculated by dividing the number of stuttering incidences by the total number of words produced and multiplying by 100. For example, if a speaker had seven incidents of dysfluency in their speech sample and produced 100 words, they would be given a %SLD of 7%.



### 3.2.4 Procedure for measuring hearing acuity and oro-motor function

The materials and procedures used for measuring hearing acuity and oro-motor function for the speakers with DS are described in Chapter 2 (see sections 2.2.5 and 2.2.6 in Study 1). In addition, the typical speakers were required to pass a hearing screen to be eligible for inclusion in the study (explained above in section 3.2.1).

### 3.2.5 Procedure for measuring speech intelligibility

The procedure used to measure speech intelligibility for the speakers with DS was an orthographic transcription task completed by 16 adult listeners (see section 2.2.8 in Study 1).

### 3.2.6 Data analysis

To assess inter-rater reliability, a second investigator, who was an SLT experienced in acoustic analysis of speech, used the same procedures described above and analysed the speech samples from three speakers with DS and three

typical speakers (10% of the speech samples) who were randomly selected. The percentage agreement score for each parameter was calculated by dividing the smaller rating score from one judge by the larger rating from the other judge, and multiplying by 100 (e.g. Karimi et al., 2014). The procedure for measuring each speaker's speech intelligibility is described in section 2.2.9 of Study 1.

The Statistical Package for the Social Sciences (version 26) was used to analyse the data. The data was checked for normality by examining the Q-Q plots and histograms of each acoustic parameter. Scatterplots were also computed to examine if the relationship between the speech intelligibility and each parameter was linear. To examine the differences between the speakers with DS and the typical speakers, Mann-Whitney *U* tests were for computed for each acoustic parameter. For the parameters that were identified to differentiate between the two speaker groups, correlation analysis was carried out to examine if there was a relationship between these parameters and speech intelligibility. As explained in Study 1, correlation analysis was used to identify the parameters that were related to speech intelligibility because it was possible that not all of the parameters that were associated with speech intelligibility would get into a final regression model (Field, 2018). Stepwise multiple regression analysis with blockwise entry methods was then carried out to investigate which acoustic parameters contributed to the speech intelligibility scores for the speakers with DS. The dependent variable was the speech intelligibility score and the independent variables were those acoustic parameters that differentiated between the two speaker groups. In line with the first study in Chapter 2, hearing acuity was adjusted for by entering the scores into the first block of the regression model and entering the independent variables in the second block with stepwise

selection. Diagnostic testing, as explained in Study 1, was carried out to ensure that no assumptions for multiple linear regression were violated.

### **3.3 Results**

The speech intelligibility, hearing acuity and oro-motor function scores for the speakers with DS are presented in Table 2.3 and Table 2.4 in Study 1 (p. 99).

#### **3.3.1 Acoustic parameters that differentiated between the speakers with Down syndrome and typical speakers**

Visual inspection of the histograms and Q-Q plots for each acoustic parameter showed that the data was not normally distributed (Appendix K). Therefore, Mann-Whitney *U* tests were carried out to compare the acoustic parameters between the speakers with DS and the typical speakers (see Table 3.1 for a summary of the mean values for each acoustic parameter and the Mann-Whitney results). There was a significant difference between the speakers with DS and typical speakers for 12 of the 30 parameters. For respiration, the speakers with DS had a significantly lower MPT compared to the typical speakers. There was also a significant difference between the two groups of speakers for one of the measures of phonatory function, where the speakers with DS showed a significantly higher mean F0. For articulation of vowels, the speakers with DS had a significantly reduced VSA and shallower F2 slope for /a/. Regarding articulation of consonants, the VOT for /d/ was significantly longer for the speakers with DS compared to the typical speakers. Additionally, the speakers with DS had a significantly lower M1 for /s/ and /f/, and significantly higher M1 for /j/ compared to the typical speakers. Analysis of parameters relating to prosody showed that the speakers with DS had a significantly higher mean amplitude level, higher amplitude range, slower speaking rate, and higher incidence of dysfluency compared to the typical speakers.

**Table 3.1.** Means, Standard Deviations (SD) and Ranges for each Acoustic Parameter for the Speakers with Down syndrome (DS) and the Typical Speakers, along with Mann Whitney (U) Results comparing Parameters across the Two Groups.

| Parameter                        | <u>Speakers with DS</u> |                                  | <u>Typical speakers</u> |                                  | U     |
|----------------------------------|-------------------------|----------------------------------|-------------------------|----------------------------------|-------|
|                                  | Mean                    | SD<br>(Range)                    | Mean                    | SD<br>(Range)                    |       |
| Respiration                      |                         |                                  |                         |                                  |       |
| MPT (seconds)                    | 6.11                    | 6.09<br>(2.80-28.46)             | 12.11                   | 6.07<br>(8.07-29.24)             | 95*** |
| Phonation                        |                         |                                  |                         |                                  |       |
| Mean F0 of /a/ (hertz)           | 193.12                  | 64.34<br>(88.28-358.06)          | 154.54                  | 51.69<br>(88.28-248.81)          | 270** |
| Mean amplitude of /a/ (decibels) | 70.09                   | 5.83 (<br>52.37-90.80)           | 67.51                   | 3.88<br>(62.18-76.93)            | 342   |
| HNR (decibels)                   | 17.51                   | 4.43<br>(2.14-27.49)             | 16.77                   | 3.19<br>(10.27-23.82)            | 389   |
| Articulation                     |                         |                                  |                         |                                  |       |
| VSA (hertz <sup>2</sup> )        | 156016.94               | 111078.47<br>(7099.67-474486.41) | 246188.48               | 94939.10<br>(58564.06-451951.06) | 310*  |
| VOT of /p/ (seconds)             | 0.08                    | 0.03<br>(0.01-0.23)              | 0.07                    | 0.02<br>(0.04-0.12)              | 438   |
| VOT of /b/ (seconds)             | 0.01                    | 0.01<br>(0.00-0.05)              | 0.01                    | 0.01<br>(0.00-0.05)              | 419   |
| VOT of /t/ (seconds)             | 0.09                    | 0.15<br>(0.05-0.2)               | 0.09                    | 0.02<br>(0.06-0.13)              | 355   |
| VOT of /d/ (seconds)             | 0.03                    | 0.08                             | 0.02                    | 0.01                             | 271** |

| Parameter                                   | <u>Speakers with DS</u> |                               | <u>Typical speakers</u> |                               | <i>U</i> |
|---------------------------------------------|-------------------------|-------------------------------|-------------------------|-------------------------------|----------|
|                                             | Mean                    | SD<br>(Range)                 | Mean                    | SD<br>(Range)                 |          |
| VOT of /k/ (seconds)                        | 0.09                    | (0.01-0.09)<br>0.14           | 0.09                    | (0.01-0.04)<br>0.02           | 420      |
| VOT of /g/ (seconds)                        | 0.04                    | (0.02-0.16)<br>0.12           | 0.03                    | (0.06-0.12)<br>0.01           | 366      |
| F2 slope of /i/ (hertz per millisecond)     | -0.76                   | (0.01-0.13)<br>2.64           | 11.28                   | (0.02-0.06)<br>3.53           | 408      |
| F2 slope of /a/ (hertz per millisecond)     | 1.76                    | (-6.16-9.81)<br>1.43          | 2.78                    | (-6.16-9.81)<br>1.52          | 231***   |
| F2 slope of /u/ (hertz per millisecond)     | 0.78                    | (-0.72-6.76)<br>1.62          | 0.08                    | (-0.60-6.06)<br>1.70          | 325      |
| F2 slope of /æ/ (hertz per millisecond)     | 0.47                    | (-2.44-4.61)<br>1.23          | 0.71                    | (-2.24-4.61)<br>1.49          | 439      |
| M1 of /s/ (hertz)                           | 6668.06                 | (-3.57-3.86)<br>1778.50       | 8420.11                 | (-3.57-3.86)<br>1647.53       | 254**    |
| M1 of /f/ (hertz)                           | 4087.21                 | (2199.26-11152.14)<br>2024.51 | 5725.29                 | (4634.54-11152.14)<br>1800.64 | 228***   |
| M1 of /ʃ/ (hertz)                           | 4861.13                 | (610.50-11003.95)<br>1436.39  | 4415.78                 | (2152.46-11003.95)<br>464.15  | 309*     |
|                                             |                         | (1885.79-8261.48)             |                         | (3302.50 5483.07)             |          |
| Resonance                                   |                         |                               |                         |                               |          |
| 1/3 octave band: 800-1000 hertz (decibels)  | -7.85                   | 11.23                         | -8.39                   | 13.99                         | 443      |
|                                             |                         | (-23.00-35.67)                |                         | (-23.00-35.67)                |          |
| 1/3 octave band: 1000-1250 hertz (decibels) | -8.41                   | 10.01                         | -10.00                  | 12.49                         | 405      |
|                                             |                         | (-19.36-31.31)                |                         | (-19.36-31.31)                |          |

| Parameter                                       | <u>Speakers with DS</u> |                         | <u>Typical speakers</u> |                          | <i>U</i> |
|-------------------------------------------------|-------------------------|-------------------------|-------------------------|--------------------------|----------|
|                                                 | Mean                    | SD<br>(Range)           | Mean                    | SD<br>(Range)            |          |
| 1/3 octave band: 1250-1600 hertz (decibels)     | -8.32                   | 9.49<br>(-19.55-29.02)  | -9.94                   | 11.29<br>(-15.04-29.02)  | 409      |
| 1/3 octave band: 1600-2000 hertz (decibels)     | -3.96                   | 8.93<br>(-13.86-30.03)  | -6.12                   | 10.72<br>(-13.86-30.03)  | 446      |
| 1/3 octave band: 2000-2500 hertz (decibels)     | 3.47                    | 9.79<br>(-11.01-35.25)  | 4.44                    | 12.09<br>(-11.01-35.25)  | 388      |
| 1/3 octave band: 2500-3200 hertz (decibels)     | 8.28                    | 9.82<br>(-3.34-46.86)   | 10.99                   | 11.69<br>(-3.34-46.86)   | 341      |
| Prosody                                         |                         |                         |                         |                          |          |
| Mean F0 of spontaneous speech (hertz)           | 174.04                  | 64.34<br>(88.28-358.06) | 180.97                  | 57.27<br>(85.23-359.51)  | 358      |
| F0 range (hertz)                                | 288.65                  | 82.59<br>(89.12-421.96) | 318.66                  | 77.21<br>(146.61-407.65) | 381      |
| Mean amplitude of spontaneous speech (decibels) | 68.46                   | 3.89<br>(52.10-76.47)   | 64.93                   | 2.19<br>(60.48-69.02)    | 190***   |
| Amplitude range (decibels)                      | 54.01                   | 14.12<br>(37.86-69.68)  | 43.19                   | 15.84<br>(37.86-58.62)   | 110***   |
| Speaking rate (words per minute)                | 48.24                   | 46.73<br>(20.18-90.31)  | 126.09                  | 32.12<br>(71.97-216.41)  | 6***     |
| % SLD                                           | 2.4                     | 3.33<br>(0-13.30)       | 0.8                     | 2.83<br>(0.00-6.90)      | 199***   |

*Note.* SD = standard deviation; MPT = maximum phonation time; F0 = fundamental frequency; HNR = harmonics-to-noise ratio; VSA = vowel space area; VOT = voice onset time; M1 = first spectral moment; SLD = stuttering-like dysfluencies.

\* $p < .05$ . \*\* $p < .01$ . \*\*\* $p < .001$ .



### **3.3.2 Acoustic parameters of speech production that contributed to speech intelligibility for the speakers with Down syndrome**

For this set of analyses, only the acoustic parameters that significantly differed between the speakers with DS and the typical speakers were included. Visual inspection of the scatterplots showed that the relationship between speech intelligibility (the dependent variable) and each acoustic parameter (independent variable) was roughly linear (Appendix L). Points of high leverage were also examined for validity and no changes were made to the data. As the data was not normally distributed, Spearman rank order correlation analysis was carried out to identify the parameters that were significantly related to speech intelligibility in case they did not emerge from the regression model. Table 3.2 shows the results for the Spearman rank-order correlations between speech intelligibility and each of the acoustic parameters. The results showed that four of the acoustic parameters were significantly positively correlated with speech intelligibility: they were VSA, M1 of /s/, mean amplitude of spontaneous speech, and speaking rate. Figure 3-8 depicts a solar correlation map representing the strength of relationship between speech intelligibility and each of the acoustic parameters. There was no inter-correlation greater than 0.8 between the parameters hence, there are no moons in the solar correlation map (Appendix M). Table 3.3 and Table 3.4 summarise the results of the multiple regression model.

**Table 3.2.** *Spearman Rank-order Correlation Results indicating the Strength of Relationship between each of the Acoustic Parameters and the Speech Intelligibility Scores*

| Acoustic parameter (unit of measurement)        | Spearman $r_s$ |
|-------------------------------------------------|----------------|
| MPT (seconds)                                   | 0.26           |
| Mean F0 of /a/ (hertz)                          | 0.28           |
| VSA (hertz <sup>2</sup> )                       | 0.44*          |
| VOT /d/ (seconds)                               | −0.35          |
| F2 slope of /a/ (hertz per millisecond)         | 0.33           |
| M1 of /s/ (decibels)                            | 0.38*          |
| M1 /of f/ (decibels)                            | −0.05          |
| M1 of /f/ (decibels)                            | −0.13          |
| Mean amplitude of spontaneous speech (decibels) | 0.40*          |
| Amplitude range (dB)                            | 0.20           |
| Speaking rate (words per minute)                | 0.45*          |
| % SLD                                           | −0.31          |

*Note.* MPT = maximum phonation time; F0 = fundamental frequency; VSA = vowel space area; VOT = voice onset time; F2 = second formant; M1 = first spectral moment; SLD = stuttering-like dysfluencies.

\* $p < .05$ . \*\* $p < .01$ . \*\*\* $p < .001$ .

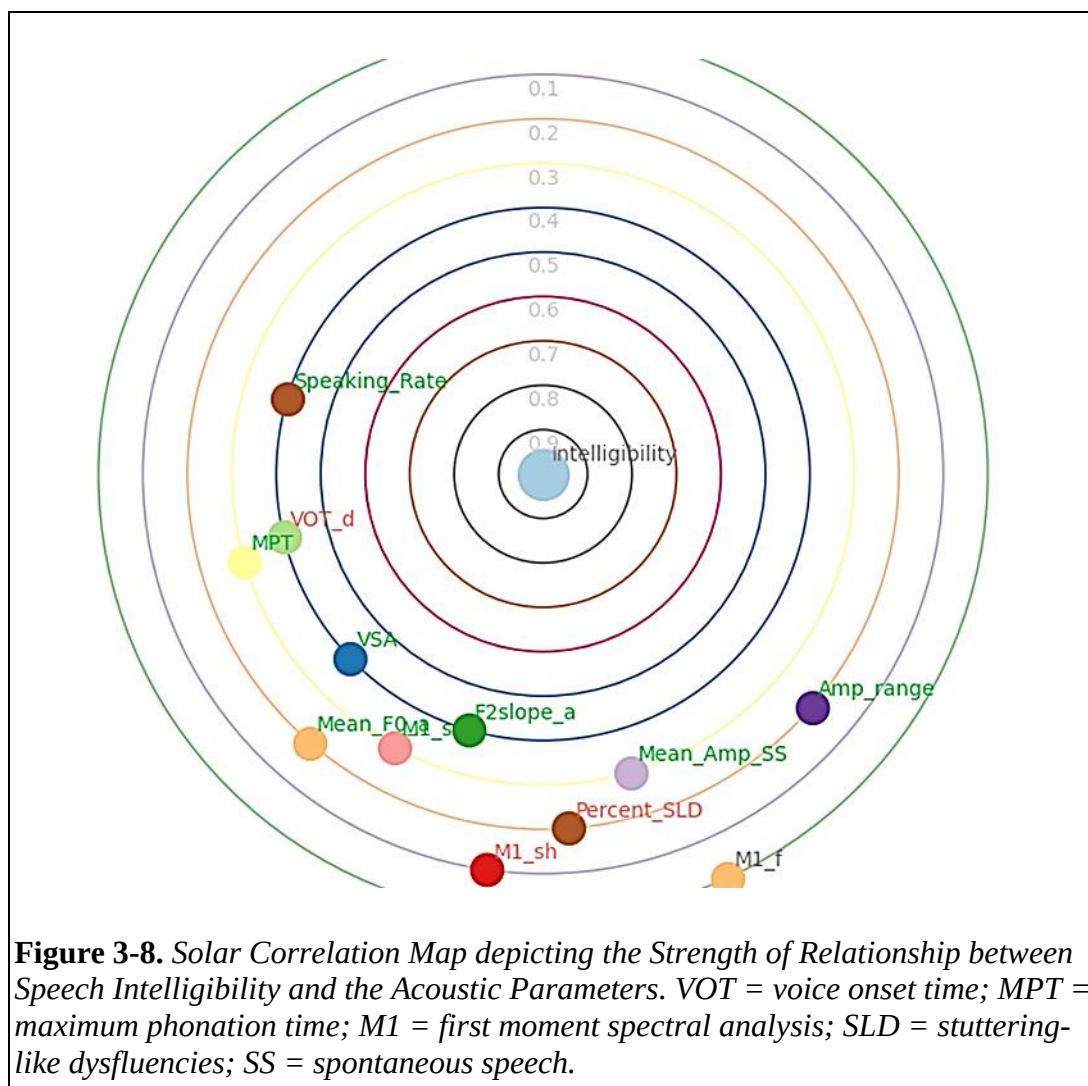


**Table 3.3.** Summary of Regression Model for Study 2

| Model | Variable     | $R^2$ | Adjusted $R^2$ | $R^2$ Change | $F$ Change | Sig |
|-------|--------------|-------|----------------|--------------|------------|-----|
| 1     | Hearing      | 0.01  | −0.03          | 0.01         | 0.16       | .69 |
| 2     | F2 slope /a/ | 0.27  | 0.22           | 0.26         | 9.76       | .00 |
| 3     | VOT /d/      | 0.40  | 0.33           | 0.13         | 5.66       | .03 |

Note. Sig = significance level; F2 = second formant; VOT = voice onset time.

**Table 3.4.** Coefficients of Regression Model for Study 2

| Variable     | $B$     | Standard error | $T$   | Sig  | VIF  |
|--------------|---------|----------------|-------|------|------|
| Hearing      | −0.12   | 0.39           | −0.30 | 0.77 | 1.35 |
| F2 slope /a/ | 8.20    | 3.08           | 2.66  | 0.01 | 1.09 |
| VOT /d/      | −526.39 | 221.21         | −2.38 | 0.03 | 1.36 |

Note. Sig = significance level; VIF = variance inflation factor; F2 = second formant; VOT = voice onset time.

The results of the regression show that, along with hearing acuity, two independent variables, F2 slope of /a/ and VOT of /d/, accounted for 33% of the variance in speech intelligibility scores. The positive *B* value for F2 slope (see Table 3.4) shows that there was a positive relationship between F2 slope and speech intelligibility. That is, when F2 slope increased by one unit, speech intelligibility also increased by 8.2. On the other hand, a negative relationship was found between VOT and speech intelligibility. That is, when VOT /d/ increased by 0.01 seconds, speech intelligibility scores decreased by 5.26.

### **3.3.3 Inter-rater reliability**

The inter-rater reliability results for each acoustic parameter are presented in Appendix N. The percentage agreement between the first and second investigator was calculated for each acoustic parameter and agreement for most parameters was above 80%.

### **3.3.4 Diagnostic tests for regression model**

The results for checking the five assumptions of stepwise regression were as follows:

**Assumption 1:** Regarding the linearity between the dependent variable and each of the contributing variables, the results did not show any clear pattern among the residuals of the model (Figure 3-9). Hence, a linear relationship between can be assumed between the dependent variable and the each of the independent variables.

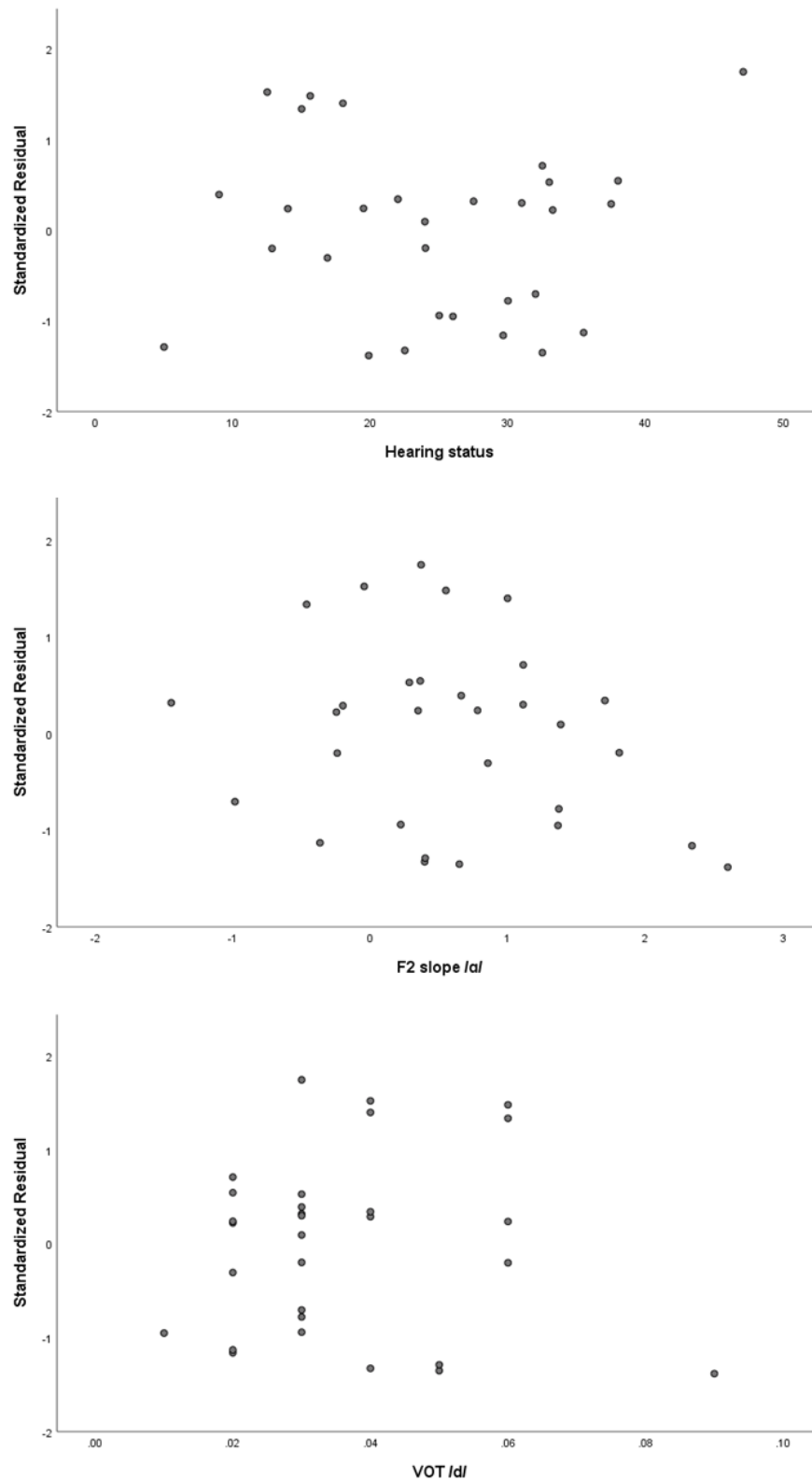


**Figure 3-9.** Scatterplots of the Standardised Residuals as a Function of each of the Contributor Variables for Study 2: Hearing Acuity (top), F2 Slope of /a/ (middle), and VOT (voice onset time) of /d/ (bottom).

**Assumption 2:** The result of the Durbin-Watson test was 1.63. As this is close to 2, we can assume that there is no autocorrelation among the independent variables.

**Assumption 3:** The Breusch-Pagan test showed a chi-square value of 4.05,  $p = 0.44$ . As this is above the significance level of 0.05, we can reject the null hypothesis that heteroscedasticity exists in the residual of this regression model.

**Assumption 4:** The scatterplot in Figure 3-10 roughly follows a straight line which indicates that the residuals of the regression model are normally distributed.

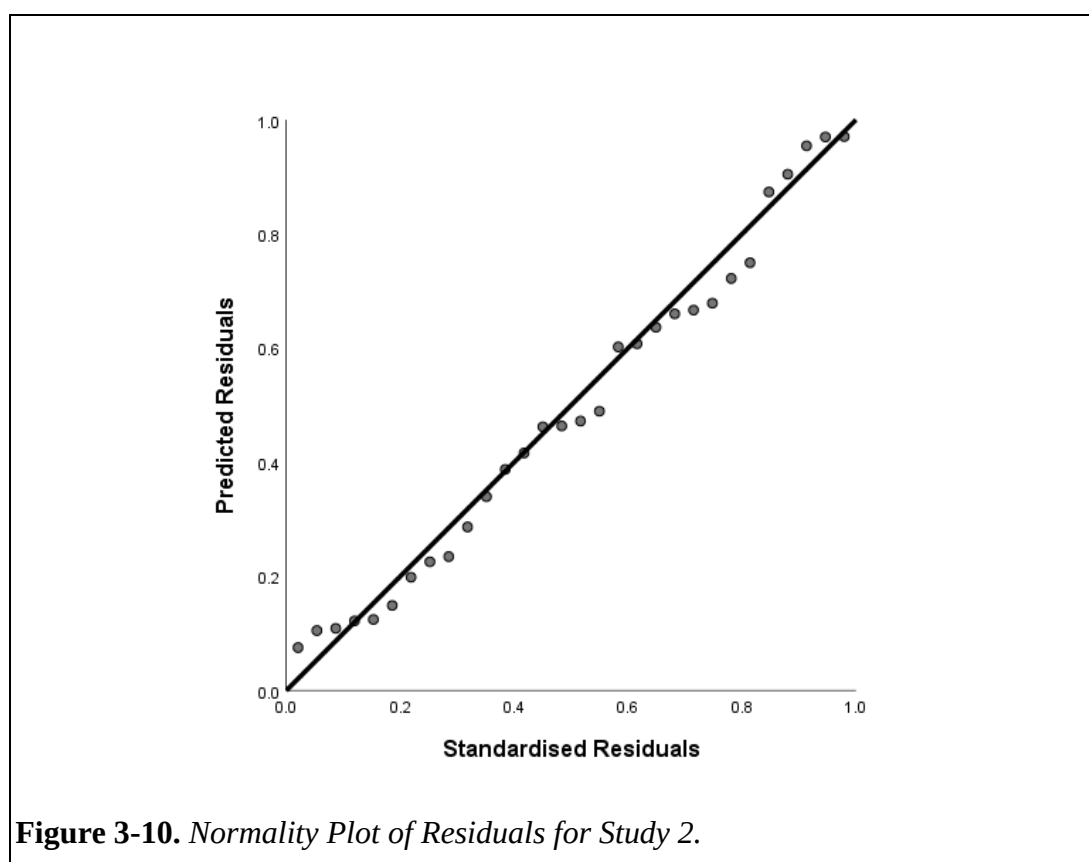


**Figure 3-10.** *Normality Plot of Residuals for Study 2.*

**Assumption 5:** The variance inflation factors (VIF) for each variable are below ten (see Table 3.4), which indicates a low risk of multicollinearity within the data.

### 3.3.5 Summary of results

The results showed that speakers with DS were significantly different from the typical speakers for 12 acoustic parameters: MPT, mean F0 of /a/, VOT of /d/, M1 of /s/, /ʃ/, /f/, mean amplitude of spontaneous speech, amplitude range, speaking

rate, and %SLD. Regression analysis showed that F2 slope of /a/ and VOT of /d/ strongly contributed to speech intelligibility scores for the speakers with DS. Specifically, as F2 slope increased, speech intelligibility scores also increased. On the other hand, as the duration of VOT of /d/ increased, speech intelligibility decreased. Correlational analysis also showed that four other acoustic parameters were significantly related to speech intelligibility: these were VSA, mean amplitude of spontaneous speech, speaking rate, and M1 of /s/.

### **3.4 Discussion**

The aim of this study was to evaluate the five components of speech production for the speakers with DS using acoustic analysis and to compare the acoustic parameters to a group of typical speakers. The study also aimed to examine the contribution of the acoustic parameters to speech intelligibility scores, as measured by orthographic transcription by a group of experienced listeners, for the speakers with DS.

#### **3.4.1 Acoustic parameters of speech production that differentiate between speakers with Down syndrome and typical speakers**

The first main finding showed that there was a significant difference between the speakers with DS and the typical speakers for 12 of the 30 acoustic parameters. Some of these differences are in agreement with findings from previous research that have used acoustic analysis of speech production in speakers with DS. Regarding respiration, the speakers with DS had a reduced MPT compared to the typical speakers which indicates generally poorer respiratory support for speech production. A reduced MPT in speakers with DS has also been reported in a previous study (Seifpanahi et al., 2011). On other hand, another study found comparable MPTs between a group of speakers with DS and a group of typical speakers (Lee et al.,

2009b). However, as discussed in Chapter 1, the speakers in that study were members of a theatre group. Activities involved in a theatre group may include breathing exercises in order to develop acting skills and voice projection may have impacted on the speakers' ability to sustain phonation and thus, influenced their MPT. Studies that have used physiological measures of respiration report that reduced respiratory function is common in individuals with DS (Dichter et al., 1993).

Results of the present study also showed that the speakers with DS had a significantly higher mean F0 compared to the typical speakers. This finding has been described in studies who examined phonation in adults with DS (e.g. Albertini et al., 2010; Lee et al., 2009b; Seifpanahi et al., 2011). A higher mean F0 may be due to the speakers with DS having a smaller larynx compared to the age-matched typical speakers (Miller & Leddy, 1999). A smaller larynx would indicate shorter vocal folds that move more quickly, resulting in a higher mean F0 (MacKenzie, 2013). Kent, Vorperian, Kent, and Duffy (2003) also suggested that a relatively higher mean F0 can be due to certain neurological impairments, such as dysarthria, that impact on the motor control of the anatomical structures involved in phonation. Alternatively, the higher mean F0 may reflect a compensatory strategy in order to optimise laryngeal closure (Pinto, Chan, Guimarães, Rothe-Neves, & Sadat, 2017). Also noteworthy is that there was no significant difference for mean F0 of spontaneous speech between the speakers with DS and the typical speakers. Therefore, it is possible that the nature of the speech elicitation task used to evaluate phonation (sustained /a/) may have influenced the speakers with DS to produce phonation in a manner that did not reflect the way they would usually, thus, impacting on their mean F0.



Two other acoustic parameters of phonatory function, mean amplitude and HNR, did not differ between the speakers with DS and the typical speakers. The findings relating to amplitude indicate that the speakers with DS used similar levels of amplitude compared to the typical speakers. The mean HNR values of 16-17 dB indicate that both speaker groups did not have abnormally high levels of noise in the speech signal (Boersma, 1993). Previous studies that measured HNR in children with DS reported a lower HNR compared to typically developing children (Moura et al., 2008; Pentz & Gilbert, 1983). Another study on adults reported that some speakers had lower HNR values compared to typical speakers while others had typical HNR values (Moran & Gilbert, 1982). It may be that the HNR varies across speakers with DS which may have impacted on the current study's analysis.

For articulation of vowels, the finding that the speakers with DS had a reduced VSA has also been reported by Bunton and Leddy (2011) and Dar et al. (2020). A smaller VSA can indicate reduced range of movement of the tongue, impacting on tongue height and advancement during articulation of speech sounds (Lam & Tjaden, 2016). However, a recent study by Carl et al. (2020) did not find a significant difference in VSA between eight young adults with DS and eight age- and gender-matched typical speakers. Rochet-Capellan and Dohen (2015) actually reported a higher VSA for a group of young adults with DS. One possible reason for these inconsistent findings regarding VSA across studies may be due to the age of the speakers. The speakers who participated in these studies ranged in age from 4 years to late twenties. Production of vowels in speakers with DS has been found to change with age (Wild et al., 2018); hence, this may have had an impact on the VSA findings. Another possible reason for the different VSA findings may reflect the variability in speech production within the acoustic space among those with DS

(Rochet-Capellan & Dohen, 2015). The second acoustic measure of vowel articulation, F2 slope, was found to be significantly shallower for /a/ in the group with DS. A shallower F2 slope indicates a slower rate of vocal tract change due to restricted tongue movement (Kim et al., 2009).

Regarding articulation of consonants, findings relating to VOT are in line with those of Brown-Sweeney and Smith (1997) who also found longer VOTs for voiced stop sounds in children with DS compared to typically developing children. Longer VOTs of voiced stops can be related to impaired fine co-ordination between articulation and phonation and can also reflect reduced or slower motor control during speech (Kim et al., 2009; Ludlow et al., 2019). Results of the M1 showed some interesting results; for /s/ and /f/, the speakers with DS had considerably lower M1 values compared to the typical speakers. Typically, the lower the M1 value, the further back in the mouth the place of articulation (Jongman, Wayland, & Wong, 1998). The lower M1 values for the speakers with DS indicate that /s/ and /f/ were produced in a more posterior place of articulation compared to the typical speakers' production possibly reflecting reduced distinction of tongue placement (Jongman et al., 1998).

In regard to prosody, a higher mean amplitude and higher amplitude range during spontaneous speech as found in the current study was also reported by Corrales-Astorgano et al. (2018). The higher mean amplitude may reflect a compensatory strategy arising from hearing difficulties (N.H.S., n.d.). That is, the speakers spoke louder in order to hear themselves speak better. Corrales-Astorgano et al. (2018) suggested that a higher amplitude range could indicate increased variability in laryngeal function and reduced motor control during speech for the speakers with DS. Additionally, the speakers with DS were also found to have a

significantly slower speaking rate when compared to the group of typical speakers; the typical speakers were nearly three times faster than the speakers with DS. Chapman et al. (1998) also reported a slower speaking rate in children and adolescents with DS compared to a control group. The slower speaking may have been caused by the speakers with DS needing more time to formulate their utterances and using longer pauses during speech production (Chapman et al. 1998).

Lastly, it is not surprising that the speakers with DS were found to have a higher number of SLD in their speech compared to the group of typical speakers. Based on observations gained during the analysis, the most common dysfluencies were syllable and word repetitions. The higher incidence of dysfluency in people with DS compared to the typical population has been well documented (Kent & Vorperian, 2013). As discussed in Chapter 1, the prevailing theories regarding the nature of dysfluency in speakers with DS are that dysfluent speech may be due to a linguistic impairment, motor speech impairment, or where both linguistic and motor processes interact (Howell, 2004). It may be that during the spontaneous speech task, the speakers with DS had difficulty formulating the linguistic content and structure of their spoken message which caused the linguistic processes to become out of sync with speech production sequences, resulting in syllable and word repetitions. It may also be that the motor demands of the speech task exceeded the motor capacity of the speakers with DS which interrupted sequences of movements during speech production (Howell, 2004).

### **3.4.2 Acoustic parameters of speech production that contributed to speech intelligibility scores for speakers with Down syndrome**

Regression analysis showed that two parameters pertaining to articulation, F2 slope of /a/ and voice onset time of /d/, were found to be the strongest contributors to

speech intelligibility for the speakers with DS. Findings pertaining to F2 slope showed that when F2 slope increased, speech intelligibility scores also increased. As mentioned previously, F2 slope represents the rate of change in vocal tract configuration from movement of the tongue (Kim et al., 2009). Therefore, similar to other speakers with motor speech disorders, shallower F2 slopes indicate that speakers with DS can have reduced control during speech production which can have a considerable impact on listener judgement of speech intelligibility. Although this was the first study to measure F2 slope in the speech of people with DS, the strong correlation between F2 slope and speech intelligibility is similar to findings of previous studies which have measured F2 slope in other populations such as those with cerebral palsy and Parkinson's disease (Kim, Kent, & Weismer, 2011b; Lee et al., 2014).

The VOT of the alveolar /d/ was the second strongest contributor to speech intelligibility for the speakers with DS. The negative relationship between VOT and speech intelligibility scores indicates that longer VOTs for the voiced /d/ consonant impeded on perception of speech intelligibility. It may be that alveolar sounds, which involve movement of the tongue to the top of the mouth, are particularly difficult for speakers with DS. Previous research using other types of instrumental analysis has reported difficulty with tongue-palate contact for production of alveolar sounds among speakers with DS (e.g. Timmins, Hardcastle, Wood, & Cleland, 2011). VOT of the alveolar sounds /d/ and /t/ have also emerged from regression models as strong contributors to intelligibility in people with dysarthria and those who are hearing-impaired (Metz et al., 1985; Monsen, 1978).

### 3.4.3 Other findings

Some acoustic parameters that did not emerge from the regression model as strong contributors to speech intelligibility were found during separate analyses to significantly correlate with speech intelligibility; these were VSA, M1 of /s/, mean amplitude of spontaneous speech, and speaking rate. As mentioned earlier, the VSA of the speakers with DS was significantly reduced compared to the typical speakers. The finding that VSA was significantly associated with speech intelligibility coincides with findings from studies that have investigated VSA and intelligibility in speakers with dysarthria (Allison et al., 2017; Higgins & Hodge, 2002; Kim, Hasegawa-Johnson, & Perlman, 2011a). A reduced VSA indicates restricted articulatory precision which can impact on the acoustic signal and reduce speech intelligibility (Kim et al., 2011b). The M1 of /s/ has also been found to be significantly associated with perception of consonant precision for speakers with amyotrophic lateral sclerosis (Tjaden & Turner, 1997). Moreover, Tjaden and Turner (1997) also explained that an increased distinctiveness in M1 between /s/ and /f/ aided listeners' perception of speech production. This acoustic distinction between /s/ and /f/ was reduced for the speakers with DS in the current study which may explain why the M1 of /s/ was significantly associated with speech intelligibility.

The finding that the speakers' mean amplitude was positively correlated with speech intelligibility supports previous studies which have reported that speaking louder can increase speech intelligibility for people with Parkinson's disease (Cannito et al., 2012). Improved speech intelligibility with increased speaking amplitude has also been found for two adults with DS (Mahler & Jones, 2012). Potential reasons for the link between amplitude and speech intelligibility are an ongoing debate. Researchers have proposed that increased amplitude can lead to

changes in acoustic properties such as increased F0 range and improved segmental articulation which may enhance the speech signal and thus, aid listener perception (Dromey & Ramig, 1998; Tjaden & Turner, 1997).

The speaking rate of the speakers with DS, which was considerably slower compared to the typical speakers, was found to correlate with speech intelligibility. Findings from the current study showed that as speaking rate increased, speech intelligibility also increased. One possible reason why speaking rate was associated with speech intelligibility may be that the slower than typical rate of the speakers with DS was associated with changes to prosodic features that negatively impacted on listener judgement of speech intelligibility (Tjaden et al., 2014b; Tjaden & Wilding, 2011). A slower than typical speaking rate is common in populations with motor speech impairment (Kent & Kim, 2003). Finally, as also discussed in the previous chapter, interspeaker variability was high among the speakers with DS. Parameters such as VSA, fluency, and amplitude range differed considerably across speakers. Variability was also higher compared to the typical speakers.

### **3.5 Conclusion**

The results from this study show that the speakers with DS differed from the typical speakers across a number of acoustic parameters pertaining to respiration, phonation, articulation, and prosody. The two groups of speakers did not differ in terms of resonance. Regression analysis showed that F2 slope of /a/ and VOT of /d/ contributed to speech intelligibility for the speakers with DS. The other acoustic parameters that were found to be associated with speech intelligibility were VSA, M1 of /s/, mean amplitude of spontaneous speech, and speaking rate. These findings indicate certain characteristics that feature in the speech intelligibility profile of speakers with DS including reduced co-ordination between phonation and

articulation, restricted tongue movement, reduced articulatory range for vowels, and reduced motor control for speech production.

## Chapter 4

# THE IMPACT OF LANGUAGE ABILITY ON SPEECH INTELLIGIBILITY IN INDIVIDUALS WITH DOWN SYNDROME

### 4.1 Introduction

The previous two studies employed auditory-perceptual judgements and acoustic analysis to investigate aspects of speech production that contributed to speech intelligibility in adolescents and adults with DS. This third study sought to build on these findings and investigated if aspects of language ability also contributed to speech intelligibility for this group. According to Castellanos et al. (2014), because both speech production and language utilise the same core information-processing systems, encoding, storage and retrieval, performance in one aspect is likely to influence performance in the other. The information-processing model discussed in Chapter 1 (Figure 1-5**Error! Reference source not found.**) illustrates this connection between language systems and speech systems. As discussed in section 1.6.1, when producing a spoken message, decisions made at the higher linguistic levels can guide the decisions made at the lower phonetic level, which then drive the motor aspects of speech production (Kent, 2009). In addition, speech production is monitored by the comprehension system and adjustments to speech production can be made if errors are identified. Therefore, it is possible that the linguistic difficulties commonly experienced by people with DS can affect their speech production, which would in turn impact on the acoustic signal and influence listener judgement of speech intelligibility (Flipsen et al., 2009).

As discussed in Chapter 1, people with DS can have a marked difficulty with both speech and language when measured relative to their cognitive impairment and when compared to other populations with the same level of cognitive ability



(Abbeduto et al., 2001; Chapman, 2006). Regarding the relationship between speech and language in this population, researchers have mainly focused on how speech intelligibility might impact on language ability. Miller and Leddy (1999) suggest that if reduced speech intelligibility interrupts successful communication for an individual with DS, then they would be more likely to reduce their number of speaking attempts and miss opportunities to practice their expressive language skills hence, impacting on language development. Chapman et al. (1998) also suggested that improving language skills for people with DS without increasing their speech intelligibility may be of limited functional value as it is speech intelligibility that permits the effective use of the language skills that have been developed.

However, when viewing the relationship between speech intelligibility and language from the other direction, that is, how language might impact on speech intelligibility, considerably less literature is available. As discussed in 1.7.2 of Chapter 1, just two studies have examined how aspects of language ability in those with DS have contributed to their speech intelligibility. One study by Chapman et al. (2000) used multiple regression analysis to examine the impact of language comprehension along with other variables, on speech intelligibility in 48 children and adolescents with DS. Speech intelligibility was measured by calculating the proportion of intelligible utterances from a spontaneous speech sample and language comprehension was measured using the total raw score from the Test of Auditory Comprehension of Language-Revised (Carrow-Woolfolk, 1985). Out of hearing acuity, chronological age, cognition level, and maternal education, language comprehension was the strongest contributor to speech intelligibility scores for the speakers with DS, but still only accounted for 14% of the variance. Chapman et al. (2000) concluded that comprehension skills should continue to be targeted in therapy

for adolescents and adults with DS as comprehension can make positive contributions to their speech intelligibility. However, the expressive language of those with DS was not measured in this study, leaving an incomplete picture of the relationship between language ability and speech intelligibility for the individuals with DS.

The results of the second study by Cleland et al. (2010) proposed that reduced speech intelligibility in speakers with DS may be independent of language ability. They investigated the relationship between speech intelligibility, language skills, and cognition for 15 children and adolescents with DS. A variety of standardised measures were used to estimate the participants' speech, language, and cognition abilities. To measure speech intelligibility, they used the Children's Speech Intelligibility Measure (Wilcox & Morris, 1999). This assessment involves an unfamiliar listener listening to 50 words produced by the speaker. For each word, the listener is given a list of 12 words including the target word and 11 phonetically similar options (e.g. if the target word was tall, the other words in the list would be stall, wall, shawl, call, all, fall, ball, hall, crawl, mall, and Paul). The listener then chooses the word from the list that they thought the speaker produced. However, using correlation analysis, Cleland et al. found no significant relationship between speech intelligibility and any measure of language ability, as measured by age equivalent scores from the receptive and expressive subtests of the Clinical Evaluation of Language Fundamentals-Preschool (Wiig et al., 2006). The authors suggested that the speech intelligibility difficulties in DS were caused by some factor other than language, most likely a difficulty with speech motor control.

In addition to the findings of the two studies discussed above, there are a number of other aspects that are known about language ability in people with DS that

could impact on their speech intelligibility. Firstly, as discussed previously in section 1.7.2 of Chapter 1, people with DS can have considerable difficulties with phonological representations (Dodd & Thompson, 2001; Laws & Bishop, 2003). If speakers have under-developed knowledge of words and their phonological characteristics, it is likely that this will impact on the production of these words and thus affect listener judgement of speech intelligibility. Secondly, people with DS have expressive language skills that lag behind their receptive language development and mental age. They have been reported to use shorter sentences at the expense of syntactic complexity and cohesion (Chapman et al., 1998). Shorter utterances provide the listener with limited opportunities to decipher the spoken message (Magnus, 2011). Moreover, a marked difficulty with expressive syntax in people with DS may result in the omission of grammatical markers resulting in the misinterpretation of a spoken utterance which could impact on listener judgement of speech intelligibility (Laws, 2004). Lastly, individuals with DS have also been found to have less efficient word retrieval strategies (Nash & Snowling, 2008). Difficulties with word retrieval have been commonly reported to negatively impact on fluency and prosodic patterns during speech production for people with dysarthria and aphasia (Kavé & Goral, 2017). Hence, word retrieval may also have an influence on prosody and fluency for speakers with DS which could distort the speech signal and negatively impact on perception of speech intelligibility.

To summarise the limited evidence so far, the way in which language ability contributes to speech intelligibility in those with DS is somewhat unclear. If SLTs knew more about the nature of this relationship, they would be able to use this knowledge to maximise therapeutic success when seeking to increase speech intelligibility for those with DS. This study aimed to investigate how language

ability contributed to speech intelligibility in adolescents and adults with DS. The following research question was posed for this study:

1. What measures of language ability contribute to speech intelligibility in people with DS?

## **4.2 Method**

### **4.2.1 Participants**

The speakers were the same 30 adolescents and adults with DS who were included in the two previous studies. The listeners were also the same group of 16 listeners. The characteristics of the speakers and the listeners are detailed in section 2.2.1 in Chapter 2.

### **4.2.2 Procedure for measuring receptive language**

The Test for Auditory Comprehension of Language-4<sup>th</sup> edition (TACL-4, Carrow-Woolfolk, 2014), which is a standardised test for evaluating receptive language in children aged 3-12 years, was administered to the speakers with DS to evaluate their receptive language. This assessment contains three subtests that evaluate (1) receptive vocabulary of nouns, verbs, describing words and concepts; (2) understanding of grammatical morphemes, including prepositions, pronouns, determiners, and inflections; and (3) understanding of elaborated phrases and sentences. All three subtests were administered to each speaker with DS in accordance with the test manual; individuals heard a word or sentence spoken by the investigator and were asked to identify the corresponding picture from a choice of four items. The raw score for each subtest was used to obtain three measures of receptive language (e.g. Miolo et al., 2005). The raw scores were used instead of standard scores as the TACL-4 is not standardised for people with DS and

individuals were over 12 years of age, which was the upper age limit of the assessment.

### **4.2.3 Procedure for measuring expressive language**

To measure expressive language for the individuals with DS, their spontaneous speech samples were analysed by obtaining two measures using Computerised Language Analysis (CLAN) software (MacWhinney, 2000). As described in Chapter 2, spontaneous speech was elicited by asking speakers to talk about life topics, including friends, families, school/work, and hobbies while being recorded (Wilson et al., 2019b). The first measure obtained using CLAN was MLU which represents the average number of morphemes in an utterance. The second measure obtained was vocabulary diversity (vocD, Malvern et al., 2008). The vocD is a mathematical model that analyses the probability of new vocabulary being introduced as speech samples increase in length (see section 1.7.2 in Chapter 1 for more discussion about these receptive and expressive language measures). In the current study, the spontaneous speech sample from each speaker was transcribed, coded and separated into C-units in accordance with CHAT transcription guidelines (CHAT stands for Codes for the Human Analysis of Transcripts and is the transcription format that is compatible with CLAN software). A C-unit is an independent clause and any associated subordinate or co-ordinate clause, not unlike a sentence. The “KIDEVAL” function in CLAN was then used to obtain the MLU in morphemes and the vocD.

### **4.2.4 Procedure for measuring speech intelligibility**

The procedure used for measuring speech intelligibility was an orthographic transcription task completed by 16 listeners (see section 2.2.8 in Study 1).

#### **4.2.5 Procedure for measuring hearing acuity and oro-motor function**

The materials and procedure used for administering the hearing test for the speakers with DS and evaluating their oro-motor function was the same (see sections 2.2.5 and 2.2.6 in Study 1).

#### **4.2.6 Data analysis**

To assess inter-rater reliability for the measures of language ability, a second investigator, who was experienced in using CLAN software analysed a randomly selected 20% of the expressive language samples. The record sheets for the receptive language assessment were also reviewed by the second investigator to ensure they were scored correctly. The procedure for calculating the speech intelligibility scores is outlined in section 2.2.9 in Study 1.

The Statistical Package for the Social Sciences (version 26) was used to analyse the collected data. Frequency distributions for speech intelligibility, the three measures of receptive language (vocabulary, grammatical morphemes, and elaborated phrases and sentences) and the two measures of expressive language (MLU and vocD) were inspected. Q-Q plots were computed to ensure normality of distribution. Scatterplots were also computed to examine if the relationship between the speech intelligibility and each language measure was roughly linear. Correlation analysis was used to examine the relationship between speech intelligibility and each language measure. Then, multiple regression with stepwise entry methods was used to examine which receptive and/or expressive language measures (independent variables) contributed to the speakers' intelligibility (dependent variable). As was the method for the previous two studies, hearing acuity scores were added into the first block of the regression model to control for its effects on speech production.

Diagnostic testing was carried out to ensure that the data did not violate the five assumptions for multiple regression (as explained in section 2.2.9 of Chapter 2).

## **4.3 Results**

### **4.3.1 Language measures**

The speech intelligibility, hearing acuity and oro-motor function scores are presented in Table 2.3 and Table 2.4 in Study 1 (p. 99). Table 4.1 below summarises the receptive and expressive language scores for each speaker; age equivalents for the three receptive language measures are also included. The mean score was 34.37 out of 60 (SD = 7.08; range = 20-50) for receptive vocabulary, 29.53 out of 60 (SD = 8.59; range = 7-44) for grammatical morphemes, and 20.63 out of 56 (SD = 7.85; range = 8-40) for elaborated phrases and sentences. For expressive language, the mean MLU score was 8.21 (SD = 2.65; range = 3.67-12.87) and the mean vocD score was 71.88 (SD = 18.30; range = 32.97-111.03).

**Table 4.1.** *Raw Scores (RS) and Age Equivalents (AE) for Measures of Receptive Language (Vocabulary; Grammatical Morphemes; Elaborated Phrases & Sentences) and those of Expressive Language (MLU; vocD) for each Speaker with Down syndrome*

| Sp | Vocabulary |       | Grammatical morphemes |      | Elaborated phrases & sentences |      | MLU   | VocD  |
|----|------------|-------|-----------------------|------|--------------------------------|------|-------|-------|
|    | RS (60)    | AE    | RS (60)               | AE   | RS (56)                        | AE   |       |       |
| 1  | 44         | 7;06  | 39                    | 5;0  | 22                             | 4;03 | 10.69 | 47.90 |
| 2  | 28         | 4;03  | 19                    | 3;06 | 17                             | 3;09 | 10.02 | 38.17 |
| 3  | 48         | 9;06  | 34                    | 5;03 | 37                             | 6;06 | 11.07 | 50.29 |
| 4  | 48         | 9;06  | 39                    | 5;09 | 27                             | 5;00 | 8.04  | 67.47 |
| 5  | 36         | 5;06  | 15                    | 3;0  | 16                             | 3;60 | 6.65  | 67.58 |
| 6  | 29         | 4;06  | 13                    | <3;0 | 15                             | 3;90 | 3.71  | 33.09 |
| 7  | 28         | 4;03  | 31                    | 4;09 | 11                             | 3;03 | 6.16  | 79.76 |
| 8  | 28         | 4;03  | 32                    | 5;0  | 13                             | 3;06 | 7.15  | 33.89 |
| 9  | 29         | 4;06  | 24                    | 3;09 | 13                             | 3;06 | 4.24  | 69.95 |
| 10 | 27         | 4;03  | 25                    | 3;09 | 13                             | 3;06 | 6.9   | 51.27 |
| 11 | 22         | 3;06  | 22                    | 3;09 | 12                             | 3;06 | 6.02  | 27.63 |
| 12 | 33         | 5;03  | 31                    | 4;09 | 24                             | 4;09 | 4.59  | 45.98 |
| 13 | 34         | 5;03  | 31                    | 4;09 | 28                             | 5;00 | 5.94  | 44.72 |
| 14 | 38         | 5;09  | 36                    | 5;06 | 31                             | 5;06 | 11.26 | 56.23 |
| 15 | 31         | 5;0   | 24                    | 3;09 | 20                             | 3;09 | 7.34  | 53.23 |
| 16 | 37         | 5;09  | 42                    | 6;06 | 26                             | 5;00 | 11.23 | 54.51 |
| 17 | 35         | 5;06  | 29                    | 4;06 | 21                             | 4;00 | 10.67 | 39.58 |
| 18 | 40         | 6;03  | 33                    | 5;0  | 18                             | 3;09 | 7.67  | 61.42 |
| 19 | 20         | 3;03  | 7                     | <3;0 | 8                              | 3;00 | 3.31  | 50.75 |
| 20 | 37         | 5;09  | 30                    | 4;09 | 18                             | 3;09 | 9.56  | 38.32 |
| 21 | 33         | 5;03  | 27                    | 4;03 | 22                             | 4;03 | 6.66  | 78.34 |
| 22 | 37         | 5;09  | 38                    | 5;09 | 36                             | 6;03 | 10.65 | 78.32 |
| 23 | 33         | 5;03  | 32                    | 5;0  | 21                             | 4;00 | 10.31 | 65.58 |
| 24 | 34         | 5;03  | 29                    | 4;06 | 20                             | 3;09 | 12.87 | 76.11 |
| 25 | 37         | 5;09  | 35                    | 5;03 | 16                             | 3;09 | 11.09 | 83.31 |
| 26 | 37         | 5;09  | 21                    | 3;06 | 17                             | 3;09 | 10.21 | 56.76 |
| 27 | 50         | 10;09 | 44                    | 7;0  | 40                             | 6;09 | 11.38 | 81.61 |
| 28 | 29         | 4;06  | 35                    | 5;03 | 14                             | 3;06 | 8.98  | 56.27 |
| 29 | 38         | 5;09  | 36                    | 5;06 | 22                             | 4;03 | 5.96  | 72.37 |
| 30 | 31         | 5;0   | 33                    | 5;0  | 21                             | 4;00 | 62    | 69.80 |

*Note.* Numbers in brackets represent total possible scores. Sp = speaker; MLU = mean length of utterance; vocD = vocabulary diversity.



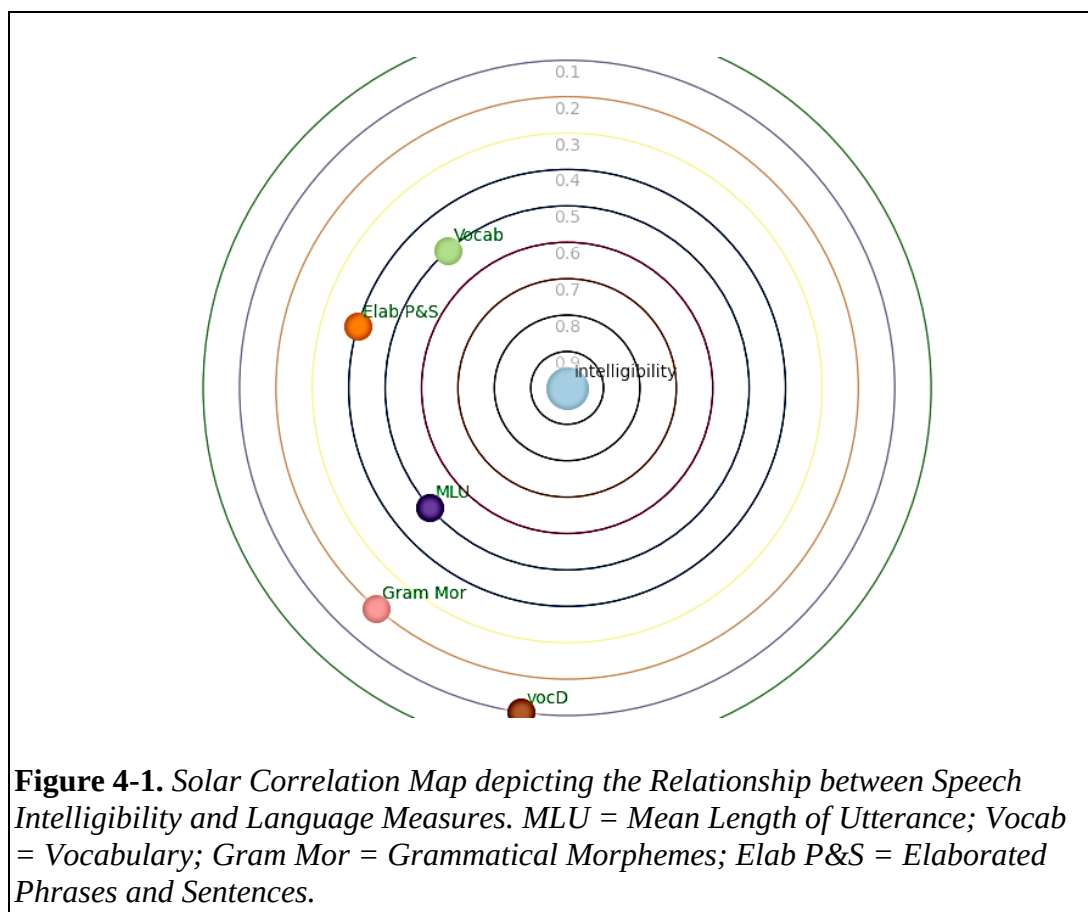
### 4.3.2 The relationship between language ability and speech intelligibility in people with Down syndrome

The examination of Q-Q plots and histograms showed that the data was not normally distributed (Appendix O). Therefore, Spearman rank-order correlations were computed to examine the relationship between the speech intelligibility and each of the language measures. Table 4.2 and Figure 4-1 summarise the correlation results between speech intelligibility and each language measure. Speech intelligibility scores were found to be significantly positively correlated with receptive vocabulary and MLU. There was no significant correlation greater than 0.8 between any of the language measures (Appendix P), hence there are no moons in Figure 4-1.

**Table 4.2.** *Spearman Rank-order Correlations between Speech Intelligibility and Receptive and Expressive Language Measures*

|                        | Vocabulary | Grammatical morphemes | Elaborated phrases & sentences | MLU     | VocD |
|------------------------|------------|-----------------------|--------------------------------|---------|------|
| Speech intelligibility | 0.43*      | 0.12                  | 0.35                           | 0.53*** | 0.16 |

*Note.* MLU = mean length of utterance; VocD = vocabulary diversity.



### 4.3.3 Language measures that contributed to speech intelligibility for the speakers with Down syndrome

Examination of scatterplots showed that the relationship between speech intelligibility and each language measure variable was roughly linear (Appendix Q). Table 4.3 and Table 4.4 summarise the results of the regression model. The results indicated that MLU independently explained 25% of the variance in speech intelligibility scores, adjusted  $R^2 = 0.25$ ,  $F(1, 28) = 10.64$ ,  $p < .01$ . These results indicate that, while all other variables remained constant, as MLU scores increased by one-unit speech intelligibility scores also increased by 4.7. Similar to the previous studies, hearing acuity did not impact on speech intelligibility scores.

**Table 4.3.** *Summary of Regression Model for Study 3*

| Variable       | $R^2$ | Adjusted $R^2$ | $R^2$ change | $F$ change | Sig  |
|----------------|-------|----------------|--------------|------------|------|
| Hearing acuity | 0.00  | -0.03          | 0.00         | 0.07       | 0.79 |
| MLU            | 0.30  | 0.25           | 0.30         | 11.65      | 0.00 |

*Note.* Sig = significance level; MLU = mean length of utterance.

**Table 4.4.** *Coefficients of Regression Model for Study 3*

| Variable       | $B$  | Standard error | $T$   | Sig  | VIF  |
|----------------|------|----------------|-------|------|------|
| Hearing acuity | 0.01 | 0.36           | -0.03 | 0.98 | 1.02 |
| MLU            | 4.56 | 1.34           | 3.40  | 0.00 | 1.02 |

*Note.* Sig = significance level; VIF = variance inflation factor; MLU = mean length of utterance.

#### 4.3.4 Inter-rater reliability

The percentage agreement scores for MLU and vocD were 92% and 91% respectively.

#### 4.3.5 Diagnostics tests

Below is the outcome of the diagnostic tests for checking whether the data violated any of the assumptions required for multiple regression.

**Assumption 1:** Figure 4-2 plots the residuals of the regression model on the y-axis against the contributing variable MLU and shows that there is no clear pattern among the residuals. Hence, a linear relationship can be assumed between the dependent variable and the contributing variable.

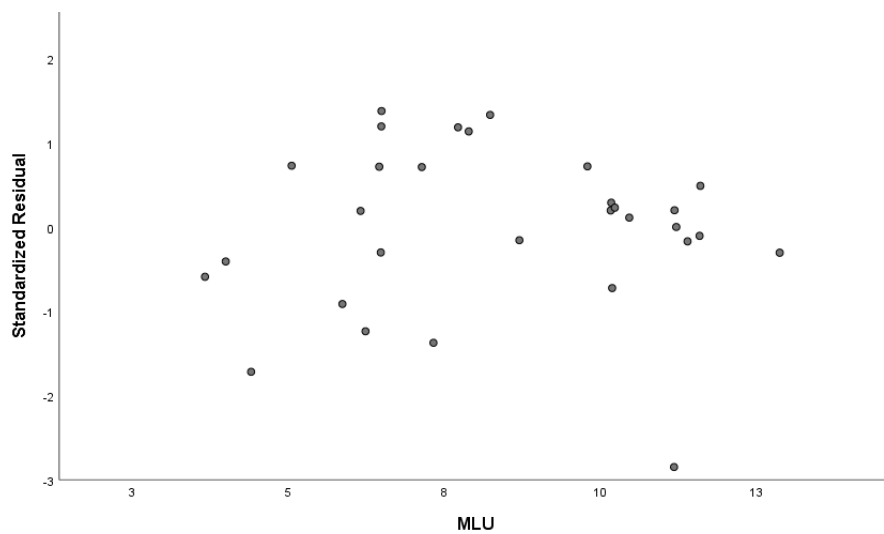
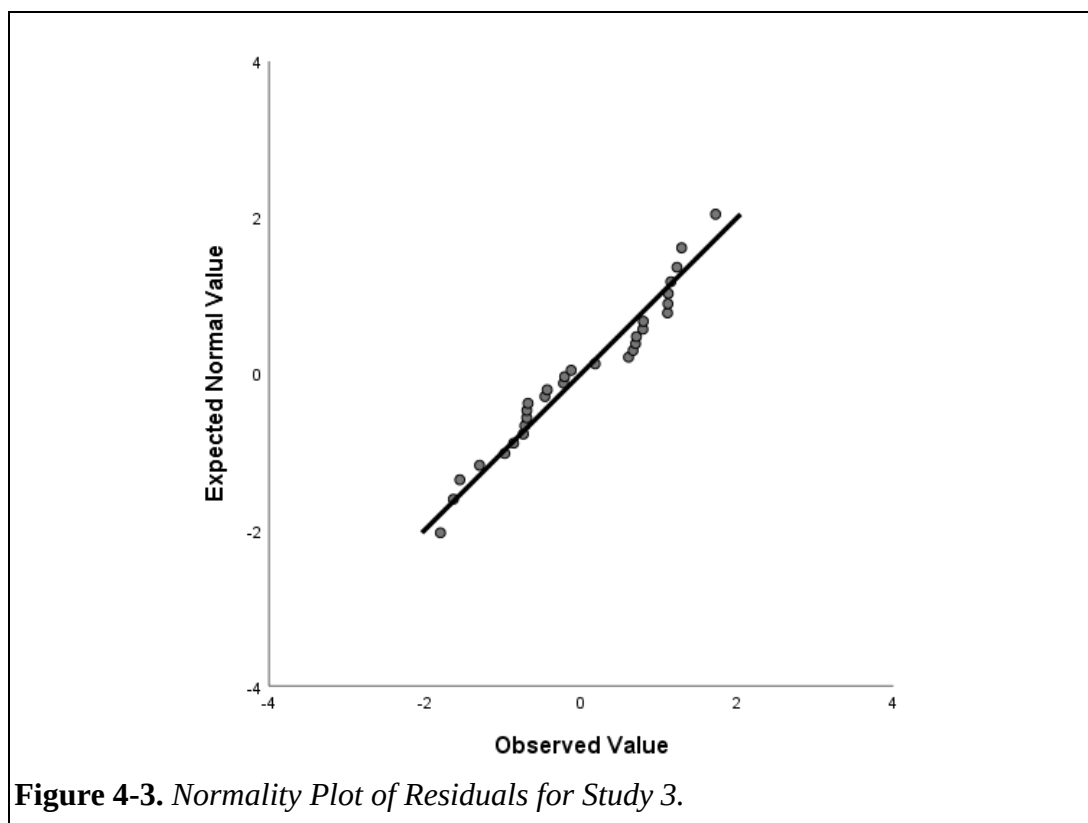


**Figure 4-2.** *Scatterplot of the Standardised Residuals as Function of Mean Length of Utterance (MLU, contributor variable) for Study 3.*

**Assumption 2:** The result of the Durbin-Watson test was 2.13. As this value is close to 2, we can assume that the residuals are not highly correlated with each other.

**Assumption 3:** The Breusch-Pagan test showed a chi-square value of 1.13,  $p = 0.29$ . As this is above the significance level of 0.05, we can reject the null hypothesis that heteroscedasticity exists in the residuals of this regression model.

**Assumption 4:** Figure 4-3 plots the predicted residual values on the x-axis against the standardised residuals on the y-axis. The scatterplot follows a straight line which indicates that the residuals are normally distributed.



**Assumption 5:** The variance inflation factors (VIF) are below ten, which indicates a low risk of multicollinearity within the data (see Table 4.4).

#### 4.3.6 Summary of results

The correlation analyses showed that receptive vocabulary and MLU were significantly associated with speech intelligibility for the speakers with DS. The multiple regression results showed that out of five variables representing receptive and expressive language skills, MLU was the strongest contributor to speech intelligibility, in that as MLU increased, so did speech intelligibility scores.

### 4.4 Discussion

This study aimed to examine how aspects of language ability contributed to speech intelligibility in speakers with DS. The language measures were vocabulary, grammatical morphemes, and elaborated phrases and sentences for capturing the receptive language abilities and MLU and vocD for expressive language abilities.

Similar to the perceptual and acoustic measures in the previous two studies (see Chapter 2 and 3), there was high variability in language scores among those with DS, indicating a heterogeneous group in terms of receptive and expressive language skills. Correlational analysis showed that MLU and receptive vocabulary were significantly associated with speech intelligibility scores. Results of multiple regression showed that MLU was the primary contributor to the speakers' speech intelligibility accounting for 25% of the variability. There are a few possible reasons to explain the relationship between language ability and speech intelligibility that was found in this study.

Firstly, as MLU can be used as a broad index of overall expressive language development (Flipsen & Kangas, 2014), it may be that the speakers with DS who had stronger expressive language skills were likely to make more attempts at verbal communication, hence being encouraged to practice speech production more often resulting in higher speech intelligibility (Miller, 2013). The findings also align with the information-processing model of speech production (Figure 1-5). That is, those with DS who had better overall language skills, as indicated by a higher MLU (Flipsen & Kangas, 2014), had less difficulty at the linguistic level of processing, hence the phonetic and motor aspects of speech production were less impacted upon resulting in higher perceived speech intelligibility (Kent, 2009).

From the perspective of the listener, if speakers produced longer sentences (i.e. had a higher MLU), the listeners would be provided with more opportunity to identify the words spoken by the speakers. This may also explain why the speakers in the current study who had higher MLUs were judged to have higher speech intelligibility compared to the speakers who spoke in shorter sentences. This finding is congruent with that of Magnus (2011) who found that a longer mean length of

response was associated with better speech intelligibility in speakers with cleft lip and palate. However, one previous study found that speech intelligibility in speakers with DS decreased as sentence length or MLU increased (Bray & Woolnough, 1988). Another study by Chapman et al. (1998) also found no relationship between speech intelligibility and MLU for children and adolescents with DS. The authors of these studies suggested that as speakers with DS produce longer sentences, there is an increased demand on motor speech performance which can result in reduced speech intelligibility.

The finding that speech intelligibility was also positively associated with receptive vocabulary was partially in agreement with that of Chapman et al. (2000). Using regression analysis, Chapman et al. (2000) found that comprehension was the strongest contributor to speech intelligibility in children and adolescent speakers with DS. However, a measure of expressive language was not included in their regression model which makes direct comparison of the results with the present study difficult. One possible explanation for the significant relationship between receptive vocabulary and speech intelligibility may be that those with better receptive skills can understand and process instructions better, resulting in a better response to therapy targeting increased speech intelligibility. On the other hand, if this was the case, one may also expect a correlation between speech intelligibility and the other measures of receptive language, grammatical morphemes and understanding of phrases and sentences, which was not the case. Nonetheless, the significant association between receptive vocabulary and speech intelligibility found in this study supports the theory of Chapman et al. (2000) in that language comprehension can be a facilitator for the improvement of speech production and increased speech intelligibility in those with DS.

The results from the current study contrasted somewhat with those of Cleland et al. (2010). The current study found that MLU and receptive vocabulary were positively correlated with speech intelligibility scores. However, Cleland et al. (2010) found no significant relationship between speech intelligibility and any measure of receptive or expressive language for a group of speakers with DS. They proposed that the difficulties with speech intelligibility in people with DS were not related to language. However, the study by Cleland et al. (2010) and the present study differed in a number of ways. Firstly, the speakers in the Cleland et al. (2010) study were recruited as part of an intervention study targeting improved speech production. On this point, the authors state that the participants were recruited into their study for the purpose of speech intervention to increase intelligibility “they may represent a group of children with usually severe speech disorders ... families of children with very intelligible speech were not likely to present themselves for inclusion in an intervention study aiming to improve speech” (p. 92). Secondly, different aspects of expressive language were measured in the two studies. Cleland et al. (2010) evaluated naming of nouns and verbs, sentence recall, and expression of morphological rules. Whereas the current study measured MLU and vocD, which could be considered to be more global indicators of expressive language ability. These differences between the two studies would have affected the statistical analyses in each study and may explain the contrasting findings. Lastly, the age range of the speakers in Cleland et al.’s (2010) study was 9-18 years compared to 16-47 years for the speakers in the current study. It may be that the relationship between speech and language in individuals with DS changes as they grow older.



#### **4.5 Conclusion**

The results of this study showed that, out of five language measures, MLU strongly contributed to speech intelligibility for the speakers with DS. Receptive vocabulary was also positively correlated with speech intelligibility but to a lesser degree. These findings suggest that language ability may play an influential role in the speech intelligibility of those with DS, but that other factors could mediate between speech and language in this group and more investigation is required to explore the nature of the association further.

## **Chapter 5**

### **EFFECT OF LISTENER EXPERIENCE AND MEASUREMENT METHOD ON SPEECH INTELLIGIBILITY SCORES IN DOWN SYNDROME**

#### **5.1 Introduction**

The first and second studies have reported the perceptual and acoustic parameters of speech production that can contribute to speech intelligibility in adolescent and adult speakers with Down syndrome (DS). The third study showed that language skills, and in particular mean length of utterance (MLU), can also contribute to speech intelligibility for this group. However, in addition to the aspects of speech and language investigated in the first three studies, other factors may also impact on speech intelligibility for this group. As described in Chapter 1, factors of intelligibility assessment, such as the method of measurement and the experience level of listeners, can also influence speech intelligibility outcomes (Barreto & Ortiz, 2008). However, even though these factors of speech intelligibility assessment have been examined in other clinical populations, they have not been investigated for speakers with DS.

The main methods that are used to measure speech intelligibility have been described in section 1.5 in Chapter 1. The most commonly used methods include orthographic transcription and scaling procedures, such as equal-appearing interval scale (EAI), direct magnitude estimation (DME) and visual analogue scale (VAS, Barreto & Ortiz, 2008; Walshe et al., 2008). However, as discussed in section 1.6.4, the different methods of measuring speech intelligibility can yield different outcome scores. In general, speech intelligibility scores obtained from orthographic transcription tend to be higher than scores obtained from more impressionistic scaling methods. This finding has been reported for speakers with dysarthria,

Parkinson's disease, and multiple sclerosis (e.g. Abur et al., 2019; Stipancic et al., 2016; Tjaden, Kain, & Lam, 2014a; Yorkston & Beukelman, 1978). When comparing the use of orthographic transcription and VAS as measurement methods for speech intelligibility, studies have also found that even when the speech intelligibility scores obtained using the two methods significantly differed, the scores strongly correlated with each other (Abur et al., 2019; Stipancic et al., 2016). The authors of these studies surmised that VAS may be a viable method for measuring speech intelligibility in a busy clinic.

Another important factor to consider when interpreting speech intelligibility scores is the experience of the listener who judges the speech sample. As discussed in section 1.6.3 in Chapter 1, the majority of studies show that experienced listeners can perceive speech as more intelligible compared to inexperienced listeners (e.g. Beukelman & Yorkston, 1980; Flipsen, 1995; McGarr, 1983). On the other hand, when measuring speech intelligibility in those with dysarthria, some studies have found that naive and experienced listeners did not perceive speech intelligibility differently (Keintz et al., 2007; Smith et al., 2019; Walshe et al., 2008). However, some methodological differences in relation to the criteria used to classify a listener as inexperienced or experienced exist across studies which may account for some of the inconsistent findings. As very few studies have used the same experimental protocol when investigating these factors of speech intelligibility assessment, it makes interpretation and comparison of results difficult. Nevertheless, these factors have not yet been examined in relation to the evaluation of speech intelligibility in speakers with DS and this study sought to address this gap in knowledge.

The methods of measurement chosen for investigation in the current study were orthographic transcription and VAS. Orthographic transcription was chosen as

it is the most frequently used method for objectively measuring speech intelligibility (Stipancic et al., 2016). VAS was chosen for use as the subjective rating method because it provides more statistical analysis options compared to other scaling methods (Baylis et al., 2015). VAS has also been shown to have higher reliability compared to EAI scales and DME scales when evaluating aspects of speech production (Munson & Carlson, 2016). Furthermore, scaling tasks, such as VAS, can be more attractive for use by SLTs as they are less time-consuming and less labour intensive than orthographic transcription (Miller, 2013; Schellinger, Munson, & Edwards, 2017). However, as mentioned earlier in this chapter, the comparison of different methods used to measure speech intelligibility has not been carried out for speakers with DS; nor has the effect of listener experience on judgement of speech intelligibility been examined for this group.

This study aimed to address these gaps in knowledge around speech intelligibility assessment in those with DS by examining the differences between speech intelligibility scores when (a) measured using orthographic transcription versus VAS and (b) when judged by experienced versus naive listeners. The study also aimed to investigate the association between the four sets of speech intelligibility scores obtained by the two methods of measurement judged by the two different groups of listeners. It was hypothesised, based on previous studies, that the listeners would achieve higher scores in the orthographic transcription task compared to the VAS task. Regarding the effect of listener experience on the measurement of speech intelligibility, it was also hypothesised that due to their increased exposure to atypical speech, the experienced listener group would score higher in both measurement methods compared to the naive group. A version of this study has been

accepted for peer-review publication in the International Journal of Language and Communication Disorders.

## **5.2 Method**

### **5.2.1 Participants**

For this experiment, the participants were the 16 speakers with DS described in the Study 1 (section 2.2.1, Chapter 2), and 32 typical adult listeners (16 experienced and 16 naive) recruited to judge the speech intelligibility of the speakers with DS. The experienced listeners were those who judged speech intelligibility reported in Study 1, 2, and 3. To recap, they were professionals who had been working full-time with individuals who had learning or speech difficulties for a minimum of three years. The listeners in the naive group, by self-report, had not received any training in phonetics or judgement of speech disorders; and did not have any regular contact with individuals with DS or those with an intellectual disability. Additionally, all listeners were monolingual Irish-English speakers, had been working in Cork, Ireland for at least five years, and passed a hearing screen at 25 dBHL at 1000, 2000, and 4000 Hz in both ears.

### **5.2.2 Procedure for measuring speech intelligibility**

The listeners completed both an orthographic transcription task and a rating task using VAS on the same set of stimuli to obtain two measures of speech intelligibility for each speaker. Rating and transcribing the same sentences allowed for a direct comparison of scores between the two methods. The listeners completed the two tasks on separate days at least one week apart to prevent a learning effect and the order of completion of each task was counterbalanced across the listeners. The same materials and procedure for orthographic transcription described in section 2.2.8 of Study 1 was applied to the 16 naive listeners; hence, each of the eight sets of

sentences produced by the 30 speakers with DS were judged by eight experienced listeners and eight naive listeners (see also Figure 2-3 in Chapter 2). For the rating task, the listeners heard a sentence and were asked to make a mark along a 100 mm VAS which reflected their perception of the speaker's speech intelligibility. The left end of the scale represented "0% intelligibility" and the right end represented "100% intelligibility." One VAS was completed for each sentence and listeners were allowed one repetition of each sentence before moving on (see Appendix R for listening task instructions).

### **5.2.3 Data analysis**

The procedure for calculating the orthographic transcription scores is explained in Study 1. To reiterate, the orthographic transcription score for each speaker was obtained by dividing the number of correctly transcribed words by the total number of target words and multiplying by 100. In order to obtain the VAS scores for each sentence, the distance from the left end of the VAS to the mark made by the listener was measured in mm. The mean rating score was obtained for each sentence and then for each speaker.

The data was analysed using the Statistical Package for the Social Sciences (version 26). Initial inspection of histograms and Q-Q plots was carried out to check if the data was normally distributed. A two-way repeated measures analysis of variance (ANOVA) was carried out to investigate the differences between the speech intelligibility scores for (1) the two measurement methods: orthographic transcription and VAS; and (2) the two groups of listeners: experienced and naive. Spearman rank-order correlation analysis was also carried out to examine the relationship between the four sets of speech intelligibility scores measured by each listener group using each measurement method.

## 5.3 Results

### 5.3.1 Speech intelligibility scores

The speech intelligibility scores for each speaker obtained using orthographic transcription and VAS rating by the experienced and naive listeners are summarised in Table 5.1. For the experienced listener group, the mean speech intelligibility score measured using orthographic transcription was 73.6 (SD = 21.44; range = 20.67-98.33) and the mean speech intelligibility score measured using VAS was 64.4 (SD = 22.58; range = 13.25-98.17). For the naive listener group, the mean speech intelligibility score was 70.10 (SD = 24.04; range = 20.00-98.89) as measured using orthographic transcription and 60.40 (SD = 23.96; range = 14.5-94.5) as measured using VAS.

**Table 5.1.** *Speech Intelligibility Scores obtained from Orthographic Transcription (OT) and Visual Analogue Scale (VAS); and the Experienced (Exp) and Naive Listeners*

| Speaker | OT - Exp | OT - Naive | VAS - Exp | VAS - Naive |
|---------|----------|------------|-----------|-------------|
| 1       | 67.86    | 70.56      | 64.54     | 58.92       |
| 2       | 94.42    | 94.44      | 79.04     | 79.00       |
| 3       | 83.78    | 82.78      | 81.33     | 80.21       |
| 4       | 97.32    | 98.89      | 90.30     | 87.13       |
| 5       | 90.77    | 81.67      | 77.79     | 73.46       |
| 6       | 44.79    | 30.56      | 32.25     | 20.04       |
| 7       | 66.44    | 72.78      | 68.08     | 60.50       |
| 8       | 47.69    | 28.89      | 37.96     | 32.96       |
| 9       | 27.08    | 20.00      | 13.25     | 14.50       |
| 10      | 57.81    | 56.67      | 43.75     | 43.71       |
| 11      | 43.97    | 48.33      | 31.00     | 26.04       |
| 12      | 71.43    | 60.56      | 52.83     | 39.79       |
| 13      | 78.57    | 72.22      | 65.92     | 67.13       |
| 14      | 88.24    | 82.78      | 73.92     | 55.42       |
| 15      | 93.23    | 87.22      | 87.77     | 80.71       |
| 16      | 31.77    | 30.00      | 23.96     | 15.83       |
| 17      | 89.96    | 90.00      | 83.50     | 83.88       |
| 18      | 93.15    | 91.11      | 80.96     | 83.08       |
| 19      | 39.88    | 33.89      | 32.00     | 26.83       |
| 20      | 86.53    | 91.11      | 76.92     | 79.25       |
| 21      | 80.88    | 81.67      | 69.13     | 68.79       |
| 22      | 85.64    | 86.11      | 69.79     | 77.29       |
| 23      | 84.67    | 83.33      | 78.58     | 70.58       |
| 24      | 87.95    | 80.56      | 78.04     | 78.96       |
| 25      | 86.76    | 88.33      | 82.75     | 71.42       |
| 26      | 87.05    | 88.33      | 76.71     | 76.79       |
| 27      | 98.29    | 98.89      | 99.17     | 94.50       |
| 28      | 72.69    | 63.89      | 52.21     | 52.88       |
| 29      | 41.37    | 30.00      | 41.42     | 31.17       |
| 30      | 87.80    | 77.22      | 85.88     | 79.63       |

### 5.3.2 Comparison of the four sets of speech intelligibility scores

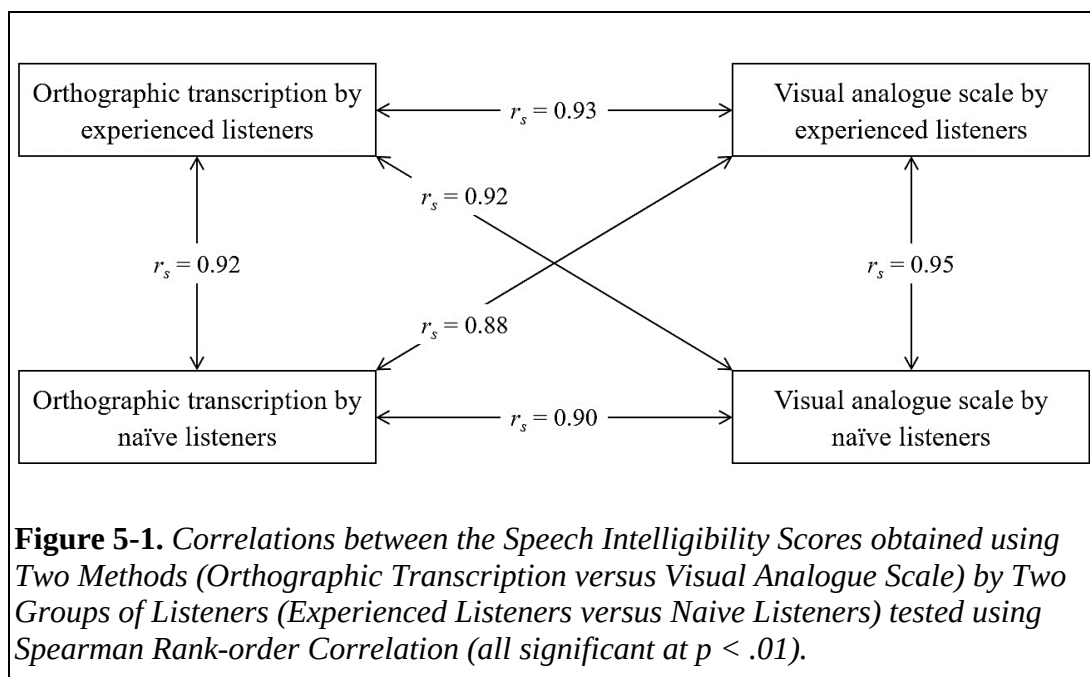
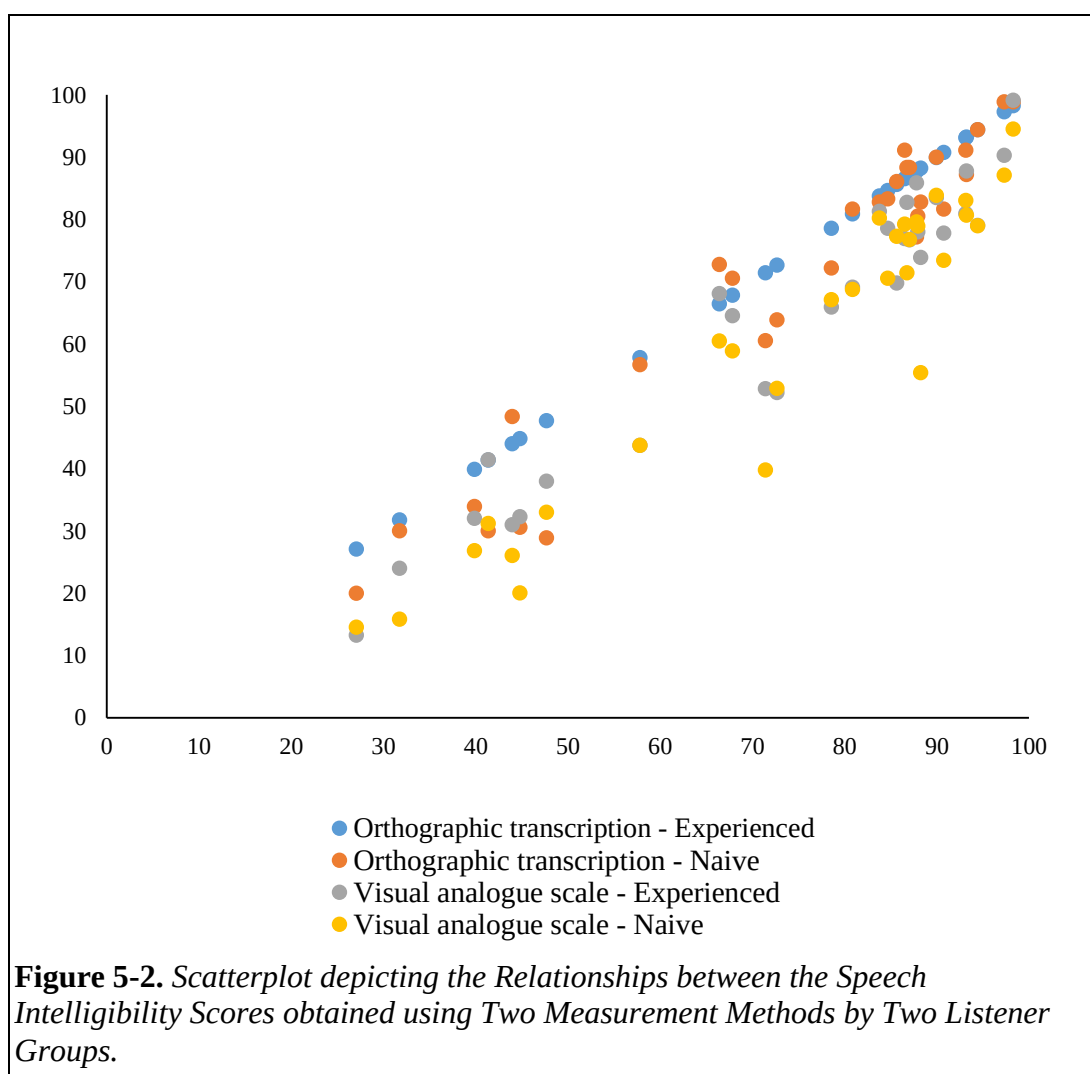
Inspection of histograms and Q-Q plots showed that the data was not normally distributed (Appendix S). However, ANOVA has been shown to be robust against moderate departures from normality (Blanca, Alarcon, Arnau, Bono, & Bendayan, 2017). The results of the ANOVA showed a significant main effect of



task,  $F(1, 29) = 94.35, p < .001$ , with a partial eta squared of 0.74, indicating a large effect size (Cohen, 1988). Speech intelligibility scores obtained by orthographic transcription scores were on average, 9.49 points higher than scores obtained using VAS; this difference was significant,  $p < .001$ . A significant main effect for listener group was also found,  $F(1, 29) = 19.31, p < .001$ , with a partial eta squared of 0.40, again indicating a large effect size (Cohen, 1988). Intelligibility scores judged by the experienced listener group were on average 3.76 points higher compared to the naive group, this difference was also significant,  $p < .00$ . There was no significant interaction effect between task and group,  $F(1, 29) = 0.16, p = .69$ .

### **5.3.3 The relationship across the four sets of speech intelligibility scores**

Spearman rank-order correlation analysis was carried out to examine the association between the speech intelligibility scores measured by the two different methods and the two listener groups. The speech intelligibility scores between the two tasks were highly correlated with each other both within and across listener groups. Figure 5-1 summarises the correlation results; all were significant at approximately 0.9. Figure 5-2 shows a scatterplot of the data and illustrates the strong linear relationship between the four sets of speech intelligibility scores.



## 5.4 Discussion

The aim of this fourth study was to investigate the effect of measurement method—orthographic transcription and VAS—and listener experience on speech intelligibility scores in speakers with DS. As hypothesised, the results showed that there was a significant difference between the speech intelligibility scores across the two measurement methods, in that the scores obtained using orthographic transcription were higher than those measured using VAS. Furthermore, the speech intelligibility scores judged by the experienced listeners were significantly higher compared to the naive listeners. However, despite the statistically significant differences between the task scores and group scores, the speech intelligibility scores across all conditions were strongly correlated with each other.

In relation to the method used to measure speech intelligibility, the finding that the speech intelligibility scores obtained via orthographic transcription were higher than those obtained via VAS is in agreement with previous studies that compared these same measurement methods in other clinical populations (Abur et al., 2019; Stipancic et al., 2016; Yorkston & Beukelman, 1978). The difference between the speech intelligibility scores measured by the two methods may be related to the fact that measurement involving orthographic transcription provides a score reflecting only the number of spoken words understood by the listener, whereas a rating task may also be sensitive to additional subjective listener judgements of speech features (Tjaden et al., 2014a). That is, when using a rating scale such as VAS, the listeners are likely to give an overall estimation of what they can understand, considering all the features that are present in the speech stimulus. These features would probably include the aspect that the listeners have to judge (i.e. speech intelligibility) and other additional features; for example, nasality in speakers

with cleft palate (Whitehill, 2002). In speakers with DS, difficulties with breathiness and hoarseness are common (Lee et al., 2009b; O'Leary et al., 2019). Hence, the listeners may have judged these speech features differently depending on the measurement method being used, which may explain the differences between the speech intelligibility scores obtained using orthographic transcription and VAS.

In terms of listener experience, the findings of this study support those of DePaul and Kent (2000) and McGarr (1983) in that speech intelligibility was judged to be higher by the experienced group compared to the naive group. On the other hand, the findings are in contrast to a study by Smith et al. (2019), who found no difference in scores obtained by orthographic transcription from trained and untrained listeners. However, the trained listeners in Smith et al.'s study were second year SLT students who may not have experienced the same length of exposure to unclear speech as the experienced listeners in the current study, who had been working with people with intellectual and speech difficulties for at least three years. Perhaps the discrepancy in terms of the level of previous exposure to disordered speech between the trained and untrained listeners in Smith et al.'s study was not as substantial as that between the experienced and naive listeners in the present study, which might explain the contrasting findings. As mentioned in the introduction of this chapter, the criteria used to define a listener as experienced can vary across studies making comparison of results challenging.

The speech intelligibility scores in the current study were found to be highly correlated across both orthographic transcription and VAS measurement methods, which is in agreement with findings reported by Abur et al. (2019) and Stipancic et al. (2016). The strong positive correlation across tasks indicates that while the speech intelligibility scores differed, the general pattern of scores was similar. Hence, even

though scores between the measurement were not the same, both methods are valid in ranking speech samples of different levels of intelligibility.

### **5.5 Conclusion**

The findings from the current study show that, when measuring speech intelligibility in speakers with DS, the scores obtained using a rating scale (VAS) are generally lower than the scores measured using orthographic transcription. Additionally, the speakers with DS were judged to be more intelligible by the experienced listeners compared to the naive listeners regardless of which measurement method was used. Section 6.5 in Chapter 6 will discuss the clinical implications of these findings.

## **Chapter 6**

### **GENERAL DISCUSSION**

Speech intelligibility represents the amount of acoustic signal produced by the speaker that is understood by the listener (Yorkston et al., 1996) and is often highlighted as an area of difficulty for individuals with Down syndrome (DS). Previous studies on speech disorders in different clinical populations have shown that reduced speech intelligibility can affect an individual's quality of life. It is important to learn more about the nature of reduced speech intelligibility in order to understand the difficulty and to help those with DS, their families, and healthcare professions manage the difficulty appropriately. Hence, the overarching aim of this study was to understand more about speech intelligibility in individuals with DS. Until this PhD study, no previous study had directly examined the relative contribution to speech intelligibility when considering all five components of speech production in this group. Furthermore, to date, limited research has examined the impact of language ability on speech intelligibility in those with DS or how certain factors can impact on the measurement of speech intelligibility for this group.

The results of the current study contributed to the existing knowledge in two main areas: identifying those aspects of speech production that contributed to speech intelligibility scores in speakers with DS using perceptual and acoustic analyses, and identifying factors that can affect the measurement of speech intelligibility for this population. The four discussion sections in Chapters 2-5 interpreted the specific findings of each study and summarised how they compared to previous studies. For this general discussion, the following sections will discuss the overall findings according to four broad topics raised by the integrated findings of the four individual studies. The clinical implications, limitations and directions for future research are

also discussed. It is important to remember, however, that the significant individual differences among those with DS indicate that these findings may apply to most but not all individuals in this group (Karmiloff-Smith et al., 2016).

### **6.1 The strong contribution of phonation to speech intelligibility in speakers with Down syndrome**

Perceptual analysis of speech intelligibility is the most widely used method employed in routine practice by clinicians. The somewhat unexpected findings from the use of perceptual analysis showed that *breathiness*, a phonatory characteristic, was the strongest contributor to speech intelligibility for the speakers with DS. Even though voice quality has been reported to be an area of difficulty for this group (e.g. Moura et al., 2008; Price, 1994), previous research had not investigated whether abnormal phonation contributes more or less than articulation, prosody, resonance and respiration to speech intelligibility.

Study 1 (Chapter 2), which examined perceptual parameters that contributed to speech intelligibility scores, showed that even when all of the five components of speech production were included in the analysis, breathiness contributed the most to the speakers' intelligibility. This finding was rather unexpected as most studies that examined speech production in those with DS emphasised difficulties with articulation to be the primary contributor (Jones et al., 2019; Wilson et al., 2019b). Moreover, this finding was not consistent with previous research that evaluated the relative contribution of speech production components to intelligibility in those with dysarthria using perceptual analysis. A study by De Bodt et al. (2002) reported that phonation was not as strong a contributor to speech intelligibility compared to articulation and prosody in speakers with dysarthria secondary to cerebral palsy. Difficulties with phonation or atypical voice quality, such as breathiness, appears to

be more of an influential feature on perceived speech intelligibility in those with DS. It could be that the increased levels of noise in the voice reduces speech clarity and disrupts how listeners perceive the acoustic signal (Porcaro et al., 2019).

The presence of a breathy voice, as identified by perceptual judgement, indicates a difficulty with laryngeal function such as impaired structure or function of the vocal folds (Hartl et al., 2003; Klatt & Klatt, 1990). Breathiness may also be due to other factors such as hearing loss, hypotonia, or vocal abuse (Boone, 1997; Boone et al., 2014; Hillenbrand et al., 1994). However, limited research has directly examined the underlying cause of phonation difficulties in those with DS (Kent & Vorperian, 2013). Future research could focus on the investigation of phonation using perceptual, acoustic, aerodynamic, and imaging methods to gain more insight into why voice difficulties are so common in this group (Mehta & Hillman, 2008).

## **6.2 The contribution of articulation and language ability to speech intelligibility in speakers with Down syndrome**

Study 1 and Study 2 (Chapters 2 and 3) showed that, in addition to phonation, aspects of articulation, as measured by both perceptual and acoustic analysis, were also found to significantly contribute to speech intelligibility for the speakers with DS. These were percent consonants correct (PCC), the slope of the second formant (F2) for /a/, and the voice onset time (VOT) of /d/. This finding was expected based on the pilot study and other previous studies that also found articulation to strongly contribute to speech intelligibility in other populations with speech difficulties (Ansel & Kent, 1992; De Bodt et al., 2002; Lee et al., 2014; O'Leary et al., 2019). Difficulties with articulation in those with DS can be due to a number of factors such as anatomical features of the syndrome, hearing loss, and/or restricted motor control during speech production (see section 1.7 in Chapter 1). As



previously explained, imprecise or distorted articulation of vowels and consonants can make considerable changes to the acoustic signal and impact on how speech is understood by the listener, thus affecting speech intelligibility.

Further to examining how perceptual and acoustic parameters contributed to speech intelligibility, Study 3 (Chapter 4) showed that an aspect of expressive language, mean length of utterance (MLU), also contributed to speech intelligibility for the individuals with DS. Specifically, those with higher MLUs also had higher speech intelligibility scores. As discussed in Study 3 (Chapter 4), hearing longer sentences produced by the speakers may have provided the listeners with more opportunity to decode the acoustic signal and enhance their perception of intelligibility (Hall, Amir, & Yairi, 1999). Another possible interpretation may be one put forward by Magnus (2011) in that those with a longer MLU had better-developed language skills overall, which had a further positive impact on their speech production resulting in higher perceived speech intelligibility scores. This explanation is supported by the finding from the present study in that receptive vocabulary was also shown to significantly correlate with speech intelligibility for those with DS. It may be that those with stronger receptive and expressive language skills can draw on these abilities during therapy targeting increased intelligibility, resulting in better outcomes compared to those with poorer language skills.

### **6.3 Perceptual and acoustic analyses of speech in those with Down syndrome do not always agree**

In Study 1 and 2, findings from perceptual analysis and findings from acoustic analysis were discussed separately. However, it is relevant to examine the agreement between the findings obtained by perceptual methods and those obtained from the more objective acoustic measures. The acoustic analysis findings can be

useful in confirming those gathered from perceptual analysis to help understand the nature of reduced speech intelligibility for the speakers with DS (Kent et al., 1999). In the present study, the results from acoustic analysis coincided with those yielded from perceptual analysis for most aspects of speech production. The agreement between the two sets of analyses for certain parameters is strong evidence that these particular features were present in the speech of those with DS. For example, significantly reduced PCC scores for the speakers with DS concurred with differences across the majority of acoustic parameters used to measure articulation of consonants between the speakers with DS and the typical speakers. Difficulties with fluency were also identified by both perceptual and acoustic analysis as measured by visual analogue scale (VAS) and percentage of stuttering-like dysfluencies (%SLD) respectively. On the other hand, some findings obtained from acoustic analysis did not agree with those obtained using perceptual analysis. In order to integrate perceptual and acoustic evaluation of speech production and speech intelligibility, it is important to understand what may underlie inconsistent findings across the two evaluation methods.

Discrepancies between perceptual and acoustic analysis methods have already been reported in some previous studies that have examined aspects of speech production in DS. For example, a relatively high mean F0 has been reported in speakers with DS who were perceived as speaking with a low pitch (Hollien & Copeland, 1965; Michel & Carney, 1964; Montague Jr et al., 1978; Moura et al., 2008; O'Leary et al., 2019). This discrepancy also came to light for the current study in a number of ways. Firstly, 21 out of the 30 speakers with DS were perceived to have atypical pitch; mostly due to listeners perceiving a lower than expected pitch. However, acoustic analysis showed that the group of speakers with DS had a

significantly higher mean fundamental frequency (F0) compared to the group of typical speakers matched for age and gender. It has been suggested by Michel and Carney (1964) that because there can be a variety of features present in the speech of those with DS (Kent & Vorperian, 2013), listeners can perceive what they think is a low pitch or deep voice, when other features such as unusual intonation or poor voice quality may be impacting on their judgement. Previous studies have shown that when listeners are judging speech where a few features co-occur, their perception of certain features can be affected (Imatomi, 2005; Lee et al., 2020; Tardif, Berti, Marino, Pardo, & Bressmann, 2018). The speakers with DS in the current study were noted to have difficulties with breathiness and roughness; hence, it may have been these features that caused the investigator to perceive a low pitch rather than an actual lower pitched voice. Montague Jr et al. (1978) also suggest that it is the variability in production of pitch by those with DS rather than their actual pitch level that can impact on listener judgement.

Secondly, harmonics-to-noise ratio (HNR) has been found to correlate with perceptions of roughness and breathiness in those with voice disorders (e.g. Muñoz et al., 2003; Niedzielska, 2001; Yumoto et al., 1982). Yet, the speakers with DS in the present study had a similar mean HNR compared to that of the typical speakers, despite their voices being perceived as rough and breathy. The reason for this discrepancy may be due to the nature of how HNR is measured. Acoustic analysis software that calculates the HNR depends on the identification of cycle-to-cycle boundaries in the acoustic signal (Qi & Hillman, 1997). However, in severely dysphonic or breathy voices, the cycle-cycle-boundaries cannot always be accurately identified by the software due to aperiodicity, thus resulting in an inaccurate HNR finding that does not capture the possible presence of roughness or breathiness

(Awan & Roy, 2009; Carding et al., 2004). This may have been the case in the current study and could explain the discrepancy between the findings pertaining to HNR obtained from perceptual and acoustic analysis.

Thirdly, acoustic analysis showed that for articulation of vowels, the speakers with DS had a significantly reduced vowel space area (VSA) compared to the typical speakers. Whereas, from perceptual analysis, only six speakers were perceived to have difficulty with vowels obtaining a percent vowels correct (PVC) less than 100. This is surprising since previous research has found PVC to be significantly correlated with VSA (Liu et al., 2005). Nevertheless, PVC is a relatively broad measure of vowel articulation (Shriberg, 1997a). Thus, when perceptually evaluating production of vowels, the investigator may possibly have allowed for some variation in production. Therefore, a vowel error would have to be more salient to be identified by perceptual judgement whereas acoustic analysis would be considerably more sensitive to smaller changes in the formant values (Weismer & Martin, 2002). This may explain the inconsistent results between perceptual and acoustic analysis of vowel production.

Lastly, in relation to prosody, the speakers with DS were found to have a significantly higher mean amplitude and amplitude range during spontaneous speech compared to the typical speakers, which is congruent with previous research (Corrales-Astorgano et al., 2018). However, no difficulties with loudness were noted from perceptual analysis. Moreover, the speakers with DS were found to have a significantly slower speaking rate compared to the typical speakers even though little difficulties with speaking rate were identified from perceptual analysis. Direct comparison of perceptual and acoustic evaluation of spoken loudness and speaking rate has not been previously reported for speakers with DS. The reason for these

discrepancies may be because the investigator's own internal standard of loudness did not lead to the perception of atypical loudness levels in the speech of the speakers with DS (Summers, Pisoni, Bernacki, Pedlow, & Stokes, 1988). In relation to speaking rate, it may be that other perceptual aspects of prosody such as “short rushes of speech” and “increased rate in segments” coincided with acoustic measures of speaking rate more than the perception of rate in general.

#### **6.4 The role of speech motor control and its impact on speech intelligibility**

When the results of Study 1 and 2 (Chapters 2 and 3) are taken into consideration, the findings support previous research indicating a motor speech difficulty in speakers with DS that is likely to have an impact on perceived intelligibility (see also: Bunton & Leddy, 2011; Carl et al., 2020; Cleland et al., 2010). As discussed in Chapter 1, Wilson et al. (2019a) evaluated the speech of 45 speakers with DS aged 10-20 years old and found that 98% of the speakers presented with some form of motor speech impairment as measured by the Speech Disorders Classification System (Shriberg, Kwiatkowski, & Mabie, 2019; Wilson et al., 2019a). The most common types of motor speech impairments were dysarthria, motor speech delay, apraxia, and concurrent dysarthria and apraxia. Among those identified to have dysarthria, ataxia was the most common. In their subsequent study of the same group of speakers, motor speech impairments were significantly associated with low to moderate speech intelligibility (Wilson et al., 2019b). The authors proposed that the findings of their studies supported the theory that motor speech disorders were the main cause of reduced speech intelligibility in speakers with DS. Subtle difficulties with motor speech can be difficult to identify using perceptual analysis alone; however, as discussed in Chapter 1, acoustic analysis can identify more features in the speech signal that may not always be readily

identifiable by the human ear (Kent & Read, 2010). The acoustic findings from the present study that indicated difficulties with motor speech in the speakers with DS include significant differences between the F2 slope, VOT, VSA, amplitude range, speaking rate, and %SLD between the speakers with DS and the typical speakers (see Table 3.1 p.160).

In particular, the present findings relating to F2 slope point towards a difficulty with tongue movement and tongue-jaw co-ordination in those with DS as previously highlighted by Carl et al. (2020) and Langlois, Tucker, Sawatzky, Reed, and Boliek (2020). The F2 slope represents the rate of change of the vocal tract resulting mainly from tongue movement and a shallower F2 slope has been used in previous studies as an identifying factor for impaired motor control of the tongue (e.g. Kim et al., 2009; Weismer et al., 1992). Moreover, the speakers with DS in this study had a reduced VSA compared to the typical speakers which can also reflect restricted movement of the tongue (Carl et al., 2020). However, it is possible that anatomical factors could have accounted for some of the differences between the VSA of the speakers with DS and the typical speakers. For example, the smaller oral cavity in people with DS can impact on the range of tongue movement (Guimaraes et al., 2008). Moreover, the smaller pharyngeal space could contribute to a reduced articulatory working space and therefore, impact on the acoustic space, reducing the VSA (Wild et al., 2018).

For articulation of consonants, the distinction between the mean first spectral moment (M1) values for the /s/ and /ʃ/ fricative sounds was reduced for the speakers with DS compared to the typical speakers. Difficulty with production of fricatives has been noted as a prominent feature among speakers with DS (Sommers et al., 1988; Van Borsel, 1996). The reduced M1 difference between /s/ and /ʃ/ could

indicate a reduced distinction of tongue placement due to impaired motor control (Jongman et al., 1998). As production of fricatives requires finer motor control of the tongue, difficulties with motor aspects of speech may explain why these sounds are more difficult for speakers with DS to produce accurately. Motor speech control also facilitates the control and co-ordination of across speech systems (Yu et al., 2014). For example, VOT, which represents the fine co-ordination between phonation and articulation (Kent, 1990), was also a differentiating factor between the speakers with DS and the typical speakers. The longer VOTs evident in the speech of those with DS in the current study reflect restricted motor control between the phonatory and articulatory components of speech production.

In relation to prosody, acoustic analyses showed a higher amplitude range for the speakers with DS compared to the typical speakers. The higher range of amplitude indicates more variance in loudness during speech production and may reflect impaired or inconsistent motor control during speech production (Corrales-Astorgano et al., 2018). The speakers with DS also had a significantly slower speaking rate compared to the typical speakers. Previous research has shown that a slower speaking rate is common in populations with motor speech difficulties as this reflects difficulties with the movement and co-ordination of the components of speech production (Hustad, Gorton, & Lee, 2010; Kent & Kim, 2003). Studies that have investigated the nature of variable speaking rate have reported how the location and duration of pauses within the speech sample can have a significant effect on a speaker's rate of speech (e.g. Hammen & Yorkston, 1996). Use and duration of pauses could also relate to the feature "short phrases" that was observed among the majority of speakers with DS. The use of short phrases and a slow speaking rate may reflect the speakers with DS needing more time to co-ordinate and plan their speech

movements due to motor speech difficulties (Hall et al., 1999). However, it is also possible that the use of short phrases and a slower speaking rate is related to the language ability of those with DS. That is, impairment at the linguistic level resulting in difficulty with formulating utterances could have caused the speakers with DS to use short phrases, pause more often, and speak slower (Miller & Leddy, 1999).

The higher incidence of dysfluency in the speech of those with DS, which was identified by both perceptual and acoustic analysis, can also indicate an underlying difficulty with speech motor control. As discussed in sections 1.6.1 and 1.7.2, one theory regarding the nature of dysfluency in DS is that it can arise when the spoken message exceeds the motoric abilities of the speaker. If a spoken utterance involves more complex motor planning and movement, the speakers with DS may have difficulty producing these movements resulting in disrupted speech output and a dysfluent utterance (Dromey & Bates, 2005). It should be noted however, that similar to speaking rate and use of short phrases, a difficulty with dysfluency could be indicative of a linguistic impairment as well as a motor speech problem.

A secondary piece of evidence supporting the theory of a motor speech difficulty in those with DS are the oro-motor findings from the current study (see Table 2.4 on p. 100). The oro-motor function results showed that some of the speakers with DS had difficulty with aspects of lip, tongue, and jaw movement which could impact on speech production and perceived speech intelligibility. Previous studies have also reported these types of oro-motor difficulties in those with DS (Barnes et al., 2006; Spano et al., 1999; Spender et al., 1995). In addition, the findings showed that the speakers' oro-motor difficulties became more pronounced when producing multisyllabic words, which indicates a problem with



sequencing of speech movements suggestive of a dyspraxic type of difficulty with motor speech control.

In terms of the type of motor speech disorder, it was not the aim of this study to identify if the speakers with DS presented with specific impairments such as dysarthria and/or apraxia. However, the general findings are consistent with those of previous studies that have reported speakers with DS to exhibit symptoms of apraxia and dysarthria, mainly of ataxic type (Rupela et al., 2016; Wilson et al., 2019a). A speaker with ataxic dysarthria usually presents with a scanning pattern of speech, impaired articulation of consonants and vowels, and atypical voice quality and prosody (Kent et al., 2000). Imaging studies have shown that people with DS have been found to have significantly reduced cerebellar volume which is the site from which ataxic dysarthria is known to originate (Aylward et al., 1997; Wilson et al., 2019a). In addition to motor execution, the cerebellum is said to also be involved in motor programming which may explain why apraxia is also reported in speakers with DS (Wilson et al., 2019a). The speakers with DS in the present study showed some signs of apraxia from the oro-motor assessment and other speech tasks; for example, they had difficulty with tongue co-ordination, imitation of words and omitted sounds and syllables (Rupela et al., 2016). However, there is no neurological data available for the speakers in this study; therefore, a definitive finding regarding neurological characteristics is not possible. Furthermore, more detailed assessment would be needed to explore if the speakers had dysarthria, apraxia, or both.

### **6.5 Clinical implications**

During the assessment of speech production, a speech intelligibility score is usually obtained for clients as a global measure of the severity of impairment and as a reference against which to measure progress in therapy. However, even if two

individuals are assigned the same intelligibility score, their scores may be the product of very different speech features (Kent, Miolo, & Bloedel, 1994). This present study has highlighted that, out of all the speech components, perceptual phonatory features such as breathiness are likely to be a major contributory factor to speech intelligibility in those with DS. Articulation is also likely to contribute, particularly in the areas of inaccurate production of consonants and sounds that require fine movement of the tongue. This study has also shown that aspects of language ability can impact on speech intelligibility. Moreover, the findings showed that certain factors of the assessment process can also influence speech intelligibility outcome scores. If SLTs were aware of the general speech intelligibility profile in DS and factors that can impact on intelligibility measurement, they would be better able to interpret outcome scores and prioritise appropriate treatment goals, bearing in mind the individual differences within this population (Bunton & Leddy, 2011; Karmiloff-Smith et al., 2016; McDaniel & Yoder, 2016).

Studies that have investigated the nature of reduced speech intelligibility in speakers with DS have largely focused on articulation (Barnes et al., 2009; Bunton et al., 2007). This is not surprising as there are many approaches to the treatment of articulation available to SLTs. However, the findings of the current study showed that out of all the parameters examined across the five components of speech production, breathiness was the strongest perceptual contributor to speech intelligibility for the speakers with DS. Hence, it is possible that even if articulation improves from therapy, reduced speech intelligibility may still remain for some people with DS if other aspects of speech production are not considered (Yoder,

Camarata, & Woynaroski, 2016). Therefore, clinicians should consider *phonation* as a focus when assessing the nature of reduced speech intelligibility in those with DS.

In addition to phonation, both perceptual and acoustic aspects of *articulation* were also found to contribute to speech intelligibility for the speakers with DS. Evaluating the accuracy of production of consonants and vowels is a common approach to understanding the nature of a speaker's reduced speech intelligibility in the clinic (Baker & McLeod, 2011; Sommers, Logsdon, & Wright, 1992). Therefore, when assessing speech intelligibility for clients with DS, SLTs should continue to focus on the accuracy and consistency of consonant and vowel production. Furthermore, as discussed in section 6.4 above, the general findings of this study indicate a motor speech difficulty in DS. Thus, incorporating a motor approach to the assessment of speech production may also shed light on the cause of reduced speech intelligibility in this group.

Another aspect of clinical assessment that could help to understand reduced speech intelligibility in DS is the language ability of the individual. This study has shown that the speakers' MLU significantly contributed to their speech intelligibility. This finding suggests that if SLTs targeted the development of a client's expressive language skills in the clinic, the new skills may have a positive impact on their speech intelligibility (Miller & Leddy, 1999). Likewise, if a client's speech intelligibility is increased, it can facilitate the effective use of the expressive language skills that they have developed (Chapman et al., 1998; Ní Cholmain, 1994).

In terms of the method used to measure overall speech intelligibility, the results of this study showed that intelligibility scores obtained from orthographic transcription were significantly higher than those obtained from VAS, but both sets of scores were highly correlated with each other. This finding suggests that although

both methods index severity in a similar manner, they may provide different information about speech intelligibility (Allison, 2020). For orthographic transcription, SLTs are typically required to audio-record a speaker producing a selection of words or sentences and must also score the listener responses (Hustad, 2006). But the majority of SLTs use the less time-consuming scaling methods, such as VAS, to measure and monitor speech intelligibility (Miller, 2013). As described in Study 4, orthographic transcription measures the number of words a listener understands in a speech sample, whereas a rating task may also involve additional subjective listener judgements of speech features (Tjaden et al., 2014a). The consequence of such additional listener judgement in a rating task is that listeners tend to judge a speech sample more harshly compared to when completing orthographic transcription. SLTs should be aware of the potential differences between the two methods of measurement in relation to what each method assesses and the purpose for which they are using a particular method (Price & Kent, 2008). If SLTs were aware of these differences, they could interpret results from whichever method they use.

The amount of listener exposure to disordered speech can also impact on how speech intelligibility is judged. Findings of the current study coincided with most previous research and found that, due to their increase exposure to disordered speech, the experienced listeners perceived speech as more intelligible compared to the naive listeners (DePaul & Kent, 2000; McGarr, 1983). As a group who are more exposed to hearing atypical speech, SLTs should consider their experience when interpreting assessment results for speakers with DS. They should be aware that those with DS who are perceived by experienced listeners as showing a high level of speech intelligibility may still sound quite unclear to those listeners who are not

familiar with the speech characteristics of this group. So, for example, when an SLT is measuring speech intelligibility for a client with DS, they should consider that, if they think they can understand 80% of what the client is saying, the general public, who generally have less exposure to disordered speech, may probably understand less than 80% of what the same person is saying. To overcome the effect of listener experience on speech intelligibility judgement, assessment could incorporate features of the Intelligibility in Context Scale (McLeod et al., 2012) when evaluating intelligibility. By asking the client themselves and relevant family members and other close-working professionals how much they think the speaker is understood, it may help to give a more “real-world” indication of the speaker’s intelligibility.

## **6.6 Limitations and future directions**

The results of the current study should be interpreted in relation to a number of factors. First and foremost, the individual differences among those with DS should be taken into account. Research has shown that there is large variability among people with DS at every level of description, and reporting group data can camouflage these individual differences (Karmiloff-Smith et al., 2016). The high inter-speaker variability among speech and language parameters in the current study also supported the theory that those with DS are a heterogeneous group. Therefore, the findings of this study relating to the nature of reduced speech intelligibility in DS may not apply to all speakers in this group. Future studies could draw on a method used by Wilson et al. (2019a) that separated speakers with DS according to perceived intelligibility and compare and contrast the features between the two groups to help identify the nature of reduced speech intelligibility.

Secondly, as outlined in section 1.6.1 (p. 48), phonological short-term memory can impact on speech production. If phonological short-term memory is

impaired, it can disrupt how the pronunciation of phonemes are stored, how speech sequences are planned, and also how a speaker monitors their speech productions. Impaired phonological short-term memory is an aspect that people with DS can have a marked difficulty with (Jarrold & Baddeley, 2001; Nip et al., 2011). In the current study, the phonological short-term memory of the speakers with DS was not measured, but tasks were designed to place as little demand on speakers' memory as possible (i.e. most speech tasks were elicited by repetition and with visual support). Nonetheless, it cannot be known if phonological short-term memory also impacted on the speakers' intelligibility along with the other identified contributors. Short-term memory may also have played a role in the participants' understanding of instructions in the receptive language assessment. Future research investigating the nature of speech intelligibility in those with DS should examine the role of phonological short-term memory alongside the other factors highlighted in the study.

In regard to the testing set-up that was used to judge the intelligibility of the speakers with DS (see section 2.2.4 p. 89), one might argue that repetition of sentences in a soundproof booth in front of a microphone may not have facilitated a true representation of their speech production; and thus, yield an inaccurate representation of the speakers' perceived speech intelligibility (Goberman, Recker, & Parveen, 2010; Pennington & Hustad, 2019). A review of speech intelligibility assessment methods by Miller (2013) recommends that intelligibility should be measured using natural contexts in naturalistic environments. Therefore, alternative methods such as an adapted version of the Intelligibility in Context Scale (McLeod et al., 2012) could be used to obtain a more functional measure of speech intelligibility. However, Miller (2013) also states that variables such as the recording environment and test stimuli need to be controlled in order for accurate comparison

across speech intelligibility scores. It is difficult to control for these variables while also ensuring a true-to-life testing environment. Future research could compare speech intelligibility scores in speakers with DS when measured using a controlled testing set-up versus a more natural real-life scenario.

Concerning the speech material used in the measurement of intelligibility, some researchers recommend using spontaneous speech as the stimulus rather than prescribed sentence sets, such as the ASSIDS used in the current study. They argue that a speaker's spontaneous speech is more reflective of their natural speech performance (Barrett, McCabe, Masso, & Preston, 2020; Flipsen, 2006). However, using spontaneous speech material poses another considerable challenge to measuring speech intelligibility in that the correct target is not known (Pennington & Hustad, 2019). When using orthographic transcription to measure speech intelligibility, intelligibility is calculated as the number of words correctly transcribed divided by the total number of words. If the target is not known, then the total number of words cannot be identified and speech intelligibility cannot be accurately calculated. The target would be particularly difficult to identify for those with speech difficulties and indeed language difficulties.

It must also be noted how that the current study measured listener perception of speech intelligibility, that is, the amount of acoustic signal that is received by the listener. As discussed in Chapter 1, other measures of listener perception, comprehensibility and acceptability have also been used in the literature. While acceptability does not measure listener understanding (Dagenais et al., 2011), it is possible that, had listener judgement of comprehensibility been used as the measure of speech performance, different results may have been obtained. Both clinically and socially, factors relating to comprehensibility (e.g. gesture, physical context) can be

important for enhancing communication (Miller, 2013). Therefore, future studies could investigate aspects that impact on speech comprehensibility in adolescents and adults with DS.

Regarding the acoustic parameters used to measure speech production in Study 2, it is possible that not all of the parameters fully captured their related speech component. For example, recent research has suggested that maximum phonation time (MPT) may not be the most reliable way to measure speech respiration (Ziegler, Schölderle, Brendel, Amsellem, & Staiger, 2019). Additionally, as mentioned earlier in this chapter, HNR may not be the most appropriate measure of phonation (i.e. voice quality) for those with DS as it is influenced by aperiodicity in the speech signal (Carding et al., 2004). Studies have shown that other acoustic analysis methods, such as cepstral analysis, are not affected by aperiodicity in the signal and can therefore facilitate more accurate measurement of voice quality (Awan & Roy, 2009). Future research could build on the work completed in this study and explore the use of cepstral analysis to evaluate speech production in DS. It should also be mentioned that intra-speaker variability was not evaluated in this study. For a number of acoustic parameters (e.g. F2 slope of vowels; M1 analysis of fricatives), the mean value over five productions of a speech stimulus was used in analysis. Using the mean value would not have accounted for variability within speakers. Intra-speaker variability has been reported to be high for studies that have investigated motor speech in speakers with DS (e.g. Rupela et al. 2016). Hence, future studies could focus on speech variability within speakers with DS and examine how this variability may impact on intelligibility.

Furthermore, other types of instrumental measures for analysing components of speech production, such as laryngoscopy, nasometry, ultrasound, and



electropalatography, were not employed in this study. Research involving the use of these evaluation methods can provide insight into the physiological function of certain aspects of speech production and shed more light on the nature of speech errors and reduced speech intelligibility; they would also help to confirm results obtained from both perceptual and acoustic analysis (e.g. Cleland et al., 2020; Theodoros et al., 1999). Some studies have already used electropalatography to evaluate tongue-palate contact in speakers with DS to support perceptual findings of difficulties with production of alveolar sounds (e.g. Wood, Timmins, Wishart, Hardcastle, & Cleland, 2019). Another study used an early version of the nasometer to compare perceptual ratings of resonance in a group of speakers with DS (Kline & Hutchinson, 1980).

In relation to language ability, Study 3 obtained measures pertaining to receptive and expressive language for the participants with DS, including their MLU. When analysing a language sample for measuring MLU, grammatical markers are identified and transcribed for analysis. However, even if the speakers with DS intended to produce these grammatical markers, their reduced speech intelligibility may have prevented them from being identified by the examiner and thus, excluded from analysis and possibly resulting in a lower MLU (Cleland et al., 2010). In the present study however, very few utterances were discarded from analysis due to being unintelligible; hence, it is likely that MLU was a relatively accurate measure of speakers' expressive language ability. In regard to how the language ability of those with DS contributed to their speech intelligibility, more research is required in order to fully understand the nature of this association. Further studies, possibly using a longitudinal research design and employing consistent methods for measuring language, could help to gain more insight into the development of the relationship

between language ability and speech intelligibility in those with DS. It would be useful to examine the parallel development of both speech intelligibility and language ability and to investigate how one aspect can impact on the other across the lifespan.

It should also be highlighted that the group of experienced listeners who judged speech intelligibility was half made up of SLTs and the other half were other professionals who worked full-time with people who had speech and learning difficulties. That is, these two subgroups of listeners differed in terms of whether they had training in phonetics, which could have impacted on their judgement of speech intelligibility. However, the measurement methods used in this study—orthographic transcription and VAS—did not require any background knowledge of phonetics or specialised training to complete, and all of the listeners in both the experienced and naive groups were provided with the same instructions for measuring speech intelligibility. It is possible that the length of the listeners' exposure to atypical speech (e.g. a professional working for 3 years compared to a professional working for 20 years) may have impacted on their judgement of intelligibility; however, it was not the aim of this study to investigate this aspect. Future research could investigate the impact of the length of exposure to disordered speech, as well as training in phonetics, on the listener judgement of speech intelligibility in those with DS.

In addition, when judging speech intelligibility, the listeners had the option of hearing each sentence twice. It is possible that the listeners' judgement of speech intelligibility may have been influenced by the number of times they heard the sentences; however, whether listeners heard the sentences once or twice was not recorded. Future research could record the number of times that listeners choose to

listen to a speech stimulus which may shed light on further listener factors that influence the measurement of speech intelligibility in DS.

In general, there is still much to learn around the evaluation of speech intelligibility in people with DS. Other factors of assessment, such as the type of test stimuli, the presentation mode of stimuli to the listeners, listeners' familiarity with the stimuli, and listening conditions can influence judgement of speech intelligibility scores (Barreto & Ortiz, 2008; Hustad, 2006; Miller, 2013); however, these factors have not yet been investigated in relation to the speech of those with DS. In order to fully understand the nature of speech intelligibility in this group and how it is measured, more studies are required. Importantly, as mentioned previously in this chapter, the area of phonation and its impact on speech intelligibility warrants further investigation in speakers with DS. If more is understood around the phonation difficulty in individuals with DS, specific treatments could be designed which would have a positive impact on their speech intelligibility.

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## Appendix A

### Ethical Approval Form



Tel: + 353-21-490 1901  
Fax: + 353-21-490 1919

Coláiste na hOllscoile Corcaigh, Éire  
**University College Cork, Ireland**

COISTE EITICE UM THAIGHDE CLINICIÚIL  
**Clinical Research Ethics Committee**

Lancaster Hall,  
6 Little Hanover Street,  
Cork,  
Ireland.

9<sup>th</sup> August 2017

ECM 4 (cc) 15/08/17

Dr Alice Lee  
Lecturer  
Department of Speech and Hearing Sciences  
University College Cork  
Room 1.31  
Brookfield Health Sciences Complex  
College Road  
Cork

**Re: Perceptual and acoustic features of speech of individuals with Down syndrome and their impact on speech intelligibility.**

Dear Dr Lee

Approval is granted to carry out the above study at:

- GP Surgeries and University College Cork.

The following documents have been approved:

- Application form signed 17 July 2017
- Study protocol
- Evidence of insurance
- CV for chief investigator
- Information letter for organisation/school version 1 dated July 2017
- Information letter for parents of Exp. Group version 1 dated July 2017
- Information leaflet for parents of Exp. Group version 1 dated July 2017
- Information leaflet for Exp. Group version 1 dated July 2017
- Consent form for parents of Exp. Group version 1 dated July 2017
- Visual schedule for Exp. Group version 1 dated July 2017
- Assent form for Exp. Group (under 18) version 1 dated July 2017
- Consent form for Exp. Group (over 18) version 1 dated July 2017
- Data collection record form for Exp. Group version 1 dated July 2017
- Information letter for listeners version 1 dated July 2017
- Consent form for listeners version 1 dated July 2017
- Information letter for control group version 1 dated July 2017
- Information leaflet for control group version 1 dated July 2017
- Assent form for control group (under 18) version 1 dated July 2017
- Consent form for parents of control group (under 18) version 1 dated July 2017
- Consent form for control group (over 18) version 1 dated July 2017
- Data collection record form for a control group version 1 dated July 17.

We note that the co-investigators involved in this project will be:

- Professor Fiona Gibbon, Dr Ciara O'Toole, Lecturer, Dr Siobhan Laoide-Kemp, Lecturer and Deirdre O'Leary, PhD Student. Group

The date of this letter is the date of authorization of the study.

Please keep a copy of this signed approval letter in your study master file for audit purposes.



Tel: + 353-21-490 1901  
Fax: + 353-21-490 1919

COISTE EITICE UM THAIGHDE CLINICIÚIL  
**Clinical Research Ethics Committee**

Lancaster Hall,  
6 Little Hanover Street,  
Cork,  
Ireland.

Coláiste na hOllscoile Corcaigh, Éire  
**University College Cork, Ireland**

---

Yours sincerely

Professor Michael G Molloy  
Chairman  
Clinical Research Ethics Committee  
of the Cork Teaching Hospital

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*The Clinical Research Ethics Committee of the Cork Teaching Hospitals, UCC, is a recognised Ethics Committee under Regulation 7 of the European Communities (Clinical Trials on Medicinal Products for Human Use) Regulations 2004, and is authorised by the Department of Health and Children to carry out the ethical review of clinical trials of investigational medicinal products. The Committee is fully compliant with the Regulations as they relate to Ethics Committees and the conditions and principles of Good Clinical Practice.*

Ollscoil na hÉireann, Corcaigh - National University of Ireland, Cork.

## Appendix B

### Background information for speakers with Down syndrome as reported by parents/carers

| Sp | Age   | Gender | Cognition<br>(date of most recent Ax<br>and outcome) | Medical difficulties | Difficulties<br>with vision  | Difficulties with<br>hearing          | History of SLT                                                                                |
|----|-------|--------|------------------------------------------------------|----------------------|------------------------------|---------------------------------------|-----------------------------------------------------------------------------------------------|
| 1  | 44;10 | male   | NR                                                   | none                 | wears glasses<br>for reading | not sure                              | none                                                                                          |
| 2  | 24;06 | female | NR                                                   | hole in heart        | NR                           | awaiting review with<br>audiologist   | two years of weekly sessions in<br>primary school; monthly group<br>in recent years; none now |
| 3  | 16;10 | male   | assessed in 2013: mild                               | none                 | wears glasses                | wears hearing aid in<br>one ear       | individual therapy when<br>younger; monthly group therapy<br>now                              |
| 4  | 47;03 | male   | assessed 35 years ago: mild                          | psoriasis            | NR                           | NR                                    | weekly for one year when a<br>child                                                           |
| 5  | 27;0  | male   | assessed in 2008: mild                               | none                 | wears glasses                | NR                                    | 10 years ago                                                                                  |
| 6  | 22;07 | male   | NR                                                   | asthma               | wears glasses                | NR                                    | stopped four years ago                                                                        |
| 7  | 24;03 | male   | assessed in 2015: mild-to-<br>moderate               | none                 | NR                           | NR                                    | none                                                                                          |
| 8  | 32;08 | male   | NR                                                   | none                 | NR                           | NR                                    | for nine months when younger                                                                  |
| 9  | 16;07 | male   | mild-to-moderate                                     | none                 | NR                           | wears hearing aids                    | currently attending monthly<br>group therapy                                                  |
| 10 | 17;01 | male   | mild-to-moderate                                     | none                 | NR                           | recently reviewed, no<br>difficulties | intermittent blocks of monthly<br>individual therapy for last ten<br>years                    |



|    |       |        |                  |                                                                                        |               |                                             |                                                                                                                                      |
|----|-------|--------|------------------|----------------------------------------------------------------------------------------|---------------|---------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|
| 11 | 16;07 | male   | moderate         | none                                                                                   | wears glasses | wears hearing aids                          | Currently attending monthly group therapy and fortnightly individual therapy                                                         |
| 12 | 19;07 | female | mild             | none                                                                                   | NR            | NR                                          | four times a year with public service and monthly group therapy with private service                                                 |
| 13 | 19;04 | female | mild-to-moderate | none                                                                                   | wears glasses | NR                                          | currently attending monthly group therapy                                                                                            |
| 14 | 21;0  | female | NR               | none                                                                                   | NR            | NR                                          | attended both therapy by both public and private services when younger                                                               |
| 15 | 16;0  | female | NR               | underactive thyroid                                                                    | wears glasses | NR                                          | attending monthly group therapy and monthly individual therapy or last few years”                                                    |
| 16 | 19;0  | female | mild             | successful repair of atrioventricular septal defect                                    | wears glasses | NR                                          | sporadically attended therapy since a young age ;earlier therapy focused on speech sounds; current therapy focusing on social skills |
| 17 | 23;09 | female | NR               | none                                                                                   | NR            | NR                                          | none                                                                                                                                 |
| 18 | 23;11 | female | NR               | none                                                                                   | NR            | NR                                          | none                                                                                                                                 |
| 19 | 16;10 | male   | NR               | patent ductus artery with ventricular septal defect heart repair at three month of age | NR            | had hearing aid years ago but never wore it | currently attending monthly group therapy targeting conversational skills                                                            |

|    |       |        |                                              |                                                                              |               |                                  |                                                                                                                                                                                                                                                               |
|----|-------|--------|----------------------------------------------|------------------------------------------------------------------------------|---------------|----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 20 | 16;03 | female | NR                                           | patent ductus artery with ventricular septal defect heart repair when infant | NR            | NR                               | at >7 years of age, attended individual therapy every six weeks; at 7-12 years, attended fortnightly individual therapy; at 12-14 years, attended monthly individual therapy; currently attending one group session per month targeting conversational skills |
| 21 | 24;02 | male   | assessed in 2013: moderate                   | Coeliac                                                                      | wears glasses | none                             | attended both individual and group therapy from young age; stopped attending since 2015                                                                                                                                                                       |
| 22 | 28;09 | female | NR                                           | Asthma                                                                       | NR            | mild hearing difficulties        | attended individual monthly therapy when younger                                                                                                                                                                                                              |
| 23 | 31;0  | male   | NR                                           | NR                                                                           | none          | none                             | none in previous 15 years                                                                                                                                                                                                                                     |
| 24 | 28;11 | female | moderate                                     | none                                                                         | none          | none                             | none                                                                                                                                                                                                                                                          |
| 25 | 28;0  | female | assessed 16 years ago: unsure of outcome     | none                                                                         | none          | hearing difficulties since birth | attended blocks of therapy once a year until adolescence                                                                                                                                                                                                      |
| 26 | 24;06 | female | assessed at 5 years of age: mild-to-moderate | none                                                                         | none          | none                             | none                                                                                                                                                                                                                                                          |
| 27 | 19;01 | female | mild                                         | NR                                                                           | NR            | NR                               | NR                                                                                                                                                                                                                                                            |
| 28 | 26;0  | female | NR                                           | none                                                                         | NR            | NR                               | NR                                                                                                                                                                                                                                                            |
| 29 | 22;07 | male   | assessed in 2014: mild                       | none                                                                         | none          | none                             | none                                                                                                                                                                                                                                                          |
| 30 | 18;10 | female | assessed in 2012: mild                       | none                                                                         | NR            | NR                               | NR                                                                                                                                                                                                                                                            |

*Note.* Sp = speaker; Ax = assessment; NR = no response from parent; SLT = speech and language therapy.

## Appendix C

### Consent and assent forms for speakers with Down syndrome



#### **“Perceptual and acoustic features of speech of individuals with Down syndrome and their impact on speech intelligibility”**

1. I, \_\_\_\_\_, consent to my son/daughter \_\_\_\_\_, (D.O.B.: \_\_\_\_\_) participating in the above-mentioned study.
2. The purpose and nature of the study has been explained to me in writing.
3. My son/daughter is participating voluntarily.
4. I give permission for all research tasks administered to be audio-recorded.
5. I understand that if I change my mind, I can withdraw from the study at any time, whether before it starts or during participation.
6. I understand that anonymity will be ensured at all times and no identifying information will be mentioned (except the age, gender, and research task results) in any research output of this project (e.g. conference presentations, research papers). The audio/video recordings may be used in a presentation or at a conference, but again, no identifying information will be mentioned.
7. I give permission for my son/daughter to be video-recorded for some tasks.  
Yes ☐ No ☐

**Parent/Guardian Signature:**

\_\_\_\_\_

**Name in Block Capitals:**

\_\_\_\_\_

**Contact Number:** \_\_\_\_\_ **Date:** \_\_\_\_\_

Please provide your correspondence address if you would like a report summarising your son/daughter’s task results posted to you:

**Address:**

\_\_\_\_\_  
\_\_\_\_\_

**PTO→**

**Please answer the following questions:**

1. When did your son/daughter last receive a cognitive/psychological assessment from a psychologist? (this may have been quite some time ago). Please give details of results if you can, or you can provide a copy of the report - this would remain in strict confidence.

---

---

2. Does your son/daughter have any significant medical condition (e.g. epilepsy; heart problems, etc)?

Yes ☐

No ☐

Please give details:

---

---

3. Has your son/daughter previously received speech and language therapy directly targeting clearer speech?

Yes ☐

No ☐

Please give details regarding frequency and treatment goals:

---

---

**Consent form for speakers with Down syndrome**  
**(if over 18)**

|                                                                                                                                                                           |   |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---|
|                                                                                                                                                                           | ✓ |
| <p>1. The project has been explained to me.</p>                                        |   |
| <p>2. I understand what I will have to do and I am happy to do these jobs.</p>         |   |
| <p>3. I understand we are going to meet 2 times to do these activities together.</p>  |   |
| <p>4. I am happy to be audio-recorded.</p>                                           |   |
| <p>5. I understand that I can ask questions at any time.</p>                         |   |
| <p>6. I can decide to stop and finish.</p>                                           |   |

**My Signature:** \_\_\_\_\_

**My Name in Capital Letters:** \_\_\_\_\_

**Date:** \_\_\_\_\_

**Assent form for speakers with Down syndrome**  
**(if under 18)**

|                                                                                                                                                                           |   |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---|
|                                                                                                                                                                           | ✓ |
| <p>1. The project has been explained to me.</p>                                        |   |
| <p>2. I understand what I will have to do and I am happy to do these jobs.</p>         |   |
| <p>3. I understand we are going to meet 2 times to do these activities together.</p>  |   |
| <p>4. I am happy to be audio-recorded.</p>                                           |   |
| <p>5. I understand that I can ask questions at any time.</p>                         |   |
| <p>6. I can decide to stop and finish.</p>                                           |   |

**My Signature:** \_\_\_\_\_

**My Name in Capital Letters:** \_\_\_\_\_

**Date:** \_\_\_\_\_

## Appendix D

### Record form for perceptual analysis

Circle the feature that you note to be present and rate the severity on the VAS. If you do not perceive a feature to be present, leave the VAS blank.

#### **Respiration**

##### **Forced inspiration/expiration**

0  100

Definition:

Speech is interrupted by sudden forced  
inspiration/expiration sighs

##### **Audible inspiration**

0  100

Definition:

Audible, breathy inspiration

##### **Grunt at end of inspiration**

0  100

Definition:

Grunt at end of inspiration

**Phonation** (taken from CAPE-V form)

**Breathiness**

Definition:

Audible air escape in voice deviance

0  100

**Roughness**

Definition:

Perceived irregularity in voicing source

0  100

**Strain**

Definition:

Perception of excessive vocal effort (hyperfunction)

0  100



## **Pitch**

Definition:

0  100

Perceptual correlate of F0. Pitch deviates from normal for that person's gender, age, and referent culture

## **Loudness**

Definition:

0  100

Perceptual correlate of intensity. Loudness deviates from normal for that person's gender, age, and referent culture

## **Articulation**

See Goldman-Fristoe assessment

$PCC = (\text{number of consonants produced correctly} / \text{total number of consonants}) \times 100$

$PVC = (\text{number of vowels produced correctly} / \text{total number of vowels}) \times 100$

## **Resonance**

### **Hyponasality**

Definition:

Sounds excessively nasal. Excessive amount of air is resonated by nasal cavities

0  100

### **Hyponasality**

Definition:

Speech is denasal

0  100

### **Nasal emission**

Definition:

There is nasal emission of airstream

0  100

## **Prosody**

### **Rate**

Definition

Rate of actual speech is abnormally low or rapid

0  100

### **Phrases - short**

Definition:

Phrases are short. Speaker may sound as if they  
have run out of air

0  100

### **Increased rate in segments**

Definition:

Rate increases progressively within given  
segments of connected

0  100

**Increased rate overall**

Definition:

Rate increases progressively from beginning to end of sample

**Variable rate**

Definition:

Rate alternatively changes from slow to fast

**Reduced stress**

Definition:

Speech shows reduction of proper stress or emphasis patterns

**Intervals prolonged**

Definition:

Prolongation of inter-syllabic or inter-word intervals



**Inappropriate silences**

Definition:

There are inappropriate silent intervals

0  100

**Short rushes of speech**

Definition:

There are short rushes of speech separated by pauses

0  100

**Excess and equal stress**

Definition:

Excess stress on usually unstressed parts of speech

0  100

**Fluency overall**

Definition:

Speech fluency is interrupted by hesitations,  
repetitions, prolongations, and blocks

0  100

# Appendix E

## Speaker with DS 1

PARTICIPANT ID: DS1

### Sounds-in-Words (Ages 2:0-21:11)

| Item                 | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|----------------------|-------------|-------------------|----------|---------|--------|-------|
| 1                    | house       | haus              |          | h       |        | s     |
| 2                    | door        | dɔr               |          | d       |        | r     |
| 3                    | pig         | pɪg               |          | p       |        | g     |
| 4                    | cup         | kʌp               |          | k       |        | p     |
| 5                    | boy         | bɔɪ               |          | b       |        |       |
| 6                    | apple       | æpəl              |          |         | p      | l     |
| 7                    | go          | go                |          | g       |        |       |
| 8                    | duck        | dʌk               |          | d       |        | k     |
| 9                    | quack       | kwæk              |          | kw      |        | k     |
| 10                   | table       | tebəl             |          | t       | b      | l     |
| 11                   | monkey      | mʌŋki             |          | m       | ŋ k    |       |
| 12                   | hammer      | hæmə              |          | h       | m      | ə     |
| 13                   | fish        | fɪʃ               |          | f       |        | ʃ     |
| 14                   | watch       | wɒtʃ              |          | w       |        | tʃ    |
| 15                   | spider      | spɑɪdər           |          | sp      | d      | ər    |
| 16                   | web         | wɛb               |          | w       |        | b     |
| 17                   | drum        | drʌm              |          | dr      |        | m     |
| 18                   | plate       | plet              |          | pl      |        | t     |
| 19                   | knife       | naɪf              |          | n       |        | f     |
| 20                   | shoe        | ʃu                |          | ʃ       |        |       |
| 21                   | slide       | slaɪd             |          | sl      |        | d     |
| 22                   | swing       | swɪŋ              |          | sw      |        | ŋ     |
| 23                   | guitar      | ɡetər             |          | ɡ       | t      | ər    |
| 24                   | lion        | laɪən             |          | l       |        | n     |
| 25                   | chair       | tʃer              |          | tʃ      |        | r     |
| 26                   | soap        | sop               |          | s       |        | p     |
| 27                   | glasses     | ɡlæsɪz            |          | ɡl      | s      | z     |
| 28                   | tiger       | taɪɡər            |          | t       | ɡ      | ər    |
| 29                   | puzzle      | pʌzəl             |          | p       | z      | l     |
| Items 1-29 Subtotals |             |                   |          | 0       | 0      | 1     |

No vowel errors

|                                    |             |                   |          |         |        |       |
|------------------------------------|-------------|-------------------|----------|---------|--------|-------|
| Item                               | Target Word | IPA Transcription | Response | Initial | Medial | Final |
| 30                                 | finger      | fɪŋɡər            |          | f       | ŋ ɡ    | ər    |
| 31                                 | ring        | rɪŋ               |          | r       |        | ŋ     |
| 32                                 | thumb       | θʌm               |          | θ       |        | m     |
| 33                                 | elephant    | eləfənt           |          |         | l f    | nt    |
| 34                                 | vacuum      | vækjʊm            |          | v       | k j    | m     |
| 35                                 | shovel      | ʃʌvəl             |          | ʃ       | v      | l     |
| 36                                 | teacher     | ti:tʃər           |          | t       | tʃ     | ər    |
| 37                                 | zebra       | zɪbrə             |          | z       | br     | ə     |
| 38                                 | giraffe     | dʒərəf            |          | dʒ      | r      | f     |
| 39                                 | vegetable   | vɛdʒtəbəl         |          | v       | dʒ t b | l     |
| 40                                 | brushing    | brʌʃɪŋ            |          | br      | ʃ      | ɪŋ    |
| 41                                 | blue        | blu               |          | bl      |        |       |
| 42                                 | yellow      | jələʊ             |          | j       | l      |       |
| 43                                 | brother     | brʌðər            |          | br      | ð      | ər    |
| 44                                 | frog        | fɹɒɡ              |          | fr      |        | ɡ     |
| 45                                 | green       | ɡrɪn              |          | gr      |        | n     |
| 46                                 | that        | ðæt (i)           |          | ð       |        | t     |
| 47                                 | leaf        | li:f              |          | l       |        | f     |
| 48                                 | cookie      | kʊki (i)          |          | k       | k      |       |
| 49                                 | cheese      | tʃi:z             |          | tʃ      |        | z     |
| 50                                 | pajamas     | pəˈdʒæməz         |          | p       | dʒ m   | z     |
| 51                                 | teeth       | ti:θ              |          | t       |        | θ     |
| 52                                 | princess    | prɪnˈsɛs (i)      |          | pr      | n s    | s     |
| 53                                 | crown       | kraʊn             |          | kr      |        | n     |
| 54                                 | truck       | trʌk              |          | tr      |        | k     |
| 55                                 | red         | rɛd               |          | r       |        | d     |
| 56                                 | juice       | dʒʊs              |          | dʒ      |        | s     |
| 57                                 | zoo         | zu                |          | z       |        |       |
| 58                                 | star        | stɑr              |          | st      |        | r     |
| 59                                 | five        | faɪv              |          | f       |        | v     |
| 60                                 | seven       | sɛvən             |          | s       | v      | n     |
| Items 30-60 Subtotals              |             |                   |          | 1       | 1      | 0     |
| Transfer Items 1-29 Subtotals here |             |                   |          | 0       | 0      | 1     |
| Total Raw Score                    |             |                   |          | 3       |        |       |

Note: Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.

2 GFTA-3 ■ Record Form

Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 3          |
| (e) Total consonants correct (c) – (d)            | 138        |
| (f) PCC: (e) ÷ (c) x 100                          | 98         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 0         |
| (e) Total vowels correct (c) – (d)            | 88        |
| (f) PVC: (e) ÷ (c) x 100                      | 100       |

# Speaker with DS 2

PARTICIPANT ID: DS2

## Sounds-in-Words (Ages 2:0-21:11)

| Item                 | Target Word | IPA Transcription | Response | Initial | Medial | Final | Item | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|----------------------|-------------|-------------------|----------|---------|--------|-------|------|-------------|-------------------|----------|---------|--------|-------|
| 1                    | house       | haus              |          | h       |        | s     | 30   | finger      | fɪŋgə             |          | f       | ŋ g    | ə     |
| 2                    | door        | dɔr               |          | d       |        | r     | 31   | ring        | rɪŋ               |          | r       |        | ŋ     |
| 3                    | pig         | pɪg               |          | p       |        | g     | 32   | thumb       | θʌm               |          | θ       |        | m     |
| 4                    | cup         | kʌp               |          | k       |        | p     | 33   | elephant    | ɛləfənt           |          |         | l f    | nt    |
| 5                    | boy         | bɔɪ               |          | b       |        |       | 34   | vacuum      | vækjʊm            |          | v       | k j    | m     |
| 6                    | apple       | æpəl              |          |         | p      | l     | 35   | shovel      | ʃʌvəl             | /s       |         | v      | l     |
| 7                    | go          | go                |          | g       |        |       | 36   | teacher     | tɪtʃə             |          | t       | tʃ     | ə     |
| 8                    | duck        | dʌk               |          | d       |        | k     | 37   | zebra       | zɪbrə             |          | z       | br     |       |
| 9                    | quack       | kwæk              |          | kw      |        | k     | 38   | giraffe     | dʒərəf            |          | dʒ      | r      | f     |
| 10                   | table       | təbəl             |          | t       | b      | l     | 39   | vegetable   | vɛdʒəbəl          | /s       | v       | s t b  | l     |
| 11                   | monkey      | mʌŋki             |          | m       | ŋ k    |       | 40   | brushing    | brʌʃɪŋ            | /s       | br      | s      | ŋ     |
| 12                   | hammer      | hæmə              |          | h       | m      | /s    | 41   | blue        | blu               |          | bl      |        |       |
| 13                   | fish        | fɪʃ               |          | f       |        | /s    | 42   | yellow      | jələ              |          | j       | l      |       |
| 14                   | watch       | wɒtʃ              |          | w       |        | /s    | 43   | brother     | brʌðə             |          | br      | ð      | ə     |
| 15                   | spider      | spɑɪdər           |          | sp      | d      | ər    | 44   | frog        | frog              |          | fr      |        | g     |
| 16                   | web         | wɛb               |          | w       |        | b     | 45   | green       | grɪn              |          | gr      |        | n     |
| 17                   | drum        | drʌm              |          | dr      |        | m     | 46   | that        | ðæt (i)           |          | ð       |        | t     |
| 18                   | plate       | plet              |          | pl      |        | t     | 47   | leaf        | lif               |          | l       |        | f     |
| 19                   | knife       | naɪf              |          | n       |        | f     | 48   | cookie      | kʊki              |          | k       | k      |       |
| 20                   | shoe        | ʃu                | /s       |         |        |       | 49   | cheese      | tʃiz              |          | tʃ      |        | z     |
| 21                   | slide       | slaɪd             |          | sl      |        | d     | 50   | pajamas     | pəˈdʒəmeɪz        | /b       |         | dʒ m   | z     |
| 22                   | swing       | swɪŋ              |          | sw      |        | ŋ     | 51   | teeth       | tɪθ               |          | t       |        | θ     |
| 23                   | guitar      | ɡetər             |          | ɡ       | t      | r     | 52   | princess    | pɪnˈsɛs           |          | pr      | n s    | s     |
| 24                   | lion        | laɪən             |          | l       |        | n     | 53   | crown       | kraʊn             |          | kr      |        | n     |
| 25                   | chair       | tʃer              |          | tʃ      |        | r     | 54   | truck       | trʌk              |          | tr      |        | k     |
| 26                   | soap        | sop               |          | s       |        | p     | 55   | red         | rɛd               |          | r       |        | d     |
| 27                   | glasses     | ɡlæsɪz            |          | ɡl      | s      | z     | 56   | juice       | dʒʊs              | /d       |         |        | s     |
| 28                   | tiger       | taɪgər            |          | t       | ɡ      | ər    | 57   | zoo         | zu                |          | z       |        |       |
| 29                   | puzzle      | pʌzəl             |          | p       | z      | l     | 58   | star        | stɑr              |          | st      |        | r     |
| Items 1-29 Subtotals |             |                   |          | 1       | 0      | 3     | 59   | five        | fɑɪv              |          | f       |        | v     |
|                      |             |                   |          |         |        |       | 60   | seven       | sevn              |          | s       | v      | n     |

No vowel errors

Items 30-60 Subtotals

Transfer Items 1-29 Subtotals here

Total Raw Score

Note. Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.



Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 9          |
| (e) Total consonants correct (c) – (d)            | 132        |
| (f) PCC: (e) ÷ (c) x 100                          | 94         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 0         |
| (e) Total vowels correct (c) – (d)            | 88        |
| (f) PVC: (e) ÷ (c) x 100                      | 100       |

# Speaker with DS 3

PARTICIPANT ID: DS3

## Sounds-in-Words (Ages 2;0-21;11)

| Item                 | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|----------------------|-------------|-------------------|----------|---------|--------|-------|
| 1                    | house       | haʊs              |          | h       |        | 1/5   |
| 2                    | door        | dɔː               |          | d       |        | r     |
| 3                    | pig         | pɪɡ               |          | p       |        | g     |
| 4                    | cup         | kʌp               |          | k       |        | p     |
| 5                    | boy         | bɔɪ               |          | b       |        |       |
| 6                    | apple       | æpəl              |          |         | p      | l     |
| 7                    | go          | ɡoʊ               |          | ɡ       |        |       |
| 8                    | duck        | dʌk               |          | d       |        | k     |
| 9                    | quack       | kwæk              |          | kw      |        | k     |
| 10                   | table       | teɪbəl            |          | t       | b      | l     |
| 11                   | monkey      | mʌŋki             |          | m       | ŋ k    |       |
| 12                   | hammer      | hæmə              |          | h       | m      | 1/5   |
| 13                   | fish        | fɪʃ               |          | f       |        | 1/5   |
| 14                   | watch       | wɒtʃ              |          | w       |        | 1/5   |
| 15                   | spider      | spɑɪdə            |          | sp      | d      | ə     |
| 16                   | web         | wɛb               |          | w       |        | b     |
| 17                   | drum        | drʌm              |          | dr      |        | m     |
| 18                   | plate       | pleɪt             |          | pl      |        | t     |
| 19                   | knife       | naɪf              |          | n       |        | f     |
| 20                   | shoe        | ʃuː               |          | 1/5     |        |       |
| 21                   | slide       | slaɪd             |          | sl      |        | d     |
| 22                   | swing       | swɪŋ              |          | sw      |        | ŋ     |
| 23                   | guitar      | ɡetər             |          | ɡ       | t      | r     |
| 24                   | lion        | laɪən             |          | l       |        | n     |
| 25                   | chair       | tʃeər             |          | 1/5     |        | r     |
| 26                   | soap        | sɒp               |          | s       |        | p     |
| 27                   | glasses     | ɡlæsɪz            |          | ɡl      | s      | z     |
| 28                   | tiger       | taɪɡər            |          | t       | ɡ      | ər    |
| 29                   | puzzle      | pʌzəl             |          | p       | z      | l     |
| Items 1-29 Subtotals |             |                   |          | 2       | 0      | 4     |

| Item                               | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|------------------------------------|-------------|-------------------|----------|---------|--------|-------|
| 30                                 | finger      | fɪŋɡər            |          | f       | ŋ ɡ    | ər    |
| 31                                 | ring        | rɪŋ               |          | r       |        | ŋ     |
| 32                                 | thumb       | θʌm               |          | θ       |        | m     |
| 33                                 | elephant    | ɛləfənt           |          |         | l f    | nt    |
| 34                                 | vacuum      | vækjʊm (i)        |          | v       | k j    | m     |
| 35                                 | shovel      | ʃʌvəl             |          | ʃ       | v      | l     |
| 36                                 | teacher     | ti:tʃər           |          | t       | 1/5    | ər    |
| 37                                 | zebra       | zɪbrə             |          | z       | br     |       |
| 38                                 | giraffe     | dʒərəf            |          | dʒ      | r      | f     |
| 39                                 | vegetable   | vɛdʒtəbəl         |          | v       | dʒ t b | l     |
| 40                                 | brushing    | brʌʃɪŋ            |          | br      | ʃ      | ɪŋ    |
| 41                                 | blue        | bluː              |          | bl      |        |       |
| 42                                 | yellow      | jələʊ             |          | j       | l      |       |
| 43                                 | brother     | brʌðər            |          | br      | ð      | ər    |
| 44                                 | frog        | fɹɒɡ              |          | fr      |        | ɡ     |
| 45                                 | green       | ɡriːn             |          | gr      |        | n     |
| 46                                 | that        | ðæt (i)           |          | ð       |        | t     |
| 47                                 | leaf        | liːf              |          | l       |        | f     |
| 48                                 | cookie      | kʊki              |          | k       | k      |       |
| 49                                 | cheese      | tʃiːz             |          | 1/5     |        | z     |
| 50                                 | pajamas     | pəˈdʒæməz         |          | p       | dʒ m   | z     |
| 51                                 | teeth       | tiːθ              |          | t       |        | θ     |
| 52                                 | princess    | prɪnsɪs           |          | pr      | n s    | s     |
| 53                                 | crown       | kraʊn             |          | kr      |        | n     |
| 54                                 | truck       | trʌk              |          | tr      |        | k     |
| 55                                 | red         | rɛd               |          | r       |        | d     |
| 56                                 | juice       | dʒʊːs             |          | 1/5     |        | s     |
| 57                                 | zoo         | zuː               |          | z       |        |       |
| 58                                 | star        | stɑː              |          | st      |        | r     |
| 59                                 | five        | fɑɪv              |          | f       |        | v     |
| 60                                 | seven       | sevən             |          | s       | v      | n     |
| Items 30-60 Subtotals              |             |                   |          | 2       | 1      | 0     |
| Transfer Items 1-29 Subtotals here |             |                   |          | 2       | 0      | 4     |
| Total Raw Score                    |             |                   |          | 9       |        |       |

No vowel errors

Note: Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.

Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 9          |
| (e) Total consonants correct (c) – (d)            | 131        |
| (f) PCC: (e) ÷ (c) x 100                          | 94         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 0         |
| (e) Total vowels correct (c) – (d)            | 88        |
| (f) PVC: (e) ÷ (c) x 100                      | 100       |

# Speaker with DS 4

PARTICIPANT ID: DS4

## Sounds-in-Words (Ages 2:0-21:11)

| Item                               | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|------------------------------------|-------------|-------------------|----------|---------|--------|-------|
| 1                                  | house       | haus              |          | h       |        | s     |
| 2                                  | door        | dor               |          | d       |        | r     |
| 3                                  | pig         | pɪg               |          | p       |        | g     |
| 4                                  | cup         | kʌp               |          | k       |        | p     |
| 5                                  | boy         | bɔɪ               |          | b       |        |       |
| 6                                  | apple       | æpəl              |          |         | p      | l     |
| 7                                  | go          | go                |          | g       |        |       |
| 8                                  | duck        | dʌk               |          | d       |        | k     |
| 9                                  | quack       | kwæk              |          | kw      |        | k     |
| 10                                 | table       | tebəl             |          | t       | b      | l     |
| 11                                 | monkey      | mʌŋki             |          | m       | ŋ k    |       |
| 12                                 | hammer      | hæmə              |          | h       | m      | ə     |
| 13                                 | fish        | fɪʃ               |          | f       |        | ʃ     |
| 14                                 | watch       | wɒtʃ              |          | w       |        | tʃ    |
| 15                                 | spider      | spaɪdə            |          | sp      | d      | ə     |
| 16                                 | web         | wɛb               |          | w       |        | b     |
| 17                                 | drum        | drʌm              |          | dr      |        | m     |
| 18                                 | plate       | plet              |          | pl      |        | t     |
| 19                                 | knife       | naɪf              |          | n       |        | f     |
| 20                                 | shoe        | ʃu                |          | ʃ       |        |       |
| 21                                 | slide       | slaɪd             |          | sl      |        | d     |
| 22                                 | swing       | swɪŋ              |          | sw      |        | ŋ     |
| 23                                 | guitar      | geɪtər            |          | g       | t      | r     |
| 24                                 | lion        | laɪən             | (i)      | l       |        | n     |
| 25                                 | chair       | tʃeɪr             |          | tʃ      |        | r     |
| 26                                 | soap        | sop               |          | s       |        | p     |
| 27                                 | glasses     | glæsɪz            |          | gl      | s      | z     |
| 28                                 | tiger       | taɪgər            |          | t       | g      | ər    |
| 29                                 | puzzle      | pʌzəl             |          | p       | z      | l     |
| Items 1-29 Subtotals               |             |                   |          | 0       | 0      | 0     |
| 30                                 | finger      | fɪŋgər            |          | f       | ŋ g    | ər    |
| 31                                 | ring        | rɪŋ               |          | r       |        | ŋ     |
| 32                                 | thumb       | θʌm               |          | θ       |        | m     |
| 33                                 | elephant    | ɛləfənt           |          |         | l f    | nt    |
| 34                                 | vacuum      | vækjuəm           |          | v       | k j    | m     |
| 35                                 | shovel      | ʃʌvəl             |          | ʃ       | v      | l     |
| 36                                 | teacher     | ti:tʃər           |          | t       | tʃ     | ər    |
| 37                                 | zebra       | zɪbrə             |          | z       | br     |       |
| 38                                 | giraffe     | dʒərəf            |          | dʒ      | r      | f     |
| 39                                 | vegetable   | vɛdʒəbəl          |          | v       | dʒ b   | l     |
| 40                                 | brushing    | brʌʃɪŋ            |          | br      | ʃ      | ɪŋ    |
| 41                                 | blue        | blu               |          | bl      |        |       |
| 42                                 | yellow      | jələ              |          |         | l      |       |
| 43                                 | brother     | brʌðər            |          | br      | ð      | ər    |
| 44                                 | frog        | fɹɒg              |          | fr      |        | g     |
| 45                                 | green       | grɪn              |          | gr      |        | n     |
| 46                                 | that        | ðæt               | (i)      | ð       |        | t     |
| 47                                 | leaf        | li:f              |          | l       |        | f     |
| 48                                 | cookie      | kuki              |          | k       | k      |       |
| 49                                 | cheese      | tʃi:z             |          | tʃ      |        | z     |
| 50                                 | pajamas     | pædʒəmeɪz         |          | p       | dʒ m   | z     |
| 51                                 | teeth       | ti:θ              |          | t       |        | θ     |
| 52                                 | princess    | prɪnsɪs           |          | pr      | n s    | s     |
| 53                                 | crown       | kraʊn             |          | kr      |        | n     |
| 54                                 | truck       | trʌk              |          | tr      |        | k     |
| 55                                 | red         | rɛd               |          | r       |        | d     |
| 56                                 | juice       | dʒus              |          | dʒ      |        | s     |
| 57                                 | zoo         | zu                |          | z       |        |       |
| 58                                 | star        | stɑr              |          | st      |        | r     |
| 59                                 | five        | faɪv              |          | f       |        | v     |
| 60                                 | seven       | sevn              |          | s       | v      | n     |
| Items 30-60 Subtotals              |             |                   |          | 1       | 1      | 0     |
| Transfer Items 1-29 Subtotals here |             |                   |          | 0       | 0      | 0     |
| Total Raw Score                    |             |                   |          | 2       |        |       |

No vowel errors

Note: Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.

Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 2          |
| (e) Total consonants correct (c) – (d)            | 139        |
| (f) PCC: (e) ÷ (c) x 100                          | 99         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 0         |
| (e) Total vowels correct (c) - (d)            | 88        |
| (f) PVC: (e) ÷ (c) x 100                      | 100       |



# Speaker with DS 5

PARTICIPANT ID: DS5

## Sounds-in-Words (Ages 2:0-21:11)

| Item                               | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|------------------------------------|-------------|-------------------|----------|---------|--------|-------|
| 1                                  | house       | haus              |          | h       |        | s     |
| 2                                  | door        | dor               |          | d       |        | r     |
| 3                                  | pig         | pɪg               |          | p       |        | g     |
| 4                                  | cup         | kʌp               |          | k       |        | p     |
| 5                                  | boy         | bɔɪ               |          | b       |        |       |
| 6                                  | apple       | æpəl              |          |         | p      | l     |
| 7                                  | go          | go                |          | g       |        |       |
| 8                                  | duck        | dʌk               |          | d       |        | k     |
| 9                                  | quack       | kwæk              |          | kw      |        | k     |
| 10                                 | table       | tebəl             |          | t       | b      | l     |
| 11                                 | monkey      | mʌŋki             | æ        | m       | ŋ k    |       |
| 12                                 | hammer      | hæmə              |          | h       | m      | ə     |
| 13                                 | fish        | fɪʃ               |          | f       |        | ʃ     |
| 14                                 | watch       | wɒtʃ              |          | w       |        | ʃ     |
| 15                                 | spider      | spædər            |          | sp      | d      | ər    |
| 16                                 | web         | wɛb               |          | w       |        | p     |
| 17                                 | drum        | drʌm              |          | dr      |        | m     |
| 18                                 | plate       | plet              |          | pl      |        | t     |
| 19                                 | knife       | naɪf              |          | n       |        | f     |
| 20                                 | shoe        | ʃu                |          | ʃ       |        |       |
| 21                                 | slide       | slɑɪd             |          |         |        | d     |
| 22                                 | swing       | swɪŋ              |          | sw      |        | ŋ     |
| 23                                 | guitar      | ɡetər             |          | g       | t      | r     |
| 24                                 | lion        | laɪən             |          | l       |        | n     |
| 25                                 | chair       | tʃer              |          |         |        | r     |
| 26                                 | soap        | sop               |          | s       |        | p     |
| 27                                 | glasses     | glæsɪz            |          | gl      | s      | z     |
| 28                                 | tiger       | taɪgər            |          | t       | g      | ər    |
| 29                                 | puzzle      | pʌzəl             |          | p       | z      | l     |
| Items 1-29 Subtotals               |             |                   |          | 2       | 0      | 2     |
| 1 vowel error                      |             |                   |          |         |        |       |
| 30                                 | finger      | fɪŋgər            |          | f       | ŋ g    | ər    |
| 31                                 | ring        | rɪŋ               |          | r       |        | ŋ     |
| 32                                 | thumb       | θʌm               |          | θ       |        | m     |
| 33                                 | elephant    | ələfənt           |          |         | l f    | nt    |
| 34                                 | vacuum      | vækju(ɪ)          |          | v       | k j    | ɪ     |
| 35                                 | shovel      | ʃʌvəl             |          | ʃ       | v      | l     |
| 36                                 | teacher     | ti:tʃər           |          | t       |        | ʃər   |
| 37                                 | zebra       | zɪbrə             |          | z       | br     | ə     |
| 38                                 | giraffe     | dʒərəf            |          | dʒ      | r      | f     |
| 39                                 | vegetable   | vɛdʒəbəl          |          | v       | dʒ b   | l     |
| 40                                 | brushing    | brʌʃɪŋ            |          | br      | ʃ      | ɪŋ    |
| 41                                 | blue        | blu               |          | bl      |        |       |
| 42                                 | yellow      | jelo              |          |         |        |       |
| 43                                 | brother     | brʌðər            |          | br      | ð      | ər    |
| 44                                 | frog        | frog              |          | fr      |        | g     |
| 45                                 | green       | ɡrɪn              |          | gr      |        | n     |
| 46                                 | that        | ðæt (ɪ)           |          | ð       |        | t     |
| 47                                 | leaf        | li:f (ɪ)          |          | l       |        | f     |
| 48                                 | cookie      | kuki              |          | k       | k      |       |
| 49                                 | cheese      | tʃɪz              |          | tʃ      |        | z     |
| 50                                 | pajamas     | pəˈdʒəmeɪz        |          | p       | dʒ m   | z     |
| 51                                 | teeth       | ti:θ              |          | t       |        | θ     |
| 52                                 | princess    | prɪnsɪs (ɪ)       |          | pr      | n s    | s     |
| 53                                 | crown       | kraʊn             |          | kr      |        | n     |
| 54                                 | truck       | trʌk (ɪ)          |          | tr      |        | k     |
| 55                                 | red         | rɛd               |          | r       |        | d     |
| 56                                 | juice       | dʒʊs              |          | dʒ      |        | s     |
| 57                                 | zoo         | zu                |          | z       |        |       |
| 58                                 | star        | stɑr              |          | st      |        | r     |
| 59                                 | five        | fɑɪv              |          | f       |        | v     |
| 60                                 | seven       | sɛvən             |          | s       | v      | n     |
| Items 30-60 Subtotals              |             |                   |          | 1       | 3      | 3     |
| Transfer Items 1-29 Subtotals here |             |                   |          | 2       | 0      | 2     |
| Total Raw Score                    |             |                   |          |         |        | 9     |

Note: Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.

Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (f) Total number of target consonants             | <b>141</b> |
| (g) Number of consonants not elicited             | 0          |
| (h) Total number of consonants elicited (a) – (b) | 141        |
| (i) Total number of consonants in error           | 9          |
| (j) Total consonants correct (c) – (d)            | 132        |
| (k) PCC: (e) ÷ (c) x 100                          | 94         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 1         |
| (e) Total vowels correct (c) – (d)            | 87        |
| (f) PVC: (e) ÷ (c) x 100                      | 99        |

# Speaker with DS 6

PARTICIPANT ID: DS6

## Sounds-in-Words (Ages 2:0-21:11)

| Item                               | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|------------------------------------|-------------|-------------------|----------|---------|--------|-------|
| 1                                  | house       | haʊs              |          | h       |        |       |
| 2                                  | door        | dɔː               |          | d       |        |       |
| 3                                  | pig         | pɪg               |          | p       |        |       |
| 4                                  | cup         | kʌp               |          | k       |        |       |
| 5                                  | boy         | bɔɪ               |          | b       |        |       |
| 6                                  | apple       | æpəl              |          |         | p      | l     |
| 7                                  | go          | go                |          | g       |        |       |
| 8                                  | duck        | dʌk               |          | g       |        | k     |
| 9                                  | quack       | kʷæk              |          | k       |        | k     |
| 10                                 | table       | tebəl             |          | t       | b      | l     |
| 11                                 | monkey      | mʌŋki             |          | m       | ŋ k    |       |
| 12                                 | hammer      | hæmə              |          | h       | m      | ə     |
| 13                                 | fish        | fɪʃ               |          | f       |        | ʃ     |
| 14                                 | watch       | wɒtʃ              |          | w       |        | ʃ     |
| 15                                 | spider      | spɑɪdə            |          | sp      | d      | ə     |
| 16                                 | web         | web               |          | w       |        | b     |
| 17                                 | drum        | dʁʌm              |          | d       |        | m     |
| 18                                 | plate       | plet              |          | pl      |        | t     |
| 19                                 | knife       | naɪf              |          |         |        | f     |
| 20                                 | shoe        | ʃu                |          | ʃ       |        |       |
| 21                                 | slide       | slɑɪd             |          | sl      |        | d     |
| 22                                 | swing       | swɪŋ              |          | sw      |        | ŋ     |
| 23                                 | guitar      | ɡetɑː             |          | ɡ       | t      |       |
| 24                                 | lion        | laɪən             |          | l       |        | n     |
| 25                                 | chair       | tʃeə              |          | tʃ      |        |       |
| 26                                 | soap        | sop               |          | s       |        | p     |
| 27                                 | glasses     | ɡlæsɪz            |          | ɡ       | s      | z     |
| 28                                 | tiger       | taɪɡə             |          | t       | ɡ      | ə     |
| 29                                 | puzzle      | pʌzəl             |          | p       | z      | l     |
| Items 1-29 Subtotals               |             |                   |          | 10      | 0      | 2     |
| 30                                 | finger      | fɪŋɡə             |          | f       | ŋ g    | ə     |
| 31                                 | ring        | rɪŋ               |          | r       |        | ŋ     |
| 32                                 | thumb       | θʌm               |          | θ       |        | m     |
| 33                                 | elephant    | ələfənt           |          | ə       | l f    | nt    |
| 34                                 | vacuum      | vækjuːm           |          | v       |        | m     |
| 35                                 | shovel      | ʃʌvəl             |          | ʃ       | v      | l     |
| 36                                 | teacher     | ti:tʃə            |          | t       | tʃ     | ə     |
| 37                                 | zebra       | zɪbrə             |          | z       | br     |       |
| 38                                 | giraffe     | dʒərəʃ            |          | dʒ      | r      | f     |
| 39                                 | vegetable   | vedʒtəbel         |          | v       | dʒ t   | l     |
| 40                                 | brushing    | brʌʃɪŋ            |          | br      | ʃ      | ŋ     |
| 41                                 | blue        | blu               |          | bl      |        |       |
| 42                                 | yellow      | jeləʊ             |          | j       | l      |       |
| 43                                 | brother     | brʌðə             |          | br      | ð      | ə     |
| 44                                 | frog        | fɹɒɡ              |          | f       |        | ɡ     |
| 45                                 | green       | ɡriːn             |          | ɡ       |        | n     |
| 46                                 | that        | ðæt               |          | ð       |        | t     |
| 47                                 | leaf        | liːf              |          | l       |        | f     |
| 48                                 | cookie      | kʊki              |          | k       | k      |       |
| 49                                 | cheese      | tʃiːz             |          | tʃ      |        | z     |
| 50                                 | pajamas     | peɪdʒəˈmɑːz       |          | p       | dʒ m   | z     |
| 51                                 | teeth       | tiːθ              |          | t       |        | θ     |
| 52                                 | princess    | prɪˈnɛs           |          | p       | n      | s     |
| 53                                 | crown       | kraʊn             |          | kr      |        | n     |
| 54                                 | truck       | trʌk              |          | t       |        | k     |
| 55                                 | red         | red               |          | r       |        | d     |
| 56                                 | juice       | dʒʊːs             |          | dʒ      |        | s     |
| 57                                 | zoo         | zuː               |          | z       |        |       |
| 58                                 | star        | stɑː              |          | st      |        |       |
| 59                                 | five        | faɪv              |          | f       |        | v     |
| 60                                 | seven       | seːvən            |          | s       | v      | n     |
| Items 30-60 Subtotals              |             |                   |          | 15      | 6      | 1     |
| Transfer Items 1-29 Subtotals here |             |                   |          | 10      | 0      | 2     |
| Total Raw Score                    |             |                   |          | 34      |        |       |

3 vowel errors.

Note. Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.



Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (b) Total number of target consonants             | <b>141</b> |
| (l) Number of consonants not elicited             | 0          |
| (m) Total number of consonants elicited (a) – (b) | 141        |
| (n) Total number of consonants in error           | 34         |
| (o) Total consonants correct (c) – (d)            | 107        |
| (p) PCC: (e) ÷ (c) x 100                          | 76         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (g) Total number of target vowels             | <b>88</b> |
| (h) Number of vowels not elicited             | 0         |
| (i) Total number of vowels elicited (a) – (b) | 88        |
| (j) Total number of vowels in error           | 3         |
| (k) Total vowels correct (c) – (d)            | 85        |
| (l) PVC: (e) ÷ (c) x 100                      | 97        |

# Speaker with DS 7

PARTICIPANT ID: DS7

## Sounds-in-Words (Ages 2:0-21:11)

| Item                               | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|------------------------------------|-------------|-------------------|----------|---------|--------|-------|
| 1                                  | house       | haus              |          | h       |        | s     |
| 2                                  | door        | dɔr               |          | d       |        | r     |
| 3                                  | pig         | pɪg               |          | p       |        | g     |
| 4                                  | cup         | kʌp               |          | k       |        | p     |
| 5                                  | boy         | bɔɪ               |          | b       |        |       |
| 6                                  | apple       | æpəl              |          |         | p      | l     |
| 7                                  | go          | go                |          | g       |        |       |
| 8                                  | duck        | dʌk               |          | d       |        | k     |
| 9                                  | quack       | kwæk              |          | kw      |        | k     |
| 10                                 | table       | tebəl             |          | t       | b      | l     |
| 11                                 | monkey      | mʌŋki             |          | m       | ŋ k    |       |
| 12                                 | hammer      | hæmə              |          | h       | m      | ə     |
| 13                                 | fish        | fɪʃ               |          | f       |        | /s    |
| 14                                 | watch       | wɒtʃ              |          | w       |        | tʃ    |
| 15                                 | spider      | spɑɪdər           |          | sp      | d      | ər    |
| 16                                 | web         | wɛb               |          | w       |        | b     |
| 17                                 | drum        | drʌm              |          | dr      |        | m     |
| 18                                 | plate       | plet              |          | pl      |        | t     |
| 19                                 | knife       | naɪf              |          | n       |        | f     |
| 20                                 | shoe        | ʃu                |          | /s      |        |       |
| 21                                 | slide       | slaɪd             |          | sl      |        | d     |
| 22                                 | swing       | swɪŋ              |          | sw      |        | ŋ     |
| 23                                 | guitar      | ɡeɪtər            |          | ɡ       | t      | ər    |
| 24                                 | lion        | laɪən             |          | l       |        | n     |
| 25                                 | chair       | tʃeər             |          | tʃ      |        | ər    |
| 26                                 | soap        | sɒp               |          | s       |        | p     |
| 27                                 | glasses     | ɡlæsɪz            |          | ɡl      | s      | z     |
| 28                                 | tiger       | taɪgər            |          | t       | ɡ      | ər    |
| 29                                 | puzzle      | pʌzəl             |          | p       | z      | l     |
| Items 1-29 Subtotals               |             |                   |          | 1       | 0      | 1     |
| 30                                 | finger      | fɪŋgər            |          | f       | ŋ ɡ    | ər    |
| 31                                 | ring        | rɪŋ               |          | r       |        | ŋ     |
| 32                                 | thumb       | θʌm               |          | θ       |        | m     |
| 33                                 | elephant    | ələfənt           |          |         | l f    | nt    |
| 34                                 | vacuum      | vækju(ɪ)m         |          | /b      | k j    | / -   |
| 35                                 | shovel      | ʃʌvəl             |          | /s      | v      | l     |
| 36                                 | teacher     | ti:tʃər           |          | t       | tʃ     | ər    |
| 37                                 | zebra       | zɪbrə             |          | z       | br     |       |
| 38                                 | giraffe     | dʒərəf            |          | dʒ      | r      | f     |
| 39                                 | vegetable   | vedʒəbəl          |          | v       | dʒ / b | l     |
| 40                                 | brushing    | brʌʃɪŋ            |          | br      | ʃ      | ɪŋ    |
| 41                                 | blue        | blu               |          | bl      |        |       |
| 42                                 | yellow      | jələʊ             |          | j       | l      |       |
| 43                                 | brother     | brʌðər            |          | br      | ð      | ər    |
| 44                                 | frog        | fɹɒg              |          | fr      |        | g     |
| 45                                 | green       | ɡriːn             |          | gr      |        | n     |
| 46                                 | that        | ðæt               |          | ð       |        | t     |
| 47                                 | leaf        | liːf              |          | l       |        | f     |
| 48                                 | cookie      | kʊki              |          | k       | k      |       |
| 49                                 | cheese      | tʃiːz             |          | tʃ      |        | z     |
| 50                                 | pajamas     | pəˈdʒæməz         |          | p       | dʒ m   | z     |
| 51                                 | teeth       | tiːθ              |          | t       |        | θ     |
| 52                                 | princess    | ˈprɪnsɪs          |          | /p      | n s    | s     |
| 53                                 | crown       | kraʊn             |          | kr      |        | n     |
| 54                                 | truck       | trʌk              |          | tr      |        | k     |
| 55                                 | red         | red               |          | r       |        | d     |
| 56                                 | juice       | dʒʊːs             |          | dʒ      |        | s     |
| 57                                 | zoo         | zuː               |          | z       |        |       |
| 58                                 | star        | stɑː              |          | st      |        | r     |
| 59                                 | five        | faɪv              |          | f       |        | /b    |
| 60                                 | seven       | sevn              |          | s       | v      | n     |
| Items 30-60 Subtotals              |             |                   |          | 3       | 1      | 2     |
| Transfer Items 1-29 Subtotals here |             |                   |          | 1       | 0      | 1     |
| Total Raw Score                    |             |                   |          | 8       |        |       |

No vowel errors

Note: Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.

Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 8          |
| (e) Total consonants correct (c) – (d)            | 132        |
| (f) PCC: (e) ÷ (c) x 100                          | 94         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 0         |
| (e) Total vowels correct (c) – (d)            | 88        |
| (f) PVC: (e) ÷ (c) x 100                      | 100       |

# Speaker with DS 8

PARTICIPANT ID: DS8

## Sounds-in-Words (Ages 2;0-21;11)

| Item                               | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|------------------------------------|-------------|-------------------|----------|---------|--------|-------|
| 1                                  | house       | haus              |          | h       |        | s     |
| 2                                  | door        | dɔr               |          | d       |        | r     |
| 3                                  | pig         | pɪg               |          | p       |        | g     |
| 4                                  | cup         | kʌp               |          | k       |        | p     |
| 5                                  | boy         | bɔɪ               |          | b       |        |       |
| 6                                  | apple       | æpəl              |          |         | p      | l     |
| 7                                  | go          | go                |          | g       |        |       |
| 8                                  | duck        | dʌk               |          | d       |        | k     |
| 9                                  | quack       | kwæk              |          | kw      |        | k     |
| 10                                 | table       | təbəl             |          | t       | b      | l     |
| 11                                 | monkey      | mʌŋki             |          | m       | ŋ k    |       |
| 12                                 | hammer      | hæmə              |          | h       | m      | ə     |
| 13                                 | fish        | fɪʃ               |          | f       |        | ʃ     |
| 14                                 | watch       | wɒtʃ              |          | w       |        | tʃ    |
| 15                                 | spider      | spɑɪdər           |          | sp      | d      | ər    |
| 16                                 | web         | wɛb               |          | w       |        | b     |
| 17                                 | drum        | dram              |          | dr      |        | m     |
| 18                                 | plate       | plet              |          | pl      |        | t     |
| 19                                 | knife       | naɪf              |          | n       |        | f     |
| 20                                 | shoe        | ʃu                |          | ʃ       |        |       |
| 21                                 | slide       | slaɪd             |          | sl      |        | d     |
| 22                                 | swing       | swɪŋ              |          | sw      |        | ŋ     |
| 23                                 | guitar      | ɡɪtər             |          | ɡ       | t      | ər    |
| 24                                 | lion        | laɪən             |          | l       |        | n     |
| 25                                 | chair       | tʃer              |          | tʃ      |        | r     |
| 26                                 | soap        | sop               |          | s       |        | p     |
| 27                                 | glasses     | ɡlæsɪz            |          | ɡl      | s      | z     |
| 28                                 | tiger       | taɪgər            |          | t       | g      | ər    |
| 29                                 | puzzle      | pʌzəl             |          | p       | z      | l     |
| Items 1-29 Subtotals               |             |                   |          | 1       | 0      | 0     |
| 30                                 | finger      | fɪŋgər            |          | f       | ŋ g    | ər    |
| 31                                 | ring        | rɪŋ               |          | r       |        | ŋ     |
| 32                                 | thumb       | θʌm               |          | θ       |        | m     |
| 33                                 | elephant    | ɛləfənt           |          |         | l f    | nt    |
| 34                                 | vacuum      | vækju:m           |          | v       | k j    | m     |
| 35                                 | shovel      | ʃəvəl             |          | ʃ       | v      | l     |
| 36                                 | teacher     | ti:tʃər           |          | t       | tʃ     | ər    |
| 37                                 | zebra       | zɪbrə             |          | z       |        | br    |
| 38                                 | giraffe     | dʒərəf            |          | dʒ      | r      | f     |
| 39                                 | vegetable   | vɛdʒəbəl          |          | v       | dʒ b   | l     |
| 40                                 | brushing    | brʌʃɪŋ            |          | br      | ʃ      | ɪŋ    |
| 41                                 | blue        | blu               |          | bl      |        |       |
| 42                                 | yellow      | jɛlo              |          | j       |        | l     |
| 43                                 | brother     | brʌðər            |          | br      | ð      | ər    |
| 44                                 | frog        | frog              |          | fr      |        | g     |
| 45                                 | green       | ɡrɪn              |          | gr      |        | n     |
| 46                                 | that        | ðæt               |          | ð       |        | t     |
| 47                                 | leaf        | li:f              |          | l       |        | f     |
| 48                                 | cookie      | kʊki              |          | k       | k      |       |
| 49                                 | cheese      | tʃi:z             |          | tʃ      |        | z     |
| 50                                 | pajamas     | pəˈdʒæməz         |          | p       | dʒ m   | z     |
| 51                                 | teeth       | ti:θ              |          | t       |        | θ     |
| 52                                 | princess    | prɪnsɪs           |          | pr      | n s    | s     |
| 53                                 | crown       | kraʊn             |          | k       |        | n     |
| 54                                 | truck       | trʌk              |          | tr      |        | k     |
| 55                                 | red         | rɛd               |          | r       |        | d     |
| 56                                 | juice       | dʒʊs              |          | dʒ      |        | s     |
| 57                                 | zoo         | zu                |          | z       |        |       |
| 58                                 | star        | stɑr              |          | st      |        | r     |
| 59                                 | five        | fɑɪv              |          | f       |        | v     |
| 60                                 | seven       | sevn              |          | s       | v      | n     |
| Items 30-60 Subtotals              |             |                   |          | 3       | 2      | 1     |
| Transfer Items 1-29 Subtotals here |             |                   |          | 1       | 0      | 0     |
| Total Raw Score                    |             |                   |          | 7       |        |       |

No vowel errors

Note. Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.

Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 7          |
| (e) Total consonants correct (c) – (d)            | 134        |
| (f) PCC: (e) ÷ (c) x 100                          | 95         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 0         |
| (e) Total vowels correct (c) – (d)            | 8         |
| (f) PVC: (e) ÷ (c) x 100                      | 100       |



# Speaker with DS 9

PARTICIPANT ID: DS9

## Sounds-in-Words (Ages 2:0–21:11)

| Item                 | Target Word | IPA Transcription | Response        | Initial       | Medial | Final |
|----------------------|-------------|-------------------|-----------------|---------------|--------|-------|
| 1                    | house       | haus              |                 | h             |        | s     |
| 2                    | door        | dor               |                 | d             |        | r     |
| 3                    | pig         | pɪg               |                 | p             |        | g     |
| 4                    | cup         | kʌp               |                 | k             |        | p     |
| 5                    | boy         | bɔɪ               |                 | b             |        |       |
| 6                    | apple       | æpəl              |                 |               | p      | l     |
| 7                    | go          | go                |                 | g             |        |       |
| 8                    | duck        | dʌk               |                 | d             |        | k     |
| 9                    | quack       | <del>kwæk</del>   | <del>kwæk</del> | <del>kw</del> |        | k     |
| 10                   | table       | tebəl             |                 | t             | b      | l     |
| 11                   | monkey      | mʌŋki             |                 | m             | ŋ k    |       |
| 12                   | hammer      | hæmər             |                 | h             | m      | ər    |
| 13                   | fish        | fɪʃ               |                 | f             |        | ʃ     |
| 14                   | watch       | wɒtʃ              |                 | w             |        | tʃ    |
| 15                   | spider      | spɪdər            |                 | sp            | d      | ər    |
| 16                   | web         | wɛb               |                 | w             |        | b     |
| 17                   | drum        | drʌm              |                 | dr            |        | m     |
| 18                   | plate       | plet              |                 | pl            |        | t     |
| 19                   | knife       | naɪf              |                 | n             |        | f     |
| 20                   | shoe        | ʃu                |                 | ʃ             |        |       |
| 21                   | slide       | slɑɪd             |                 | sl            |        | d     |
| 22                   | swing       | swɪŋ              |                 | sw            |        | ŋ     |
| 23                   | guitar      | ɡetər             |                 | ɡ             | t      | ər    |
| 24                   | lion        | laɪən             |                 | l             |        | n     |
| 25                   | chair       | tʃer              |                 | tʃ            |        | r     |
| 26                   | soap        | sop               |                 | s             |        | p     |
| 27                   | glasses     | ɡlæsɪz            |                 | ɡl            | s      | z     |
| 28                   | tiger       | taɪɡər            |                 | t             | ɡ      | ər    |
| 29                   | puzzle      | pʌzəl             |                 | p             | z      | l     |
| Items 1–29 Subtotals |             |                   |                 | 1             | 0      | 0     |

No vowel errors

| Item                               | Target Word | IPA Transcription   | Response            | Initial      | Medial          | Final        |
|------------------------------------|-------------|---------------------|---------------------|--------------|-----------------|--------------|
| 30                                 | finger      | fɪŋɡər              |                     | f            | ŋ ɡ             | ər           |
| 31                                 | ring        | rɪŋ                 |                     | r            |                 | ŋ            |
| 32                                 | thumb       | θʌm                 |                     | θ            |                 | m            |
| 33                                 | elephant    | ələfənt             |                     |              | l f             | nt           |
| 34                                 | vacuum      | <del>vækju:m</del>  | <del>vækju:m</del>  | <del>v</del> | <del>k j</del>  | <del>m</del> |
| 35                                 | shovel      | ʃʌvəl               |                     | ʃ            | v               | l            |
| 36                                 | teacher     | ti:tʃər             |                     | t            | tʃ              | ər           |
| 37                                 | zebra       | <del>zɪbrə</del>    | <del>zɪbrə</del>    | <del>z</del> | <del>br</del>   | <del>ə</del> |
| 38                                 | giraffe     | dʒərəf              |                     | dʒ           | r               | f            |
| 39                                 | vegetable   | <del>vedʒəbəl</del> | <del>vedʒəbəl</del> | <del>v</del> | <del>dʒ b</del> | <del>l</del> |
| 40                                 | brushing    | brʌʃɪŋ              |                     | br           | ʃ               | ɪŋ           |
| 41                                 | blue        | blu                 |                     | bl           |                 |              |
| 42                                 | yellow      | jeləʊ               |                     | j            | l               |              |
| 43                                 | brother     | brʌðər              |                     | br           | ð               | ər           |
| 44                                 | frog        | fɹɒɡ                |                     | fr           |                 | ɡ            |
| 45                                 | green       | ɡri:n               |                     | ɡr           |                 | n            |
| 46                                 | that        | ðæt                 |                     | ð            |                 | t            |
| 47                                 | leaf        | li:f                |                     | l            |                 | f            |
| 48                                 | cookie      | kuki                |                     | k            | k               |              |
| 49                                 | cheese      | tʃi:z               |                     | tʃ           |                 | z            |
| 50                                 | pajamas     | pədʒəməz            |                     | p            | dʒ m            | z            |
| 51                                 | teeth       | ti:θ                |                     | t            |                 | θ            |
| 52                                 | princess    | prɪnsɪs             |                     | pr           | n s             | s            |
| 53                                 | crown       | kraʊn               |                     | kr           |                 | n            |
| 54                                 | truck       | trʌk                |                     | tr           |                 | k            |
| 55                                 | red         | red                 |                     | r            |                 | d            |
| 56                                 | juice       | dʒus                |                     | dʒ           |                 | s            |
| 57                                 | zoo         | zu                  |                     | z            |                 |              |
| 58                                 | star        | stɑ:                |                     | st           |                 | r            |
| 59                                 | five        | faɪv                |                     | <del>f</del> |                 | <del>v</del> |
| 60                                 | seven       | <del>sɛvən</del>    | <del>sɛvən</del>    | <del>s</del> | <del>b</del>    | <del>n</del> |
| Items 30–60 Subtotals              |             |                     |                     | 3            | 2               | 0            |
| Transfer Items 1–29 Subtotals here |             |                     |                     | 1            | 0               | 0            |
| Total Raw Score                    |             |                     |                     | 6            |                 |              |

Note. Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.

Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 6          |
| (e) Total consonants correct (c) – (d)            | 135        |
| (f) PCC: (e) ÷ (c) x 100                          | 96         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 0         |
| (e) Total vowels correct (c) – (d)            | 88        |
| (f) PVC: (e) ÷ (c) x 100                      | 100       |

# Speaker with DS 10

PARTICIPANT ID: DS10

## Sounds-in-Words (Ages 2:0-21:11)

| Item                 | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|----------------------|-------------|-------------------|----------|---------|--------|-------|
| 1                    | house       | haus              |          | h       |        | s     |
| 2                    | door        | dɔr               |          | d       |        | /     |
| 3                    | pig         | pɪg               |          | p       |        | g     |
| 4                    | cup         | kʌp               |          | k       |        | p     |
| 5                    | boy         | bɔɪ               |          | b       |        |       |
| 6                    | apple       | æpəl              |          |         | p      | l     |
| 7                    | go          | go                |          | g       |        |       |
| 8                    | duck        | dʌk               |          | d       |        | k     |
| 9                    | quack       | kwæk              |          | kw      |        | k     |
| 10                   | table       | tebəl             |          | t       | b      | l     |
| 11                   | monkey      | mʌŋki             |          | m       | ŋ k    |       |
| 12                   | hammer      | hæmə              | /        | /       | m      | /     |
| 13                   | fish        | fɪʃ               | /        | f       |        | /s    |
| 14                   | watch       | wɒtʃ              |          | w       |        | tʃ    |
| 15                   | spider      | spaɪdər           |          | sp      | d      | ər    |
| 16                   | web         | wɛb               |          | w       |        | b     |
| 17                   | drum        | drʌm              |          | dr      |        | m     |
| 18                   | plate       | plet              |          | pl      |        | t     |
| 19                   | knife       | naɪf              |          | n       |        | f     |
| 20                   | shoe        | ʃu                | /s       | /s      |        |       |
| 21                   | slide       | slaɪd             | /s       | /s      |        | d     |
| 22                   | swing       | swɪŋ              |          | sw      |        | ŋ     |
| 23                   | guitar      | ɡeɪtər            |          | ɡ       | t      | ər    |
| 24                   | lion        | laɪən             | /        | l       |        | n     |
| 25                   | chair       | tʃeər             | /        | /       |        | r     |
| 26                   | soap        | sop               |          | s       |        | p     |
| 27                   | glasses     | ɡlæsɪz            |          | ɡl      | s      | z     |
| 28                   | tiger       | taɪɡər            |          | t       | ɡ      | ər    |
| 29                   | puzzle      | pʌzəl             | (i)      | p       | z      | l     |
| Items 1-29 Subtotals |             |                   |          | 4       | 0      | 4     |

2 vowel errors

|                                    |           |           |     |    |      |    |
|------------------------------------|-----------|-----------|-----|----|------|----|
| 30                                 | finger    | fɪŋɡər    |     | f  | ŋ ɡ  | ər |
| 31                                 | ring      | rɪŋ       |     | r  |      | ŋ  |
| 32                                 | thumb     | θʌm       |     | θ  |      | m  |
| 33                                 | elephant  | ələfənt   |     |    | l f  | nt |
| 34                                 | vacuum    | vækju:m   | (i) | /b | k j  | /  |
| 35                                 | shovel    | ʃʌvəl     | /s  | /s | v    | l  |
| 36                                 | teacher   | ti:tʃər   |     | t  | tʃ   | ər |
| 37                                 | zebra     | zɪbrə     |     | z  | br   | ər |
| 38                                 | giraffe   | dʒərəf    |     | dʒ | r    | f  |
| 39                                 | vegetable | vɛdʒtəbəl |     | v  | dʒ b | l  |
| 40                                 | brushing  | brʌʃɪŋ    | /s  | br | /s   | ŋ  |
| 41                                 | blue      | blu       |     | bl |      |    |
| 42                                 | yellow    | jelə      |     | j  | l    |    |
| 43                                 | brother   | brʌðər    |     | br | ð    | ər |
| 44                                 | frog      | fɹɒɡ      |     | fr |      | ɡ  |
| 45                                 | green     | ɡrɪn      |     | ɡr |      | n  |
| 46                                 | that      | ðæt       |     | ð  |      | t  |
| 47                                 | leaf      | li:f      |     | l  |      | f  |
| 48                                 | cookie    | kʊki      |     | k  | k    |    |
| 49                                 | cheese    | tʃi:z     |     | tʃ |      | z  |
| 50                                 | pajamas   | pədʒəmeɪz |     | p  | dʒ m | z  |
| 51                                 | teeth     | ti:θ      |     | t  |      | θ  |
| 52                                 | princess  | prɪnsɪs   | /   | pr | n s  | s  |
| 53                                 | crown     | kraʊn     |     | kr |      | n  |
| 54                                 | truck     | trʌk      |     | tr |      | k  |
| 55                                 | red       | rɛd       |     | r  |      | d  |
| 56                                 | juice     | dʒus      | /   | /  |      | s  |
| 57                                 | zoo       | zu        | /s  | /s |      |    |
| 58                                 | star      | stɑr      |     | st |      | r  |
| 59                                 | five      | faɪv      |     | f  |      | v  |
| 60                                 | seven     | sevn      |     | s  | v    | n  |
| Items 30-60 Subtotals              |           |           |     | 4  | 2    | 1  |
| Transfer Items 1-29 Subtotals here |           |           |     | 4  | 0    | 4  |
| Total Raw Score                    |           |           |     | 15 |      |    |

Note. Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.



Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 15         |
| (e) Total consonants correct (c) – (d)            | 126        |
| (f) PCC: (e) ÷ (c) x 100                          | 89         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 2         |
| (e) Total vowels correct (c) – (d)            | 86        |
| (f) PVC: (e) ÷ (c) x 100                      | 98        |

# Speaker with DS 11

PARTICIPANT ID: DS11

## Sounds-in-Words (Ages 2:0-21:11)

| Item                 | Target Word | IPA Transcription  | Response       | Initial | Medial         | Final | Item | Target Word | IPA Transcription       | Response       | Initial | Medial | Final          |
|----------------------|-------------|--------------------|----------------|---------|----------------|-------|------|-------------|-------------------------|----------------|---------|--------|----------------|
| 1                    | house       | haus               |                | h       |                | s     | 30   | finger      | <del>/ɪŋgə/</del>       | <del>/b/</del> | ŋ       | g      | ə              |
| 2                    | door        | dɔr                |                | d       |                | r     | 31   | ring        | <del>/ɪŋ/</del>         | <del>/w/</del> |         |        | ŋ              |
| 3                    | pig         | pɪg                |                | p       |                | g     | 32   | thumb       | <del>/θʌm/</del>        | <del>/f/</del> |         |        | m              |
| 4                    | cup         | kʌp                |                | k       |                | p     | 33   | elephant    | eləfənt                 |                |         | f      | nt             |
| 5                    | boy         | bɔɪ                |                | b       |                |       | 34   | vacuum      | vækjuːm                 |                | v       | k      | j              |
| 6                    | apple       | æpəl               |                |         | p              | l     | 35   | shovel      | <del>/ʃʌvəl/</del>      | <del>/b/</del> |         |        | l              |
| 7                    | go          | go                 |                | g       |                |       | 36   | teacher     | tɪtʃər                  |                | t       | tʃ     | ər             |
| 8                    | duck        | dʌk                |                | d       |                | k     | 37   | zebra       | <del>/zɪbrə/</del>      | <del>/z/</del> |         |        |                |
| 9                    | quack       | kwæk               |                | kw      |                | k     | 38   | giraffe     | dʒərəf                  |                | dʒ      | r      | f              |
| 10                   | table       | tebəl              |                | t       | b              | l     | 39   | vegetable   | <del>/vedʒtəbəl/</del>  | <del>/b/</del> |         | dʒ     | t              |
| 11                   | monkey      | mʌŋki              |                | m       | ŋ              | k     | 40   | brushing    | brʌʃɪŋ                  |                | br      | ʃ      | ɪŋ             |
| 12                   | hammer      | hæmə               |                | h       | m              | ə     | 41   | blue        | blu                     |                | bl      |        |                |
| 13                   | fish        | fɪʃ                |                | f       |                | ʃ     | 42   | yellow      | <del>/jelə/</del>       | <del>/l/</del> |         |        |                |
| 14                   | watch       | wɒtʃ               |                | w       |                | tʃ    | 43   | brother     | brʌðər                  |                | br      | ð      | ər             |
| 15                   | spider      | spaɪdər            |                | sp      | d              | ər    | 44   | frog        | frog                    |                | fr      |        | g              |
| 16                   | web         | wɛb                |                | w       |                |       | 45   | green       | grɪn                    |                | gr      |        | n              |
| 17                   | drum        | drʌm               |                | dr      |                | m     | 46   | that        | ðæt                     |                | ð       |        | t              |
| 18                   | plate       | plet               |                | pl      |                | t     | 47   | leaf        | lif                     |                | l       |        | f              |
| 19                   | knife       | naɪf               |                | n       |                | f     | 48   | cookie      | kʊki                    |                | k       | k      |                |
| 20                   | shoe        | ʃu                 |                | ʃ       |                |       | 49   | cheese      | tʃiːz                   |                | tʃ      |        | s              |
| 21                   | slide       | <del>/slaɪd/</del> | <del>/s/</del> |         |                | d     | 50   | pajamas     | <del>/peɪdʒəmeɪz/</del> | <del>/b/</del> |         | dʒ     | m              |
| 22                   | swing       | swɪŋ               |                | sw      |                | ŋ     | 51   | teeth       | tiθ                     |                | t       |        | θ              |
| 23                   | guitar      | ɡeɪtər             |                | ɡ       | t              | r     | 52   | princess    | prɪnsəs                 |                | pr      | n      | s              |
| 24                   | lion        | laɪən              |                | l       |                | n     | 53   | crown       | <del>/kraʊn/</del>      | <del>/k/</del> |         |        | n              |
| 25                   | chair       | tʃeər              |                | tʃ      |                | r     | 54   | truck       | trʌk                    |                | tr      |        | k              |
| 26                   | soap        | sop                |                | s       |                | p     | 55   | red         | <del>/red/</del>        | <del>/w/</del> |         |        | d              |
| 27                   | glasses     | ɡlæsɪz             |                | ɡl      | <del>/b/</del> | z     | 56   | juice       | dʒʊs                    |                | dʒ      |        | s              |
| 28                   | tiger       | taɪgər             |                | t       | ɡ              | ər    | 57   | zoo         | <del>/zu/</del>         | <del>/s/</del> |         |        | r              |
| 29                   | puzzle      | pʌzəl              |                | p       | z              | l     | 58   | star        | stɑː                    |                | st      |        |                |
| Items 1-29 Subtotals |             |                    |                | 1       | 1              | 1     | 59   | five        | <del>/faɪv/</del>       |                | f       |        | <del>/b/</del> |
|                      |             |                    |                |         |                |       | 60   | seven       | sevən                   |                | s       | v      | n              |

No vowel errors

Items 30-60 Subtotals

Transfer Items 1-29 Subtotals here

Total Raw Score

|    |   |   |
|----|---|---|
| 8  | 3 | 4 |
| 1  | 1 | 1 |
| 18 |   |   |

Note: Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.

Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 18         |
| (e) Total consonants correct (c) – (d)            | 123        |
| (f) PCC: (e) ÷ (c) x 100                          | 87         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 180       |
| (e) Total vowels correct (c) – (d)            | 88        |
| (f) PVC: (e) ÷ (c) x 100                      | 100       |

# Speaker with DS 12

PARTICIPANT ID: DS12

## Sounds-in-Words (Ages 2:0-21:11)

| Item                               | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|------------------------------------|-------------|-------------------|----------|---------|--------|-------|
| 1                                  | house       | haʊs              |          | h       |        | ʃ     |
| 2                                  | door        | dɔː               |          | d       |        | r     |
| 3                                  | pig         | pɪg               |          |         |        | g     |
| 4                                  | cup         | kʌp               |          | k       |        | p     |
| 5                                  | boy         | bɔɪ               |          | b       |        |       |
| 6                                  | apple       | æpəl              |          |         | p      | l     |
| 7                                  | go          | go                |          | g       |        |       |
| 8                                  | duck        | dʌk               |          | d       |        | k     |
| 9                                  | quack       | kwæk              |          | kw      |        | k     |
| 10                                 | table       | tebəl             |          | t       | b      | l     |
| 11                                 | monkey      | mʌŋki             |          | m       | ŋ k    |       |
| 12                                 | hammer      | hæmə              |          | h       | m      | ə     |
| 13                                 | fish        | fɪʃ               |          | f       |        | ʃ     |
| 14                                 | watch       | wɒtʃ              |          | w       |        | ʃ     |
| 15                                 | spider      | spɑɪdər           |          | sp      | d      | ər    |
| 16                                 | web         | wɛb               |          | w       |        | b     |
| 17                                 | drum        | drʌm              |          | dr      |        | m     |
| 18                                 | plate       | plet              |          | pl      |        | t     |
| 19                                 | knife       | naɪf              |          | n       |        | f     |
| 20                                 | shoe        | ʃuː               |          |         |        | ʃ     |
| 21                                 | slide       | slaɪd             |          | sl      |        | d     |
| 22                                 | swing       | swɪŋ              |          | sw      |        | ŋ     |
| 23                                 | guitar      | ɡetər             |          | ɡ       | t      | ər    |
| 24                                 | lion        | laɪən             |          | l       |        | n     |
| 25                                 | chair       | tʃeər             |          | tʃ      |        | ər    |
| 26                                 | soap        | sop               |          | s       |        | p     |
| 27                                 | glasses     | glæsɪz            |          | gl      | s      | z     |
| 28                                 | tiger       | taɪɡər            |          | t       | ɡ      | ər    |
| 29                                 | puzzle      | pʌzəl             |          | p       | z      | l     |
| Items 1-29 Subtotals               |             |                   |          | 3       | 0      | 5     |
| 30                                 | finger      | fɪŋɡər            |          | f       | ŋ ɡ    | ər    |
| 31                                 | ring        | rɪŋ               |          | r       |        | ŋ     |
| 32                                 | thumb       | θʌm               |          | θ       |        | m     |
| 33                                 | elephant    | ələfənt           |          |         | l f    | nt    |
| 34                                 | vacuum      | vækjʊm            |          | v       | k j    | m     |
| 35                                 | shovel      | ʃʌvəl             |          | ʃ       | v      | l     |
| 36                                 | teacher     | ti:tʃər           |          | t       | tʃ     | ər    |
| 37                                 | zebra       | zɪbrə             |          | z       | br     |       |
| 38                                 | giraffe     | ɡɪræf             |          | ɡ       | r      | f     |
| 39                                 | vegetable   | vɛdʒtəbəl         |          | v       | dʒ t b | l     |
| 40                                 | brushing    | brʌʃɪŋ            |          | br      | ʃ      | ɪŋ    |
| 41                                 | blue        | bluː              |          | bl      |        |       |
| 42                                 | yellow      | jeloʊ             |          | j       |        | loʊ   |
| 43                                 | brother     | brʌðər            |          | br      | ð      | ər    |
| 44                                 | frog        | fɹɒɡ              |          | fr      |        | ɡ     |
| 45                                 | green       | ɡriːn             |          | gr      |        | n     |
| 46                                 | that        | ðæt (i)           |          | ð       |        | t     |
| 47                                 | leaf        | liːf              |          | l       |        | f     |
| 48                                 | cookie      | kʊki              |          | k       | k      |       |
| 49                                 | cheese      | tʃiːz             |          | tʃ      |        | z     |
| 50                                 | pajamas     | pəˈdʒæməz         |          | p       | dʒ m   | z     |
| 51                                 | teeth       | tiːθ              |          | t       |        | θ     |
| 52                                 | princess    | pɹɪnsɪs           |          | pr      | n s    | s     |
| 53                                 | crown       | kraʊn             |          | kr      |        | n     |
| 54                                 | truck       | trʌk              |          | tr      |        | k     |
| 55                                 | red         | red               |          | r       |        | d     |
| 56                                 | juice       | dʒʊːs             |          | dʒ      |        | s     |
| 57                                 | zoo         | zuː               |          | z       |        |       |
| 58                                 | star        | stɑː              |          | st      |        | r     |
| 59                                 | five        | faɪv              |          | f       |        | v     |
| 60                                 | seven       | sevn              |          | s       | v      | n     |
| Items 30-60 Subtotals              |             |                   |          | 5       | 3      | 1     |
| Transfer Items 1-29 Subtotals here |             |                   |          | 3       | 0      | 5     |
| Total Raw Score                    |             |                   |          | 17      |        |       |

No vowel errors.

Note. Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.

Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 17         |
| (e) Total consonants correct (c) – (d)            | 124        |
| (f) PCC: (e) ÷ (c) x 100                          | 88         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 0         |
| (e) Total vowels correct (c) – (d)            | 88        |
| (f) PVC: (e) ÷ (c) x 100                      | 100       |



# Speaker with DS 13

PARTICIPANT ID: DS13

## Sounds-in-Words (Ages 2:0-21:11)

| Item                               | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|------------------------------------|-------------|-------------------|----------|---------|--------|-------|
| 1                                  | house       | haʊs              |          | h       |        |       |
| 2                                  | door        | dɔː               |          | d       |        |       |
| 3                                  | pig         | pɪg               |          | p       |        |       |
| 4                                  | cup         | kʌp               |          | k       |        |       |
| 5                                  | boy         | bɔɪ               |          | b       |        |       |
| 6                                  | apple       | æpəl              |          |         | p      |       |
| 7                                  | go          | go                |          | g       |        |       |
| 8                                  | duck        | dʌk               |          | d       |        | k     |
| 9                                  | quack       | kwæk              |          | kw      |        | k     |
| 10                                 | table       | tebəl             |          | t       | b      |       |
| 11                                 | monkey      | mʌŋki             |          | m       | ŋ k    |       |
| 12                                 | hammer      | hæmə              |          | h       | m      | ə     |
| 13                                 | fish        | fɪʃ               |          | f       |        | ʃ     |
| 14                                 | watch       | wɒtʃ              |          | w       |        | tʃ    |
| 15                                 | spider      | spɑɪdər           |          | s       | p      | dər   |
| 16                                 | web         | wɛb               |          | w       |        | b     |
| 17                                 | drum        | drʌm              |          | dr      |        | m     |
| 18                                 | plate       | plet              |          | pl      |        | t     |
| 19                                 | knife       | naɪf              |          | n       |        | f     |
| 20                                 | shoe        | ʃuː               |          | ʃ       |        | uː    |
| 21                                 | slide       | slaɪd             |          | sl      |        | d     |
| 22                                 | swing       | swɪŋ              |          | sw      |        | ŋ     |
| 23                                 | guitar      | ɡɪtər (i)         |          | ɡ       | t      | r     |
| 24                                 | lion        | laɪən             |          | l       |        | n     |
| 25                                 | chair       | tʃeər             |          | tʃ      |        | r     |
| 26                                 | soap        | səʊp              |          | s       |        | p     |
| 27                                 | glasses     | ɡlæsɪz            |          | ɡl      | æs     | ɪz    |
| 28                                 | tiger       | taɪgər            |          | t       | g      | ər    |
| 29                                 | puzzle      | pʌzəl (i)         |          | p       | z      | əl    |
| Items 1-29 Subtotals               |             |                   |          | 5       | 1      | 3     |
| 30                                 | finger      | fɪŋgər            |          | f       | ŋ g    | ər    |
| 31                                 | ring        | rɪŋ               |          | r       |        | ŋ     |
| 32                                 | thumb       | θʌm               |          | θ       |        | m     |
| 33                                 | elephant    | ələfənt           |          |         | l f    | nt    |
| 34                                 | vacuum      | vækjʊm            |          | v       | k j    | m     |
| 35                                 | shovel      | ʃʌvəl             |          | ʃ       | v      | əl    |
| 36                                 | teacher     | ti:tʃər           |          | t       | tʃ     | ər    |
| 37                                 | zebra       | zɪbrə             |          |         | br     | ər    |
| 38                                 | giraffe     | dʒərəʃ            |          | dʒ      | r      | əʃ    |
| 39                                 | vegetable   | vɛdʒtəbəl         |          | v       | dʒ t b | əl    |
| 40                                 | brushing    | brʌʃɪŋ            |          | br      | ʃ      | ɪŋ    |
| 41                                 | blue        | bluː              |          | bl      |        | uː    |
| 42                                 | yellow      | jələʊ             |          | j       | l      | əʊ    |
| 43                                 | brother     | brʌðər            |          | br      | ð      | ər    |
| 44                                 | frog        | fɹɒg              |          | fr      |        | ɒg    |
| 45                                 | green       | ɡriːn             |          | gr      |        | riːn  |
| 46                                 | that        | ðæt               |          | ð       |        | t     |
| 47                                 | leaf        | liːf              |          | l       |        | f     |
| 48                                 | cookie      | kʊki              |          | k       | k      | i     |
| 49                                 | cheese      | tʃiːz (i)         |          | tʃ      |        | z     |
| 50                                 | pajamas     | pəˈdʒæməz         |          | p       | dʒ m   | z     |
| 51                                 | teeth       | tiːθ              |          | t       |        | θ     |
| 52                                 | princess    | prɪnsɪs           |          | pr      | n s    | s     |
| 53                                 | crown       | kraʊn             |          | kr      |        | n     |
| 54                                 | truck       | trʌk              |          | tr      |        | k     |
| 55                                 | red         | rɛd               |          | r       |        | d     |
| 56                                 | juice       | dʒus              |          | dʒ      |        | us    |
| 57                                 | zoo         | zuː               |          | z       |        | uː    |
| 58                                 | star        | stɑː              |          | st      |        | ɑː    |
| 59                                 | five        | faɪv              |          | f       |        | v     |
| 60                                 | seven       | sevn              |          | s       | v      | n     |
| Items 30-60 Subtotals              |             |                   |          | 6       | 4      | 0     |
| Transfer Items 1-29 Subtotals here |             |                   |          | 5       | 1      | 3     |
| Total Raw Score                    |             |                   |          | 19      |        |       |

No vowel errors

Note: Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.

Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 19         |
| (e) Total consonants correct (c) – (d)            | 122        |
| (f) PCC: (e) ÷ (c) x 100                          | 87         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 0         |
| (e) Total vowels correct (c) – (d)            | 88        |
| (f) PVC: (e) ÷ (c) x 100                      | 100       |

# Speaker with DS 14

PARTICIPANT ID: DS14

## Sounds-in-Words (Ages 2:0-21:11)

| Item                 | Target Word | IPA Transcription | Response | Initial | Medial | Final | Item | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|----------------------|-------------|-------------------|----------|---------|--------|-------|------|-------------|-------------------|----------|---------|--------|-------|
| 1                    | house       | haus              |          | h       |        | s     | 30   | finger      | fɪŋgə             |          | f       | ŋ g    | ə     |
| 2                    | door        | dɔr               |          | d       |        | r     | 31   | ring        | rɪŋ               |          | r       |        | ŋ     |
| 3                    | pig         | pɪg               |          | p       |        | g     | 32   | thumb       | θʌm               |          | θ       |        | m     |
| 4                    | cup         | kʌp               |          | k       |        | p     | 33   | elephant    | ɛləfənt           |          |         | ɪ f    | nt    |
| 5                    | boy         | bɔɪ               |          | b       |        |       | 34   | vacuum      | vækjʊm            |          | v       | k j    | m     |
| 6                    | apple       | æpəl              | ɔ        |         | p      | l     | 35   | shovel      | ʃəvəl             | ʃs       |         | v      | l     |
| 7                    | go          | go                |          | g       |        |       | 36   | teacher     | ti:tʃə            | ts       | ts      |        | ə     |
| 8                    | duck        | dʌk               |          | d       |        | k     | 37   | zebra       | zɪbrə             |          | z       | br     |       |
| 9                    | quack       | kwæk              |          | kw      |        | k     | 38   | giraffe     | dʒərəf            |          | dʒ      | r      | f     |
| 10                   | table       | tebəl             |          | t       | b      | l     | 39   | vegetable   | vɛdʒəbəl          |          | v       | ʒ t b  | l     |
| 11                   | monkey      | mʌŋki             |          | m       | ŋ k    |       | 40   | brushing    | brʌʃɪŋ            |          | br      | ʃ      | ŋ     |
| 12                   | hammer      | hæmə              |          | h       | m      | ɪs    | 41   | blue        | blu               |          | bl      |        |       |
| 13                   | fish        | fɪʃ               |          | f       |        | ʃ     | 42   | yellow      | jələ              |          | j       | l      |       |
| 14                   | watch       | wɒtʃ              |          | w       |        | ts    | 43   | brother     | brʌðə             |          | br      | ð      | ə     |
| 15                   | spider      | spɑɪdər           |          | sp      | d      | ər    | 44   | frog        | frog              |          | fr      |        | g     |
| 16                   | web         | wɛb               |          | w       |        | b     | 45   | green       | grɪn              |          | gr      |        | n     |
| 17                   | drum        | drʌm              |          | dr      |        | m     | 46   | that        | ðæt               | (i)      | ð       |        | t     |
| 18                   | plate       | plet              |          | pl      |        | t     | 47   | leaf        | li:f              |          | l       |        | f     |
| 19                   | knife       | naɪf              |          | n       |        | f     | 48   | cookie      | kʊki              |          | k       | k      |       |
| 20                   | shoe        | ʃu                | ʃs       |         |        |       | 49   | cheese      | tʃi:z             | ts       |         |        | z     |
| 21                   | slide       | slaɪd             |          | sl      |        | d     | 50   | pajamas     | pədʒəmeɪz         |          | p       | dʒ m   | z     |
| 22                   | swing       | swɪŋ              |          | sw      |        | ŋ     | 51   | teeth       | ti:θ              |          | t       |        | θ     |
| 23                   | guitar      | getər             |          | g       | t      | r     | 52   | princess    | prɪnsɪs           |          | pr      | n s    | s     |
| 24                   | lion        | laɪən             |          | l       |        | n     | 53   | crown       | kraʊn             |          | kr      |        | n     |
| 25                   | chair       | tʃer              | ts       |         |        | r     | 54   | truck       | trʌk              | (i)      | tr      |        | k     |
| 26                   | soap        | sop               |          | s       |        | p     | 55   | red         | rɛd               |          | r       |        | d     |
| 27                   | glasses     | glæsɪz            |          | gl      | s      | z     | 56   | juice       | dʒʊ:s             | ts       |         |        | s     |
| 28                   | tiger       | taɪgər            |          | t       | g      | ər    | 57   | zoo         | zu                |          | z       |        |       |
| 29                   | puzzle      | pʌzəl             |          | p       | z      | l     | 58   | star        | stɑr              |          | st      |        | r     |
| Items 1-29 Subtotals |             |                   |          | 2       | 0      | 2     | 59   | five        | faɪv              |          | f       |        | v     |
|                      |             |                   |          |         |        |       | 60   | seven       | sevn              |          | s       | v      | n     |

1 vowel error.

|                                    |   |   |   |
|------------------------------------|---|---|---|
| Items 30-60 Subtotals              | 3 | 2 | 0 |
| Transfer Items 1-29 Subtotals here | 2 | 0 | 2 |
| Total Raw Score                    | 9 |   |   |

Note: Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.



Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 9          |
| (e) Total consonants correct (c) – (d)            | 132        |
| (f) PCC: (e) ÷ (c) x 100                          | 94         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) |           |
| (d) Total number of vowels in error           | 1         |
| (e) Total vowels correct (c) – (d)            | 87        |
| (f) PVC: (e) ÷ (c) x 100                      | 99        |

# Speaker with DS 15

PARTICIPANT ID: DS15

## Sounds-in-Words (Ages 2:0-21:11)

| Item                 | Target Word | IPA Transcription | Response | Initial | Medial | Final | Item                               | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|----------------------|-------------|-------------------|----------|---------|--------|-------|------------------------------------|-------------|-------------------|----------|---------|--------|-------|
| 1                    | house       | haus              |          | h       |        | s     | 30                                 | finger      | fɪŋgə             |          | f       | ŋ g    | ə     |
| 2                    | door        | dɔr               |          | d       |        | r     | 31                                 | ring        | rɪŋ               |          | r       |        | ŋ     |
| 3                    | pig         | pɪg               |          | p       |        | g     | 32                                 | thumb       | θʌm               |          | θ       |        | m     |
| 4                    | cup         | kʌp               |          | k       |        | p     | 33                                 | elephant    | ɛləfənt           |          |         | ɪ f    | nt    |
| 5                    | boy         | bɔɪ               |          | b       |        |       | 34                                 | vacuum      | vækjʊm            |          | v       | k j    | m     |
| 6                    | apple       | æpəl              |          |         | p      | l     | 35                                 | shovel      | ʃʌvəl             |          | ʃ       | v      | l     |
| 7                    | go          | go                |          | g       |        |       | 36                                 | teacher     | tɪtʃə             |          | t       | tʃ     | ə     |
| 8                    | duck        | dʌk               |          | d       |        | k     | 37                                 | zebra       | zɪbrə             |          | z       | br     |       |
| 9                    | quack       | kwæk              |          | kw      |        | k     | 38                                 | giraffe     | dʒərəf            |          | dʒ      | r      | f     |
| 10                   | table       | təbəl             |          | t       | b      | l     | 39                                 | vegetable   | vɛdʒtəbəl         |          | v       | dʒ t b | l     |
| 11                   | monkey      | mʌŋki             |          | m       | ŋ k    |       | 40                                 | brushing    | brʌʃɪŋ            |          | br      | ʃ      | ŋ     |
| 12                   | hammer      | hæmə              |          | h       | m      | ə     | 41                                 | blue        | blu               |          | bl      |        |       |
| 13                   | fish        | fɪʃ               |          | f       |        | ʃ     | 42                                 | yellow      | jələ              |          | j       | l      |       |
| 14                   | watch       | wɒtʃ              |          | w       |        | tʃ    | 43                                 | brother     | brʌðə             |          | br      | ð      | ə     |
| 15                   | spider      | spɑɪdər           |          | sp      | d      | ər    | 44                                 | frog        | frog              |          | fr      |        | g     |
| 16                   | web         | wɛb               |          | w       |        | b     | 45                                 | green       | grɪn              |          | gr      |        | n     |
| 17                   | drum        | drʌm              |          | dr      |        | m     | 46                                 | that        | ðæt               | (i)      | ð       |        | t     |
| 18                   | plate       | plet              |          | pl      |        | t     | 47                                 | leaf        | lif               |          | l       |        | f     |
| 19                   | knife       | naɪf              |          | n       |        | f     | 48                                 | cookie      | kʊki              |          | k       | k      |       |
| 20                   | shoe        | ʃu                |          | ʃ       |        |       | 49                                 | cheese      | tʃiːz             |          | tʃ      |        | z     |
| 21                   | slide       | slaɪd             |          | sl      |        | d     | 50                                 | pajamas     | pədʒəməz          |          | p       | dʒ m   | z     |
| 22                   | swing       | swɪŋ              |          | sw      |        | ŋ     | 51                                 | teeth       | tiθ               |          | t       |        | θ     |
| 23                   | guitar      | ɡetər             |          | g       | t      | r     | 52                                 | princess    | prɪnsɪs           |          | pr      | n s    | s     |
| 24                   | lion        | laɪən             |          | l       |        | n     | 53                                 | crown       | kraʊn             |          | kr      |        | n     |
| 25                   | chair       | tʃɛr              |          | tʃ      |        | r     | 54                                 | truck       | trʌk              |          | tr      |        | k     |
| 26                   | soap        | sop               |          | s       |        | p     | 55                                 | red         | rɛd               |          | r       |        | d     |
| 27                   | glasses     | glæsɪz            |          | gl      | s      | z     | 56                                 | juice       | dʒʊs              |          | dʒ      |        | s     |
| 28                   | tiger       | tɑɪgər            |          | t       | g      | ər    | 57                                 | zoo         | zu                |          | z       |        |       |
| 29                   | puzzle      | pʌzəl             |          | p       | z      | l     | 58                                 | star        | stɑr              |          | st      |        | r     |
| Items 1-29 Subtotals |             |                   |          | 0       | 0      | 0     | 59                                 | five        | faɪv              |          | f       |        | v     |
|                      |             |                   |          |         |        |       | 60                                 | seven       | sɛvən             |          | s       | v      | n     |
|                      |             |                   |          |         |        |       | Items 30-60 Subtotals              |             |                   |          | 0       | 0      | 0     |
|                      |             |                   |          |         |        |       | Transfer Items 1-29 Subtotals here |             |                   |          | 0       | 0      | 0     |
|                      |             |                   |          |         |        |       | Total Raw Score                    |             |                   |          | 0       |        |       |

No vowel errors

Note: Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.

Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 0          |
| (e) Total consonants correct (c) – (d)            | 141        |
| (f) PCC: (e) ÷ (c) x 100                          | 100        |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 0         |
| (e) Total vowels correct (c) – (d)            | 88        |
| (f) PVC: (e) ÷ (c) x 100                      | 100       |

# Speaker with DS 16

PARTICIPANT ID: DS16

## Sounds-in-Words (Ages 2:0-21:11)

| Item                               | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|------------------------------------|-------------|-------------------|----------|---------|--------|-------|
| 1                                  | house       | haus              |          | h       |        | s     |
| 2                                  | door        | dɔr               |          | d       |        | r     |
| 3                                  | pig         | pɪg               |          | p       |        | g     |
| 4                                  | cup         | kʌp               |          | k       |        | p     |
| 5                                  | boy         | bɔɪ               |          | b       |        |       |
| 6                                  | apple       | æpəl              |          |         | p      | l     |
| 7                                  | go          | go                |          | g       |        |       |
| 8                                  | duck        | dʌk               |          | d       |        | k     |
| 9                                  | quack       | kwæk              |          | kw      |        | k     |
| 10                                 | table       | tebəl             |          | t       | b      | l     |
| 11                                 | monkey      | mʌŋki             |          | m       | ŋ k    |       |
| 12                                 | hammer      | hæmə              |          | h       | m      | ə     |
| 13                                 | fish        | fɪʃ               |          | f       |        | ʃ     |
| 14                                 | watch       | wɒtʃ              |          | w       |        | tʃ    |
| 15                                 | spider      | spɑɪdər           |          | sp      | d      | ər    |
| 16                                 | web         | wɛb               |          | w       |        | b     |
| 17                                 | drum        | dram              |          | dr      |        | m     |
| 18                                 | plate       | plet              |          | pl      |        | t     |
| 19                                 | knife       | naɪf              |          | n       |        | f     |
| 20                                 | shoe        | ʃu                |          | ʃ       |        |       |
| 21                                 | slide       | slaɪd             |          | sl      |        | d     |
| 22                                 | swing       | swɪŋ              |          | sw      |        | ŋ     |
| 23                                 | guitar      | ɡetər             |          | ɡ       | t      | ər    |
| 24                                 | lion        | laɪən             |          | l       |        | n     |
| 25                                 | chair       | tʃer              |          | tʃ      |        | r     |
| 26                                 | soap        | sop               |          | s       |        | p     |
| 27                                 | glasses     | ɡlæsɪz            |          | ɡl      | s      | z     |
| 28                                 | tiger       | taɪɡər            |          | t       | ɡ      | ər    |
| 29                                 | puzzle      | pʌzəl             |          | p       | z      | l     |
| Items 1-29 Subtotals               |             |                   |          | 1       | 0      | 2     |
| 30                                 | finger      | fɪŋɡər            |          | f       | ŋ ɡ    | ər    |
| 31                                 | ring        | rɪŋ               |          | r       |        | ŋ     |
| 32                                 | thumb       | θʌm               |          | θ       |        | m     |
| 33                                 | elephant    | ɛləfənt           |          |         | l f    | nt    |
| 34                                 | vacuum      | vækjʊm            | (1)      | v       | k j    | m     |
| 35                                 | shovel      | ʃʌvəl             |          | ʃ       | v      | l     |
| 36                                 | teacher     | ti:tʃər           |          | t       | tʃ     | ər    |
| 37                                 | zebra       | zɪbrə             |          | z       | br     |       |
| 38                                 | giraffe     | dʒərəf            |          | dʒ      | r      | f     |
| 39                                 | vegetable   | vɛdʒəbəl          |          | v       | dʒ b   | l     |
| 40                                 | brushing    | brʌʃɪŋ            |          | br      | ʃ      | ɪŋ    |
| 41                                 | blue        | blu               |          | bl      |        |       |
| 42                                 | yellow      | jəlɔ              |          | j       | l      |       |
| 43                                 | brother     | brʌðər            |          | br      | ð      | ər    |
| 44                                 | frog        | frog              |          | fr      |        | ɡ     |
| 45                                 | green       | ɡrɪn              |          | ɡr      |        | n     |
| 46                                 | that        | ðæt               |          | ð       |        | t     |
| 47                                 | leaf        | li:f              |          | l       |        | f     |
| 48                                 | cookie      | kʊki              |          | k       | k      |       |
| 49                                 | cheese      | tʃi:z             |          | tʃ      |        | z     |
| 50                                 | pajamas     | peɪdʒəmeɪz        |          | p       | dʒ m   | z     |
| 51                                 | teeth       | ti:θ              |          | t       |        | θ     |
| 52                                 | princess    | prɪnsɪs           |          | pr      | n s    | s     |
| 53                                 | crown       | kraʊn             |          | kr      |        | n     |
| 54                                 | truck       | trʌk              |          | tr      |        | k     |
| 55                                 | red         | red               |          | r       |        | d     |
| 56                                 | juice       | dʒʊs              |          | dʒ      |        | s     |
| 57                                 | zoo         | zu                |          | z       |        |       |
| 58                                 | star        | stɑr              |          | st      |        | r     |
| 59                                 | five        | faɪv              |          | f       |        | v     |
| 60                                 | seven       | sevn              |          | s       | v      | n     |
| Items 30-60 Subtotals              |             |                   |          | 3       | 2      | 0     |
| Transfer Items 1-29 Subtotals here |             |                   |          | 1       | 0      | 2     |
| Total Raw Score                    |             |                   |          | 8       |        |       |

No vowel errors

Note: Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.

Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 8          |
| (e) Total consonants correct (c) – (d)            | 133        |
| (f) PCC: (e) ÷ (c) x 100                          | 94         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 0         |
| (e) Total vowels correct (c) – (d)            | 88        |
| (f) PVC: (e) ÷ (c) x 100                      | 100       |



# Speaker with DS 17

PARTICIPANT ID: DSA

## Sounds-in-Words (Ages 2:0-21:11)

| Item                 | Target Word | IPA Transcription | Response | Initial | Medial | Final | Item | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|----------------------|-------------|-------------------|----------|---------|--------|-------|------|-------------|-------------------|----------|---------|--------|-------|
| 1                    | house       | haus              |          | h       |        | s     | 30   | finger      | fɪŋgə             |          | f       | ŋ g    | ə     |
| 2                    | door        | dɔr               |          | d       |        | r     | 31   | ring        | rɪŋ               |          | r       |        | ŋ     |
| 3                    | pig         | pɪg               |          | p       |        | g     | 32   | thumb       | θʌm               |          | θ       |        | m     |
| 4                    | cup         | kʌp               |          | k       |        | p     | 33   | elephant    | ɛləfənt           |          |         | l f    | nt    |
| 5                    | boy         | bɔɪ               |          | b       |        |       | 34   | vacuum      | vækjuːm           |          | v       | k j    | m     |
| 6                    | apple       | æpəl              |          |         | p      | l     | 35   | shovel      | ʃʌvəl             |          | ʃ       | v      | l     |
| 7                    | go          | go                |          | g       |        |       | 36   | teacher     | tɪtʃə             |          | t       | tʃ     | ə     |
| 8                    | duck        | dʌk               |          | d       |        | k     | 37   | zebra       | zɪbrə             |          | z       | br     |       |
| 9                    | quack       | kwæk              |          | kw      |        | k     | 38   | giraffe     | dʒərəf            |          | dʒ      | r      | f     |
| 10                   | table       | tebəl             |          | t       | b      | l     | 39   | vegetable   | vɛdʒtəbəl         |          | v       | dʒ t b | l     |
| 11                   | monkey      | mʌŋki             |          | m       | ŋ k    |       | 40   | brushing    | brʌʃɪŋ            |          | br      | ʃ      | ŋ     |
| 12                   | hammer      | hæmə              |          | h       | m      | ə     | 41   | blue        | blu               |          | bl      |        |       |
| 13                   | fish        | fɪʃ               |          | f       |        | ʃ     | 42   | yellow      | ˈjɛlo             |          |         | l      |       |
| 14                   | watch       | wɒtʃ              |          | w       |        | tʃ    | 43   | brother     | brʌðə             |          | br      | ð      | ə     |
| 15                   | spider      | spɑɪdə            |          | sp      | d      | ə     | 44   | frog        | frog              |          | fr      |        | g     |
| 16                   | web         | wɛb               |          | w       |        | b     | 45   | green       | grɪn              |          | gr      |        | n     |
| 17                   | drum        | drʌm              |          | dr      |        | m     | 46   | that        | ðæt               |          | ð       |        | t     |
| 18                   | plate       | plet              |          | pl      |        | t     | 47   | leaf        | li:f              |          | l       |        | f     |
| 19                   | knife       | nɑɪf              |          | n       |        | f     | 48   | cookie      | kʊki              |          | k       | k      |       |
| 20                   | shoe        | ʃu                |          | ʃ       |        |       | 49   | cheese      | tʃi:z             |          | tʃ      |        | z     |
| 21                   | slide       | slɑɪd             |          | sl      |        | d     | 50   | pajamas     | pəˈdʒəməz         |          | p       | dʒ m   | z     |
| 22                   | swing       | swɪŋ              |          | sw      |        | ŋ     | 51   | teeth       | ti:θ              |          | t       |        | θ     |
| 23                   | guitar      | ɡetər             |          | g       | t      | r     | 52   | princess    | prɪnsɪs           |          | pr      | n s    | s     |
| 24                   | lion        | laɪən             |          | l       |        | n     | 53   | crown       | kraʊn             |          | kr      |        | n     |
| 25                   | chair       | tʃɛr              |          | tʃ      |        | r     | 54   | truck       | trʌk              |          | tr      |        | k     |
| 26                   | soap        | sop               |          | s       |        | p     | 55   | red         | rɛd               |          | r       |        | d     |
| 27                   | glasses     | glæsɪz            |          | gl      | s      | z     | 56   | juice       | dʒʊs              |          | dʒ      |        | s     |
| 28                   | tiger       | tɑɪgə             |          | t       | g      | ə     | 57   | zoo         | zu                |          | st      |        | r     |
| 29                   | puzzle      | pʌzəl             |          | p       | z      | l     | 58   | star        | stɑr              |          | f       |        | v     |
| Items 1-29 Subtotals |             |                   |          | 0       | 0      | 0     | 59   | five        | fɑɪv              |          | s       | v      | n     |
|                      |             |                   |          |         |        |       | 60   | seven       | sevn              |          |         |        |       |

No vowel errors

|                                    |   |   |   |
|------------------------------------|---|---|---|
| Items 30-60 Subtotals              | 2 | 0 | 0 |
| Transfer Items 1-29 Subtotals here | 0 | 0 | 0 |
| Total Raw Score                    | 2 |   |   |

Note: Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.

Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 2          |
| (e) Total consonants correct (c) – (d)            | 139        |
| (f) PCC: (e) ÷ (c) x 100                          | 99         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 0         |
| (e) Total vowels correct (c) – (d)            | 88        |
| (f) PVC: (e) ÷ (c) x 100                      | 100       |

# Speaker with DS 18

PARTICIPANT ID: DS18

## Sounds-in-Words (Ages 2:0-21:11)

| Item                               | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|------------------------------------|-------------|-------------------|----------|---------|--------|-------|
| 1                                  | house       | haus              |          | h       |        | s     |
| 2                                  | door        | dɔr               |          | d       |        | r     |
| 3                                  | pig         | pɪg               |          | p       |        | g     |
| 4                                  | cup         | kʌp               |          | k       |        | p     |
| 5                                  | boy         | bɔɪ               |          | b       |        |       |
| 6                                  | apple       | æpəl              |          |         | p      | l     |
| 7                                  | go          | go                |          | g       |        |       |
| 8                                  | duck        | dʌk               |          | d       |        | k     |
| 9                                  | quack       | kwæk              |          | kw      |        | k     |
| 10                                 | table       | tebəl             |          | t       | b      | l     |
| 11                                 | monkey      | mʌŋki             |          | m       | ŋ k    |       |
| 12                                 | hammer      | hæmə              |          | h       | m      | ə     |
| 13                                 | fish        | fɪʃ               |          | f       |        | ʃ     |
| 14                                 | watch       | wɒtʃ              |          | w       |        | tʃ    |
| 15                                 | spider      | spaɪdər           |          | sp      | d      | ər    |
| 16                                 | web         | wɛb               |          | w       |        | b     |
| 17                                 | drum        | drʌm              |          | dr      |        | m     |
| 18                                 | plate       | plet              |          | pl      |        | t     |
| 19                                 | knife       | naɪf              |          | n       |        | f     |
| 20                                 | shoe        | ʃu                |          | ʃ       |        |       |
| 21                                 | slide       | slaɪd             |          | sl      |        | d     |
| 22                                 | swing       | swɪŋ              |          | sw      |        | ŋ     |
| 23                                 | guitar      | ɡetər             |          | g       | t      | ər    |
| 24                                 | lion        | laɪən             |          | l       |        | n     |
| 25                                 | chair       | tʃer              |          | tʃ      |        | r     |
| 26                                 | soap        | sop               |          | s       |        | p     |
| 27                                 | glasses     | ɡlæsɪz            |          | ɡl      | s      | z     |
| 28                                 | tiger       | taɪɡər            |          | t       | ɡ      | ər    |
| 29                                 | puzzle      | pʌzəl (i)         |          | p       | z      | l     |
| Items 1-29 Subtotals               |             |                   |          | 0       | 0      | 0     |
| No vowel errors                    |             |                   |          |         |        |       |
| Items 30-60 Subtotals              |             |                   |          | 1       | 0      | 0     |
| Transfer Items 1-29 Subtotals here |             |                   |          | 0       | 0      | 0     |
| Total Raw Score                    |             |                   |          | 1       |        |       |

Note: Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.



Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 1          |
| (e) Total consonants correct (c) – (d)            | 140        |
| (f) PCC: (e) ÷ (c) x 100                          | 99         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 0         |
| (e) Total vowels correct (c) – (d)            | 88        |
| (f) PVC: (e) ÷ (c) x 100                      | 100       |

# Speaker with DS 19

PARTICIPANT ID: DS19

## Sounds-in-Words (Ages 2:0-21:11)

| Item                               | Target Word | IPA Transcription         | Response     | Initial       | Medial        | Final        |
|------------------------------------|-------------|---------------------------|--------------|---------------|---------------|--------------|
| 1                                  | house       | haus                      |              | h             |               | s            |
| 2                                  | door        | <del>door</del>           | <del>g</del> | <del>g</del>  |               | r            |
| 3                                  | pig         | pɪg                       |              | p             |               | g            |
| 4                                  | cup         | <del>kʌp</del>            | <del>g</del> | <del>g</del>  |               | p            |
| 5                                  | boy         | bɔɪ                       |              | b             |               |              |
| 6                                  | apple       | æpəl                      |              |               | p             | l            |
| 7                                  | go          | go                        |              | g             |               |              |
| 8                                  | duck        | dʌk                       |              | d             |               | k            |
| 9                                  | quack       | kwæk                      |              | kw            |               | k            |
| 10                                 | table       | tebəl                     |              | t             | b             | l            |
| 11                                 | monkey      | mʌŋki                     |              | m             | ŋ k           |              |
| 12                                 | hammer      | hæmə                      |              | h             | m             | ə            |
| 13                                 | fish        | fɪʃ                       |              | f             |               | ʃ            |
| 14                                 | watch       | wɒtʃ                      |              | w             |               | tʃ           |
| 15                                 | spider      | <del>spaidə</del>         | <del>b</del> | <del>sp</del> | d             | ə            |
| 16                                 | web         | wɛb                       |              | w             |               | b            |
| 17                                 | drum        | drʌm                      |              | dr            |               | m            |
| 18                                 | plate       | plet                      |              | pl            |               | t            |
| 19                                 | knife       | <del>naɪf</del> <i>ao</i> |              | n             |               | f            |
| 20                                 | shoe        | ʃu                        |              | ʃ             |               |              |
| 21                                 | slide       | slaɪd                     |              | sl            |               | d            |
| 22                                 | swing       | swɪŋ                      |              | sw            |               | ŋ            |
| 23                                 | guitar      | <del>gɪtər</del>          | <del>k</del> | <del>g</del>  | t             | r            |
| 24                                 | lion        | laɪən                     |              | l             |               | n            |
| 25                                 | chair       | tʃɛər                     |              | tʃ            |               | r            |
| 26                                 | soap        | sɒp                       |              | s             |               | p            |
| 27                                 | glasses     | glæsɪz                    |              | gl            | ɪz            |              |
| 28                                 | tiger       | taɪgər                    |              | t             | g             | ər           |
| 29                                 | puzzle      | pʌzəl                     |              | p             | z             | l            |
| Items 1-29 Subtotals               |             |                           |              | 4             | 1             | 0            |
| 30                                 | finger      | fɪŋgər                    |              | f             | ŋ g           | ər           |
| 31                                 | ring        | <del>rɪŋ</del>            |              | r             |               | <del>ŋ</del> |
| 32                                 | thumb       | θʌm                       |              | θ             |               | m            |
| 33                                 | elephant    | ɛləfənt                   |              |               | l f           | nt           |
| 34                                 | vacuum      | vækjuəm (i)               |              | v             | k             | m            |
| 35                                 | shovel      | ʃʌvəl                     |              | ʃ             | v             | l            |
| 36                                 | teacher     | <del>tɪtʃər</del>         | <del>s</del> | t             | <del>tʃ</del> | ər           |
| 37                                 | zebra       | zɪbrə                     |              | z             | br            |              |
| 38                                 | giraffe     | dʒərəf                    |              | dʒ            | r             | f            |
| 39                                 | vegetable   | <del>vɛdʒəbəl</del>       | <del>b</del> | v             | dʒ b          | l            |
| 40                                 | brushing    | <del>brʌʃɪŋ</del>         | <del>b</del> | <del>br</del> | ʃ             | ɪŋ           |
| 41                                 | blue        | blu                       |              | bl            |               |              |
| 42                                 | yellow      | jɛlo                      |              | j             | l             |              |
| 43                                 | brother     | brʌðər                    |              | br            | ð             | ər           |
| 44                                 | frog        | frog                      |              | fr            |               | g            |
| 45                                 | green       | grɪn                      |              | gr            |               | n            |
| 46                                 | that        | ðæt                       |              | ð             |               | t            |
| 47                                 | leaf        | li:f                      |              | l             |               | f            |
| 48                                 | cookie      | kʊki                      |              | k             | k             |              |
| 49                                 | cheese      | tʃi:z                     |              | tʃ            |               | z            |
| 50                                 | pajamas     | pədʒəməz                  |              | p             | dʒ m          | z            |
| 51                                 | teeth       | ti:θ                      |              | t             |               | θ            |
| 52                                 | princess    | prɪnsɪs                   |              | pr            | n s           | s            |
| 53                                 | crown       | kraʊn                     |              | kr            |               | n            |
| 54                                 | truck       | trʌk                      |              | tr            |               | k            |
| 55                                 | red         | rɛd                       |              | r             |               | d            |
| 56                                 | juice       | dʒʊs                      |              | dʒ            |               | s            |
| 57                                 | zoo         | <del>zu</del>             | <del>s</del> | <del>z</del>  |               |              |
| 58                                 | star        | <del>stər</del>           | <del>s</del> | <del>st</del> |               | r            |
| 59                                 | five        | faɪv                      |              | f             |               | v            |
| 60                                 | seven       | sevn                      |              | s             | v             | n            |
| Items 30-60 Subtotals              |             |                           |              | 3             | 3             | 1            |
| Transfer Items 1-29 Subtotals here |             |                           |              | 4             | 1             | 0            |
| Total Raw Score                    |             |                           |              | 12            |               |              |

1 vowel error

Note: Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.

Percent Consonants Correct

|                                                    |            |
|----------------------------------------------------|------------|
| (a) Total number of target consonants              | <b>141</b> |
| (b) Number of consonants not elicited              | 0          |
| (c) Total number of consonants elicited (a) -- (b) | 141        |
| (d) Total number of consonants in error            | 12         |
| (e) Total consonants correct (c) – (d)             | 129        |
| (f) PCC: (e) ÷ (c) x 100                           | 91         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 1         |
| (e) Total vowels correct (c) – (d)            | 87        |
| (f) PVC: (e) ÷ (c) x 100                      | 99        |

# Speaker with DS 20

PARTICIPANT ID: DS20

## Sounds-in-Words (Ages 2:0-21:11)

| Item                               | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|------------------------------------|-------------|-------------------|----------|---------|--------|-------|
| 1                                  | house       | haʊs              |          | h       |        | 15    |
| 2                                  | door        | dɔː               |          | d       |        | r     |
| 3                                  | pig         | pɪg               |          | p       |        | g     |
| 4                                  | cup         | kʌp               |          | k       |        | p     |
| 5                                  | boy         | bɔɪ               |          | b       |        |       |
| 6                                  | apple       | æpəl              |          |         | p      | l     |
| 7                                  | go          | go                |          | g       |        |       |
| 8                                  | duck        | dʌk               |          | d       |        | k     |
| 9                                  | quack       | kwæk              |          | kw      |        | k     |
| 10                                 | table       | tebəl             |          | t       | b      | l     |
| 11                                 | monkey      | mʌŋki             |          | m       | ŋ k    |       |
| 12                                 | hammer      | hæmə              |          | h       | m      | ə     |
| 13                                 | fish        | fɪʃ               |          | f       |        | 15    |
| 14                                 | watch       | wɒtʃ              |          | w       |        | 15    |
| 15                                 | spider      | spaɪdə            |          | sp      | d      | ə     |
| 16                                 | web         | wɛb               |          | w       |        | b     |
| 17                                 | drum        | drʌm              |          | dr      |        | m     |
| 18                                 | plate       | plet              |          | pl      |        | t     |
| 19                                 | knife       | naɪf              |          | n       |        | f     |
| 20                                 | shoe        | ʃuː               |          | 15      |        |       |
| 21                                 | slide       | slaɪd             |          | sl      |        | d     |
| 22                                 | swing       | swɪŋ              |          | sw      |        | ŋ     |
| 23                                 | guitar      | ɡeɪtər            |          | g       | t      | r     |
| 24                                 | lion        | laɪən             |          | l       |        | n     |
| 25                                 | chair       | tʃeə              |          | 15      |        | r     |
| 26                                 | soap        | sop               |          | s       |        | p     |
| 27                                 | glasses     | ɡlæsɪz            |          | gl      | s      | z     |
| 28                                 | tiger       | taɪgər            |          | t       | g      | ər    |
| 29                                 | puzzle      | pʌzəl             |          | p       | z      | l     |
| Items 1-29 Subtotals               |             |                   |          | 2       | 0      | 3     |
| Items 30-60 Subtotals              |             |                   |          | 0       | 1      | 0     |
| Transfer Items 1-29 Subtotals here |             |                   |          | 2       | 0      | 3     |
| Total Raw Score                    |             |                   |          | 6       |        |       |

No vowel errors

Note: Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.

Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 6          |
| (e) Total consonants correct (c) – (d)            | 135        |
| (f) PCC: (e) ÷ (c) x 100                          | 96         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 0         |
| (e) Total vowels correct (c) – (d)            | 88        |
| (f) PVC: (e) ÷ (c) x 100                      | 100       |



# Speaker with DS 21

PARTICIPANT ID: DS21

## Sounds-in-Words (Ages 2;0-21;11)

| Item | Target Word | IPA Transcription | Response      | Initial | Medial | Final |
|------|-------------|-------------------|---------------|---------|--------|-------|
| 1    | house       | haus              |               | h       |        | s     |
| 2    | door        | dɔr               |               | d       |        | r     |
| 3    | pig         | pɪg               |               | p       |        | g     |
| 4    | cup         | kʌp               |               | k       |        | p     |
| 5    | boy         | bɔɪ               |               | b       |        |       |
| 6    | apple       | æpəl              |               |         | p      | l     |
| 7    | go          | go                |               | g       |        |       |
| 8    | duck        | dʌk               |               | d       |        | k     |
| 9    | quack       | <del>kwæk</del>   | <del>kw</del> |         |        | k     |
| 10   | table       | tebəl             | t             |         | b      | l     |
| 11   | monkey      | mʌŋki             | m             |         | ŋ k    |       |
| 12   | hammer      | hæmə              | h             |         | m      | ə     |
| 13   | fish        | fɪʃ               | f             |         |        | ʃ     |
| 14   | watch       | wɒtʃ              | w             |         |        | ʃ     |
| 15   | spider      | spɪdər            | sp            |         | d      | ər    |
| 16   | web         | wɛb               | w             |         |        | b     |
| 17   | drum        | drʌm              | dr            |         |        | m     |
| 18   | plate       | plet              | pl            |         |        | t     |
| 19   | knife       | nʌf               | n             |         |        | f     |
| 20   | shoe        | ʃu                | ʃ             |         |        |       |
| 21   | slide       | slʌɪd             | sl            |         |        | d     |
| 22   | swing       | <del>swɪŋ</del>   | <del>sw</del> |         |        | ŋ     |
| 23   | guitar      | gɪtər             | g             |         | t      | ər    |
| 24   | lion        | laɪən             | l             |         |        | n     |
| 25   | chair       | <del>tʃer</del>   | <del>tʃ</del> |         |        | r     |
| 26   | soap        | sɒp               | s             |         |        | p     |
| 27   | glasses     | glæsɪz            | gl            |         | s      | z     |
| 28   | tiger       | tʌɪgər            | t             |         | g      | ər    |
| 29   | puzzle      | pʌzəl             | p             |         | z      | l     |

Items 1-29 Subtotals

3 0 1

No vowel errors

| Item | Target Word | IPA Transcription | Response        | Initial | Medial | Final |
|------|-------------|-------------------|-----------------|---------|--------|-------|
| 30   | finger      | fɪŋgər            |                 | f       | ŋ g    | ər    |
| 31   | ring        | rɪŋ               |                 | r       |        | ŋ     |
| 32   | thumb       | θʌm               |                 | θ       |        | m     |
| 33   | elephant    | ələfənt           |                 |         | l f    | nt    |
| 34   | vacuum      | vækjʊm            |                 | v       | k j    | m     |
| 35   | shovel      | ʃʌvəl             | ʃ               |         |        | l     |
| 36   | teacher     | <del>tɪtʃər</del> | <del>tɪtʃ</del> |         |        | ər    |
| 37   | zebra       | zɪbrə             | z               |         | br     |       |
| 38   | giraffe     | dʒərəf            | dʒ              |         | r      | f     |
| 39   | vegetable   | vɛdʒəbəl          | v               |         | dʒ b   | l     |
| 40   | brushing    | brʌʃɪŋ            | br              |         |        | ɪŋ    |
| 41   | blue        | blu               | bl              |         |        |       |
| 42   | yellow      | <del>jelo</del>   | <del>j</del>    |         |        | l     |
| 43   | brother     | brʌðər (i)        | br              |         | ð      | ər    |
| 44   | frog        | fɹɒg              | fr              |         |        | g     |
| 45   | green       | grɪn              | gr              |         |        | n     |
| 46   | that        | ðæt (i)           | ð               |         |        | t     |
| 47   | leaf        | li:f              | l               |         |        | f     |
| 48   | cookie      | kʊki              | k               |         | k      |       |
| 49   | cheese      | tʃi:z             | tʃ              |         |        | z     |
| 50   | pajamas     | pəˈdʒæməz         | p               |         | dʒ m   | z     |
| 51   | teeth       | ti:θ              | t               |         |        | θ     |
| 52   | princess    | prɪnsɪs           | pr              |         | n s    | s     |
| 53   | crown       | kraʊn             | kr              |         |        | n     |
| 54   | truck       | trʌk              | tr              |         |        | k     |
| 55   | red         | rɛd               | r               |         |        | d     |
| 56   | juice       | dʒʊs              | dʒ              |         |        | s     |
| 57   | zoo         | zu                | z               |         |        |       |
| 58   | star        | stɑr              | st              |         |        | r     |
| 59   | five        | faɪv              | f               |         |        | v     |
| 60   | seven       | sɛvən             | s               |         | v      | n     |

Items 30-60 Subtotals

2 4 0

Transfer Items 1-29 Subtotals here

3 0 1

Total Raw Score

10

Note. Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.

Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 10         |
| (e) Total consonants correct (c) – (d)            | 131        |
| (f) PCC: (e) ÷ (c) x 100                          | 93         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 0         |
| (e) Total vowels correct (c) – (d)            | 88        |
| (f) PVC: (e) ÷ (c) x 100                      | 100       |

# Speaker with DS 22

PARTICIPANT ID: DS22

## Sounds-in-Words (Ages 2:0-21:11)

| Item                 | Target Word | IPA Transcription | Response | Initial | Medial | Final | Item | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|----------------------|-------------|-------------------|----------|---------|--------|-------|------|-------------|-------------------|----------|---------|--------|-------|
| 1                    | house       | haus              |          | h       |        | s     | 30   | finger      | fɪŋgə             |          | f       | ŋ g    | ə     |
| 2                    | door        | dɔr               |          | d       |        | r     | 31   | ring        | rɪŋ               |          | r       |        | ŋ     |
| 3                    | pig         | pɪg               |          | p       |        | g     | 32   | thumb       | θʌm               |          | θ       |        | m     |
| 4                    | cup         | kʌp               |          | k       |        | p     | 33   | elephant    | ɛləfənt           |          |         | l f    | nt    |
| 5                    | boy         | bɔɪ               |          | b       |        |       | 34   | vacuum      | vækjuəm           | (i)      | v       | k      | m     |
| 6                    | apple       | æpəl              |          |         | p      | l     | 35   | shovel      | ʃʌvəl             |          | ʃ       | v      | l     |
| 7                    | go          | go                |          | g       |        |       | 36   | teacher     | tɪtʃə             |          | t       | tʃ     | ə     |
| 8                    | duck        | dʌk               |          | d       |        | k     | 37   | zebra       | zɪbrə             |          | z       | br     |       |
| 9                    | quack       | kwæk              |          | kw      |        | k     | 38   | giraffe     | dʒərəf            |          | dʒ      | r      | f     |
| 10                   | table       | tebəl             |          | t       | b      | l     | 39   | vegetable   | vɛdʒtəbəl         |          | v       | dʒ t b | l     |
| 11                   | monkey      | mʌŋki             |          | m       | ŋ k    |       | 40   | brushing    | brʌʃɪŋ            |          | br      | ʃ      | ŋ     |
| 12                   | hammer      | hæmə              |          | h       | m      | ə     | 41   | blue        | blu               |          | bl      |        |       |
| 13                   | fish        | fɪʃ               |          | f       |        | ʃ     | 42   | yellow      | jelo              |          |         | l      |       |
| 14                   | watch       | wɒtʃ              |          | w       |        | tʃ    | 43   | brother     | brʌðə             |          | br      | ð      | ə     |
| 15                   | spider      | spɑɪdə            |          | sp      | d      | ə     | 44   | frog        | fɹɒg              |          | fr      |        | g     |
| 16                   | web         | wɛb               |          | w       |        | b     | 45   | green       | grɪn              |          | gr      |        | n     |
| 17                   | drum        | drʌm              |          | dr      |        | m     | 46   | that        | ðæt               |          | ð       |        | t     |
| 18                   | plate       | plet              |          | pl      |        | t     | 47   | leaf        | lif               |          | l       |        | f     |
| 19                   | knife       | naɪf              |          | n       |        | f     | 48   | cookie      | kʊki              |          | k       | k      |       |
| 20                   | shoe        | ʃu                |          | ʃ       |        |       | 49   | cheese      | tʃiːz             |          | tʃ      |        | z     |
| 21                   | slide       | slaɪd             |          | sl      |        | d     | 50   | pajamas     | pədʒəmeɪz         |          | p       | dʒ m   | z     |
| 22                   | swing       | swɪŋ              |          | sw      |        | ŋ     | 51   | teeth       | tiθ               |          | t       |        | θ     |
| 23                   | guitar      | gɪtər             |          | g       | t      | r     | 52   | princess    | prɪnsɪs           |          | pr      | n s    | s     |
| 24                   | lion        | laɪən             |          | l       |        | n     | 53   | crown       | kraʊn             |          | kr      |        | n     |
| 25                   | chair       | tʃɛr              |          | tʃ      |        | r     | 54   | truck       | trʌk              |          | tr      |        | k     |
| 26                   | soap        | sop               |          | s       |        | p     | 55   | red         | red               |          | r       |        | d     |
| 27                   | glasses     | glæsɪz            |          | gl      | s      | z     | 56   | juice       | dʒʊs              |          | dʒ      |        | s     |
| 28                   | tiger       | taɪgə             |          | t       | g      | ə     | 57   | zoo         | zu                |          | z       |        |       |
| 29                   | puzzle      | pʌzəl             |          | p       | z      | l     | 58   | star        | stɑr              |          | st      |        | r     |
| Items 1-29 Subtotals |             |                   |          | 0       | 0      | 0     | 59   | five        | fɑɪv              |          | f       |        | v     |
|                      |             |                   |          |         |        |       | 60   | seven       | sɛvən             |          | s       | v      | n     |

No vowel errors

Items 30-60 Subtotals

Transfer Items 1-29 Subtotals here

Total Raw Score

|   |   |   |
|---|---|---|
| 1 | 1 | 0 |
| 0 | 0 | 0 |
| 2 |   |   |

Note. Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.



Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 2          |
| (e) Total consonants correct (c) – (d)            | 139        |
| (f) PCC: (e) ÷ (c) x 100                          | 99         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 0         |
| (e) Total vowels correct (c) – (d)            | 88        |
| (f) PVC: (e) ÷ (c) x 100                      | 100       |

# Speaker with DS 23

PARTICIPANT ID: DS23

## Sounds-in-Words (Ages 2:0-21:11)

| Item                               | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|------------------------------------|-------------|-------------------|----------|---------|--------|-------|
| 1                                  | house       | haʊs              |          | h       |        | s     |
| 2                                  | door        | dɔːr              |          | d       |        | r     |
| 3                                  | pig         | pɪɡ               |          | p       |        | g     |
| 4                                  | cup         | kʌp               |          | k       |        | p     |
| 5                                  | boy         | bɔɪ               |          | b       |        |       |
| 6                                  | apple       | æpəl              |          |         | p      | l     |
| 7                                  | go          | ɡo                |          | g       |        |       |
| 8                                  | duck        | dʌk               |          | d       |        | k     |
| 9                                  | quack       | kwæk              |          | k       |        | k     |
| 10                                 | table       | tebəl             |          | t       | b      | l     |
| 11                                 | monkey      | mʌŋki             |          | m       | ŋ k    |       |
| 12                                 | hammer      | hæmə              |          | h       | m      | ə     |
| 13                                 | fish        | fɪʃ               |          | f       |        | ʃ     |
| 14                                 | watch       | wɒtʃ              |          | w       |        | tʃ    |
| 15                                 | spider      | spaɪdə            |          | sp      | d      | ə     |
| 16                                 | web         | wɛb               |          | w       |        | b     |
| 17                                 | drum        | drʌm              |          | dr      |        | m     |
| 18                                 | plate       | plet              |          | pl      |        | t     |
| 19                                 | knife       | naɪf              |          | n       |        | f     |
| 20                                 | shoe        | ʃu                |          |         |        |       |
| 21                                 | slide       | slaɪd             |          | sl      |        | d     |
| 22                                 | swing       | swɪŋ              |          | sw      |        | ŋ     |
| 23                                 | guitar      | ɡetər             |          | ɡ       | t      | r     |
| 24                                 | lion        | laɪən             |          | l       |        | n     |
| 25                                 | chair       | tʃeər             |          | tʃ      |        | r     |
| 26                                 | soap        | sɒp               |          | s       |        | p     |
| 27                                 | glasses     | ɡlæsɪz            |          | ɡl      | s      | z     |
| 28                                 | tiger       | taɪɡər            |          | t       | ɡ      | ər    |
| 29                                 | puzzle      | pʌzəl             |          | p       | z      | l     |
| Items 1-29 Subtotals               |             |                   |          | 2       | 0      | 1     |
| 30                                 | finger      | fɪŋɡər            |          | f       | ŋ ɡ    | ər    |
| 31                                 | ring        | rɪŋ               |          | r       |        | ŋ     |
| 32                                 | thumb       | θʌm               |          | θ       |        | m     |
| 33                                 | elephant    | ɛləfənt           |          |         | l f    | nt    |
| 34                                 | vacuum      | vækjʊm            | (i)      | v       | k j    | m     |
| 35                                 | shovel      | ʃʌvəl             |          | ʃ       | v      | l     |
| 36                                 | teacher     | ti:tʃər           |          | t       |        | ʃər   |
| 37                                 | zebra       | zɛbrə             |          | z       | br     |       |
| 38                                 | giraffe     | dʒərəʃ            |          | dʒ      | r      | ʃ     |
| 39                                 | vegetable   | vɛdʒtəbəl         |          | v       | dʒ t b | l     |
| 40                                 | brushing    | brʌʃɪŋ            |          | br      | ʃ      | ɪŋ    |
| 41                                 | blue        | blu               |          | bl      |        |       |
| 42                                 | yellow      | jeləʊ             |          | j       | l      |       |
| 43                                 | brother     | brʌðər            |          | br      | ð      | ər    |
| 44                                 | frog        | fɹɒɡ              |          | fr      |        | ɡ     |
| 45                                 | green       | ɡriːn             |          | gr      |        | n     |
| 46                                 | that        | ðæt               |          | ð       |        | t     |
| 47                                 | leaf        | liːf              |          | l       |        | f     |
| 48                                 | cookie      | kʊki              |          | k       | k      |       |
| 49                                 | cheese      | tʃiːz             |          | tʃ      |        | z     |
| 50                                 | pajamas     | pəˈdʒəmeɪz        |          | p       | dʒ m   | z     |
| 51                                 | teeth       | tiːθ              |          | t       |        | θ     |
| 52                                 | princess    | prɪnsɪs           |          | pr      | n s    | s     |
| 53                                 | crown       | kraʊn             |          | kr      |        | n     |
| 54                                 | truck       | trʌk              |          | tr      |        | k     |
| 55                                 | red         | red               |          | r       |        | d     |
| 56                                 | juice       | dʒʊːs             |          | dʒ      |        | s     |
| 57                                 | zoo         | zuː               |          | z       |        |       |
| 58                                 | star        | stɑː              |          | st      |        |       |
| 59                                 | five        | faɪv              |          | f       |        | v     |
| 60                                 | seven       | sevn              |          | s       | v      | n     |
| Items 30-60 Subtotals              |             |                   |          | 3       | 1      | 0     |
| Transfer Items 1-29 Subtotals here |             |                   |          | 2       | 0      | 1     |
| Total Raw Score                    |             |                   |          | 7       |        |       |

No vowel errors

Note. Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.

Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 7          |
| (e) Total consonants correct (c) – (d)            | 134        |
| (f) PCC: (e) ÷ (c) x 100                          | 95         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 0         |
| (e) Total vowels correct (c) – (d)            | 88        |
| (f) PVC: (e) ÷ (c) x 100                      | 100       |

# Speaker with DS 24

PARTICIPANT ID: DS24

## Sounds-in-Words (Ages 2:0-21:11)

| Item                 | Target Word | IPA Transcription | Response | Initial | Medial | Final | Item | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|----------------------|-------------|-------------------|----------|---------|--------|-------|------|-------------|-------------------|----------|---------|--------|-------|
| 1                    | house       | haus              |          | h       |        | s     | 30   | finger      | fɪŋgə             |          | f       | ŋ g    | ə     |
| 2                    | door        | dɔr               |          | d       |        | r     | 31   | ring        | rɪŋ               |          | r       |        | ŋ     |
| 3                    | pig         | pɪg               |          | p       |        | g     | 32   | thumb       | θʌm               |          | θ       |        | m     |
| 4                    | cup         | kʌp               |          | k       |        | p     | 33   | elephant    | ələfənt           |          |         | l f    | nt    |
| 5                    | boy         | bɔɪ               |          | b       |        |       | 34   | vacuum      | vækjʊm (i)        |          | v       | k j    | m     |
| 6                    | apple       | æpəl              |          |         | p      | l     | 35   | shovel      | ʃʌvəl             |          | ʃ       | v      | l     |
| 7                    | go          | go                |          | g       |        |       | 36   | teacher     | tɪtʃə             |          | t       | tʃ     | ə     |
| 8                    | duck        | dʌk               |          | d       |        | k     | 37   | zebra       | zɪbrə             |          | z       | br     |       |
| 9                    | quack       | kwæk              |          | kw      |        | k     | 38   | giraffe     | dʒərəf            |          | dʒ      | r      | f     |
| 10                   | table       | tebəl             |          | t       | b      | l     | 39   | vegetable   | vɛdʒtəbəl         |          | v       | dʒ t b | l     |
| 11                   | monkey      | mʌŋki             |          | m       | ŋ k    |       | 40   | brushing    | brʌʃɪŋ            |          | br      | ʃ      | ŋ     |
| 12                   | hammer      | hæmə              |          | h       | m      | ə     | 41   | blue        | blu               |          | bl      |        |       |
| 13                   | fish        | fɪʃ               |          | f       |        | ʃ     | 42   | yellow      | jɛlo              |          | j       | l      |       |
| 14                   | watch       | wɒtʃ              |          | w       |        | tʃ    | 43   | brother     | brʌðə             |          | br      | ð      | ə     |
| 15                   | spider      | spɑɪdər           |          | sp      | d      | ər    | 44   | frog        | frog              |          | fr      |        | g     |
| 16                   | web         | wɛb               |          | w       |        | b     | 45   | green       | grɪn              |          | gr      |        | n     |
| 17                   | drum        | dɹʌm              |          | dr      |        | m     | 46   | that        | ðæt               |          | ð       |        | t     |
| 18                   | plate       | plet              |          | pl      |        | t     | 47   | leaf        | li:f              |          | l       |        | f     |
| 19                   | knife       | naɪf              |          | n       |        | f     | 48   | cookie      | kʊki              |          | k       | k      |       |
| 20                   | shoe        | ʃu                |          | ʃ       |        |       | 49   | cheese      | tʃi:z             |          | tʃ      |        | z     |
| 21                   | slide       | slaɪd             |          | sl      |        | d     | 50   | pajamas     | pədzəməz (i)      |          | p       | dʒ m   | z     |
| 22                   | swing       | swɪŋ              |          | sw      |        | ŋ     | 51   | teeth       | ti:θ              |          | t       |        | θ     |
| 23                   | guitar      | gɪtər             |          | g       | t      | r     | 52   | princess    | prɪnsɪs           |          | pr      | n s    | s     |
| 24                   | lion        | laɪən             |          | l       |        | n     | 53   | crown       | kraʊn             |          | kr      |        | n     |
| 25                   | chair       | tʃer              |          | tʃ      |        | r     | 54   | truck       | trʌk              |          | tr      |        | k     |
| 26                   | soap        | sop               |          | s       |        | p     | 55   | red         | rɛd               |          | r       |        | d     |
| 27                   | glasses     | glæzɪz            |          | gl      | z      | z     | 56   | juice       | dʒʊs              |          | dʒ      |        | s     |
| 28                   | tiger       | tɑɪgər            |          | t       | g      | ər    | 57   | zoo         | zu                |          | z       |        |       |
| 29                   | puzzle      | pʌzəl             |          | p       | z      | l     | 58   | star        | stɑr              |          | st      |        | r     |
| Items 1-29 Subtotals |             |                   |          | 0       | 1      | 0     | 59   | five        | fɑɪv              |          | f       |        | v     |
|                      |             |                   |          |         |        |       | 60   | seven       | sevn              |          | s       | v      | n     |

No vowel errors

Items 30-60 Subtotals  
Transfer Items 1-29 Subtotals here

Total Raw Score

Note: Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.

Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 1          |
| (e) Total consonants correct (c) – (d)            | 140        |
| (f) PCC: (e) ÷ (c) x 100                          | 99         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 0         |
| (e) Total vowels correct (c) – (d)            | 88        |
| (f) PVC: (e) ÷ (c) x 100                      | 100       |



# Speaker with DS 25

PARTICIPANT ID: DS 25

## Sounds-in-Words (Ages 2:0-21:11)

| Item                 | Target Word | IPA Transcription | Response | Initial | Medial | Final | Item                               | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|----------------------|-------------|-------------------|----------|---------|--------|-------|------------------------------------|-------------|-------------------|----------|---------|--------|-------|
| 1                    | house       | haus              |          | h       |        | s     | 30                                 | finger      | fɪŋgə             |          | f       | ŋ g    | ə     |
| 2                    | door        | dɔr               |          | d       |        | r     | 31                                 | ring        | rɪŋ               |          | r       |        | ŋ     |
| 3                    | pig         | pɪg               |          | p       |        | g     | 32                                 | thumb       | θʌm               |          | θ       |        | m     |
| 4                    | cup         | kʌp               |          | k       |        | p     | 33                                 | elephant    | ələfənt           |          |         | l f    | nt    |
| 5                    | boy         | bɔɪ               |          | b       |        |       | 34                                 | vacuum      | ˈvækjuəm          | ✓ b      | ✓ b     | k j    | m     |
| 6                    | apple       | æpəl              |          |         | p      | l     | 35                                 | shovel      | ʃʌvəl             |          | ʃ       | v      | l     |
| 7                    | go          | go                |          | g       |        |       | 36                                 | teacher     | tɪtʃə             |          | t       | tʃ     | ə     |
| 8                    | duck        | dʌk               | 20       | d       |        | k     | 37                                 | zebra       | zɪbrə             |          | z       | br     |       |
| 9                    | quack       | kwæk              |          | kw      |        | k     | 38                                 | giraffe     | dʒərəf            |          | dʒ      | r      | f     |
| 10                   | table       | tebəl             |          | t       | b      | l     | 39                                 | vegetable   | ˈvedʒəbəl         |          | v       | dʒ b   | l     |
| 11                   | monkey      | mʌŋki             |          | m       | ŋ k    |       | 40                                 | brushing    | brʌʃɪŋ            |          | br      | ʃ      | ŋ     |
| 12                   | hammer      | hæmə              |          | h       | m      | ə     | 41                                 | blue        | blu               |          | bl      |        |       |
| 13                   | fish        | fɪʃ               |          | f       |        | ʃ     | 42                                 | yellow      | jelə              |          | j       | l      |       |
| 14                   | watch       | wɒtʃ              |          | w       |        | tʃ    | 43                                 | brother     | brʌðə             |          | br      | ð      | ə     |
| 15                   | spider      | spaɪdə            |          | sp      | d      | ə     | 44                                 | frog        | frog              |          | fr      |        | g     |
| 16                   | web         | wɛb               |          | w       |        | b     | 45                                 | green       | grɪn              |          | gr      |        | n     |
| 17                   | drum        | dram              |          | dr      |        | m     | 46                                 | that        | ðæt               |          | ð       |        | t     |
| 18                   | plate       | plet              |          | pl      |        | t     | 47                                 | leaf        | lif               |          | l       |        | f     |
| 19                   | knife       | naɪf              |          | n       |        | f     | 48                                 | cookie      | kuki              |          | k       | k      |       |
| 20                   | shoe        | ʃu                |          | ʃ       |        |       | 49                                 | cheese      | tʃiːz             |          | tʃ      |        | z     |
| 21                   | slide       | slaɪd             |          | sl      |        | d     | 50                                 | pajamas     | peɪdʒəmeɪz        |          | p       | dʒ m   | z     |
| 22                   | swing       | swɪŋ              |          | sw      |        | ŋ     | 51                                 | teeth       | tiθ               |          | t       |        | θ     |
| 23                   | guitar      | getər             |          | g       | t      | r     | 52                                 | princess    | prɪnsɪs           |          | pr      | n s    | s     |
| 24                   | lion        | laɪən             |          | l       |        | n     | 53                                 | crown       | kraʊn             |          | kr      |        | n     |
| 25                   | chair       | tʃeər             |          | tʃ      |        | r     | 54                                 | truck       | trʌk              |          | tr      |        | k     |
| 26                   | soap        | sop               |          | s       |        | p     | 55                                 | red         | red               |          | r       |        | d     |
| 27                   | glasses     | glæsɪz            |          | gl      | s      | z     | 56                                 | juice       | dʒus              |          | dʒ      |        | s     |
| 28                   | tiger       | tɪgə              |          | t       | g      | ə     | 57                                 | zoo         | zu                |          | z       |        |       |
| 29                   | puzzle      | pʌzəl             |          | p       | z      | l     | 58                                 | star        | stɑr              |          | st      |        | r     |
| Items 1-29 Subtotals |             |                   |          | 0       | 0      | 0     | 59                                 | five        | faɪv              |          | f       |        | v     |
|                      |             |                   |          |         |        |       | 60                                 | seven       | sevn              |          | s       | v      | n     |
|                      |             |                   |          |         |        |       | Items 30-60 Subtotals              |             |                   |          | 1       | 1      | 0     |
|                      |             |                   |          |         |        |       | Transfer Items 1-29 Subtotals here |             |                   |          | 0       | 0      | 0     |
|                      |             |                   |          |         |        |       | Total Raw Score                    |             |                   |          | 2       |        |       |

1 vowel error

Note: Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.

Percent Consonants Correct

|                                                    |            |
|----------------------------------------------------|------------|
| (a) Total number of target consonants              | <b>141</b> |
| (b) Number of consonants not elicited              | 0          |
| (c) Total number of consonants elicited (a) -- (b) | 141        |
| (d) Total number of consonants in error            | 2          |
| (e) Total consonants correct (c) – (d)             | 139        |
| (f) PCC: (e) ÷ (c) x 100                           | 99         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 1         |
| (e) Total vowels correct (c) – (d)            | 87        |
| (f) PVC: (e) ÷ (c) x 100                      | 99        |

# Speaker with DS 26

PARTICIPANT ID: DS26

## Sounds-in-Words (Ages 2:0-21:11)

| Item                 | Target Word | IPA Transcription | Response | Initial | Medial | Final | Item | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|----------------------|-------------|-------------------|----------|---------|--------|-------|------|-------------|-------------------|----------|---------|--------|-------|
| 1                    | house       | haus              |          | h       |        | s     | 30   | finger      | fɪŋgə             |          | f       | ŋ g    | ə     |
| 2                    | door        | dɔr               |          | d       |        | r     | 31   | ring        | rɪŋ               |          | r       |        | ŋ     |
| 3                    | pig         | pɪg               |          | p       |        | g     | 32   | thumb       | θʌm               |          | θ       |        | m     |
| 4                    | cup         | kʌp               |          | k       |        | p     | 33   | elephant    | ələfənt           |          |         | l f    | nt    |
| 5                    | boy         | bɔɪ               |          | b       |        |       | 34   | vacuum      | vækjʊm            | (D)      | v       | k j    | m     |
| 6                    | apple       | æpəl              |          |         | p      | l     | 35   | shovel      | ʃəvəl             | (D) /s   |         | v      | l     |
| 7                    | go          | go                |          | g       |        |       | 36   | teacher     | tɪtʃə             |          | t       | tʃ     | ə     |
| 8                    | duck        | dʌk               |          | d       |        | k     | 37   | zebra       | zɪbrə             |          | z       | br     |       |
| 9                    | quack       | kwæk              |          | kw      |        | k     | 38   | giraffe     | ɡɪræf             | /s       |         | r      | f     |
| 10                   | table       | tebəl             |          | t       | b      | l     | 39   | vegetable   | vɛdʒtəbəl         |          | v       | dʒ t b | l     |
| 11                   | monkey      | mʌŋki             |          | m       | ŋ k    |       | 40   | brushing    | brʌʃɪŋ            |          | br      | ʃ      | ɪŋ    |
| 12                   | hammer      | hæmə              |          | h       | m      | ə     | 41   | blue        | blu               |          | bl      |        |       |
| 13                   | fish        | fɪʃ               |          | f       |        | ʃ     | 42   | yellow      | jələ              |          | j       | l      |       |
| 14                   | watch       | wɒtʃ              |          | w       |        | tʃ    | 43   | brother     | brʌðə             |          | br      | ð      | ə     |
| 15                   | spider      | spɪdə             |          | sp      | d      | ə     | 44   | frog        | frog              |          | fr      |        | g     |
| 16                   | web         | wɛb               |          | w       |        | b     | 45   | green       | grɪn              |          | gr      |        | n     |
| 17                   | drum        | drʌm              |          | dr      |        | m     | 46   | that        | ðæt               |          | ð       |        | t     |
| 18                   | plate       | plet              |          | pl      |        | t     | 47   | leaf        | lif               |          | l       |        | f     |
| 19                   | knife       | nɑɪf              |          | n       |        | f     | 48   | cookie      | kʊki              |          | k       | k      |       |
| 20                   | shoe        | ʃu                |          | ʃ       |        |       | 49   | cheese      | tʃiz              |          | tʃ      |        | z     |
| 21                   | slide       | slaɪd             |          | sl      |        | d     | 50   | pajamas     | pɛdʒəməz          | (i)      | p       | dʒ m   | z     |
| 22                   | swing       | swɪŋ              |          | sw      |        | ŋ     | 51   | teeth       | tɪθ               |          | t       |        | θ     |
| 23                   | guitar      | ɡɪtər             |          | ɡ       | t      | r     | 52   | princess    | prɪnsɪs           |          | pr      | n s    | s     |
| 24                   | lion        | laɪən             |          | l       |        | n     | 53   | crown       | kraʊn             |          | kr      |        | n     |
| 25                   | chair       | tʃɛr              |          | tʃ      |        | r     | 54   | truck       | trʌk              | (i)      | tr      |        | k     |
| 26                   | soap        | sop               |          | s       |        | p     | 55   | red         | rɛd               |          | r       |        | d     |
| 27                   | glasses     | glæsɪz            |          | gl      | s      | z     | 56   | juice       | dʒʊs              |          | dʒ      |        | s     |
| 28                   | tiger       | tɑɪgə             |          | t       | g      | ə     | 57   | zoo         | zu                | /s       |         |        |       |
| 29                   | puzzle      | pʌzəl             | (D)      | p       | /s     | l     | 58   | star        | stɑr              |          | st      |        | r     |
| Items 1-29 Subtotals |             |                   |          | 0       | 1      | 0     | 59   | five        | fɑɪv              |          | f       |        | v     |
|                      |             |                   |          |         |        |       | 60   | seven       | sevn              |          | s       | v      | n     |

No vowel errors

Items 30-60 Subtotals  
Transfer Items 1-29 Subtotals here

Total Raw Score

Note: Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.



Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 4          |
| (e) Total consonants correct (c) – (d)            | 137        |
| (f) PCC: (e) ÷ (c) x 100                          | 97         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 0         |
| (e) Total vowels correct (c) – (d)            | 188       |
| (f) PVC: (e) ÷ (c) x 100                      | 100       |

# Speaker with DS 27

PARTICIPANT ID: DS27

## Sounds-in-Words (Ages 2:0-21:11)

| Item                               | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|------------------------------------|-------------|-------------------|----------|---------|--------|-------|
| 1                                  | house       | haʊs              |          | h       |        | s     |
| 2                                  | door        | dɔː               |          | d       |        | r     |
| 3                                  | pig         | pɪg               |          | p       |        | g     |
| 4                                  | cup         | kʌp               |          | k       |        | p     |
| 5                                  | boy         | bɔɪ               |          | b       |        |       |
| 6                                  | apple       | æpəl              |          |         | p      | l     |
| 7                                  | go          | go                |          | g       |        |       |
| 8                                  | duck        | dʌk               |          | d       |        | k     |
| 9                                  | quack       | kʷæk              |          | kʷ      |        | k     |
| 10                                 | table       | teɪbəl            |          | t       | b      | l     |
| 11                                 | monkey      | mʌŋki             |          | m       | ŋ k    |       |
| 12                                 | hammer      | hæmə              |          | h       | m      | ə     |
| 13                                 | fish        | fɪʃ               |          | f       |        | ʃ     |
| 14                                 | watch       | wɒtʃ              |          | w       |        | tʃ    |
| 15                                 | spider      | spaɪdə            |          | sp      | d      | ə     |
| 16                                 | web         | wɛb               |          | w       |        | b     |
| 17                                 | drum        | drʌm              |          | dr      |        | m     |
| 18                                 | plate       | plet              |          | pl      |        | t     |
| 19                                 | knife       | naɪf              |          | n       |        | f     |
| 20                                 | shoe        | ʃu                |          | ʃ       |        |       |
| 21                                 | slide       | slaɪd             |          | sl      |        | d     |
| 22                                 | swing       | swɪŋ              |          | sw      |        | ŋ     |
| 23                                 | guitar      | ɡetər             |          | ɡ       | t      | r     |
| 24                                 | lion        | laɪən             |          | l       |        | n     |
| 25                                 | chair       | tʃeər             |          | tʃ      |        | r     |
| 26                                 | soap        | sop               |          | s       |        | p     |
| 27                                 | glasses     | ɡlæsɪz            |          | ɡl      | s      | z     |
| 28                                 | tiger       | taɪɡə             |          | t       | ɡ      | ə     |
| 29                                 | puzzle      | pæzəl             |          | p       | z      | l     |
| Items 1-29 Subtotals               |             |                   |          | 0       | 0      | 0     |
| 30                                 | finger      | fɪŋɡə             |          | f       | ŋ ɡ    | ə     |
| 31                                 | ring        | rɪŋ               |          | r       |        | ŋ     |
| 32                                 | thumb       | θʌm               |          | θ       |        | m     |
| 33                                 | elephant    | ələfənt           |          |         | l f    | nt    |
| 34                                 | vacuum      | vækjʊm            |          | v       | k j    | m     |
| 35                                 | shovel      | ʃʌvəl             |          | ʃ       | v      | l     |
| 36                                 | teacher     | ti:tʃə            |          | t       | tʃ     | ə     |
| 37                                 | zebra       | zɪbrə             |          | z       | br     |       |
| 38                                 | giraffe     | dʒərəʃ            |          | dʒ      | r      | ʃ     |
| 39                                 | vegetable   | vɛdʒtəbəl         |          | v       | dʒ t b | l     |
| 40                                 | brushing    | brʌʃɪŋ            |          | br      | ʃ      | ɪŋ    |
| 41                                 | blue        | blu               |          | bl      |        |       |
| 42                                 | yellow      | jeləʊ             |          | j       | l      |       |
| 43                                 | brother     | brʌðə             |          | br      | ð      | ə     |
| 44                                 | frog        | frog              |          | fr      |        | ɡ     |
| 45                                 | green       | ɡrɪn              |          | ɡr      |        | n     |
| 46                                 | that        | ðæt               | (1)      | ð       |        | t     |
| 47                                 | leaf        | li:f              |          | l       |        | f     |
| 48                                 | cookie      | kʊki              |          | k       | k      |       |
| 49                                 | cheese      | tʃi:z             |          | tʃ      |        | z     |
| 50                                 | peajamas    | pəˈdʒaməz         |          | p       | dʒ m   | z     |
| 51                                 | teeth       | ti:θ              |          | t       |        | θ     |
| 52                                 | princess    | prɪnsɪs           |          | pr      | n s    | s     |
| 53                                 | crown       | kraʊn             |          | kɹ      |        | n     |
| 54                                 | truck       | trʌk              |          | tr      |        | k     |
| 55                                 | red         | red               |          | r       |        | d     |
| 56                                 | juice       | dʒʊs              |          | dʒ      |        | s     |
| 57                                 | zoo         | zu                |          | z       |        |       |
| 58                                 | star        | stɑː              |          | st      |        | r     |
| 59                                 | five        | faɪv              |          | f       |        | v     |
| 60                                 | seven       | sevn              |          | s       | v      | n     |
| Items 30-60 Subtotals              |             |                   |          | 0       | 0      | 0     |
| Transfer Items 1-29 Subtotals here |             |                   |          | 0       | 0      | 0     |
| Total Raw Score                    |             |                   |          | 0       |        |       |

No vowel errors

Note: Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.

Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 0          |
| (e) Total consonants correct (c) – (d)            | 141        |
| (f) PCC: (e) ÷ (c) x 100                          | 100        |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 9         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 0         |
| (e) Total vowels correct (c) – (d)            | 88        |
| (f) PVC: (e) ÷ (c) x 100                      | 100       |

# Speaker with DS 28

PARTICIPANT ID: DS28

## Sounds-in-Words (Ages 2;0-21;11)

| Item                               | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|------------------------------------|-------------|-------------------|----------|---------|--------|-------|
| 1                                  | house       | haus              |          | h       |        | s     |
| 2                                  | door        | dɔr               |          | d       |        | r     |
| 3                                  | pig         | pɪg               |          | p       |        | g     |
| 4                                  | cup         | kʌp               |          | k       |        | p     |
| 5                                  | boy         | bɔɪ               |          | b       |        |       |
| 6                                  | apple       | æpəl              |          |         | p      | l     |
| 7                                  | go          | go                |          | g       |        |       |
| 8                                  | duck        | dʌk               |          | d       |        | k     |
| 9                                  | quack       | kwæk              |          | kw      |        | k     |
| 10                                 | table       | tebəl             |          | t       | b      | l     |
| 11                                 | monkey      | mʌŋki             |          | m       | ŋ k    |       |
| 12                                 | hammer      | hæmə              |          | h       | m      | ə     |
| 13                                 | fish        | fɪʃ               |          | f       |        | ʃ     |
| 14                                 | watch       | wɒtʃ              |          | w       |        | tʃ    |
| 15                                 | spider      | spɑɪdər           |          | sp      | d      | ər    |
| 16                                 | web         | wɛb               |          | w       |        | b     |
| 17                                 | drum        | dɹʌm              |          | dr      |        | m     |
| 18                                 | plate       | plet              |          | pl      |        | t     |
| 19                                 | knife       | naɪf              |          | n       |        | f     |
| 20                                 | shoe        | ʃu                |          | ʃ       |        |       |
| 21                                 | slide       | slaɪd             |          | sl      |        | d     |
| 22                                 | swing       | swɪŋ              |          | sw      |        | ŋ     |
| 23                                 | guitar      | getər             |          | g       | t      | ər    |
| 24                                 | lion        | laɪən             |          | l       |        | n     |
| 25                                 | chair       | tʃer              |          | tʃ      |        | r     |
| 26                                 | soap        | sop               |          | s       |        | p     |
| 27                                 | glasses     | glæsɪz            |          | gl      | s      | z     |
| 28                                 | tiger       | taɪgər            |          | t       | g      | ər    |
| 29                                 | puzzle      | pʌzəl             |          | p       | z      | l     |
| Items 1-29 Subtotals               |             |                   |          | 0       | 0      | 0     |
| 30                                 | finger      | fɪŋgər            |          | f       | ŋ g    | ər    |
| 31                                 | ring        | rɪŋ               |          | r       |        | ŋ     |
| 32                                 | thumb       | θʌm               |          | θ       |        | m     |
| 33                                 | elephant    | ɛləfənt           |          |         | l f    | nt    |
| 34                                 | vacuum      | vækjʊm            |          | v       | k j    | m     |
| 35                                 | shovel      | ʃʌvəl             |          | ʃ       | v      | l     |
| 36                                 | teacher     | ti:tʃər           |          | t       | tʃ     | ər    |
| 37                                 | zebra       | zɪbrə             |          | z       | br     |       |
| 38                                 | giraffe     | dʒərəf            |          | dʒ      | r      | f     |
| 39                                 | vegetable   | vɛdʒtəbəl         | (i)      | v       | dʒ b   | l     |
| 40                                 | brushing    | brʌʃɪŋ            |          | br      | ʃ      | ɪŋ    |
| 41                                 | blue        | blu               |          | bl      |        |       |
| 42                                 | yellow      | ˈjelo             |          |         |        | l     |
| 43                                 | brother     | brʌðər            |          | br      | ð      | ər    |
| 44                                 | frog        | fɹɒg              |          | fr      |        | g     |
| 45                                 | green       | grɪn              |          | gr      |        | n     |
| 46                                 | that        | ðæt               |          | ð       |        | t     |
| 47                                 | leaf        | li:f              |          | l       |        | f     |
| 48                                 | cookie      | kʊki              |          | k       | k      |       |
| 49                                 | cheese      | tʃi:z             |          | tʃ      |        | z     |
| 50                                 | pajamas     | pəˈdʒæməz         |          | p       | dʒ m   | z     |
| 51                                 | teeth       | ti:θ              |          | t       |        | θ     |
| 52                                 | princess    | prɪnˈsɛs          |          | pr      | n s    | s     |
| 53                                 | crown       | kraʊn             |          | kr      |        | n     |
| 54                                 | truck       | trʌk              |          | tr      |        | k     |
| 55                                 | red         | rɛd               |          | r       |        | d     |
| 56                                 | juice       | dʒʊs              |          | dʒ      |        | s     |
| 57                                 | zoo         | zu                |          | z       |        |       |
| 58                                 | star        | stɑr              |          | st      |        | r     |
| 59                                 | five        | faɪv              |          | f       |        | v     |
| 60                                 | seven       | sevn              |          | s       | v      | n     |
| Items 30-60 Subtotals              |             |                   |          | 1       | 1      | 0     |
| Transfer Items 1-29 Subtotals here |             |                   |          | 0       | 0      | 0     |
| Total Raw Score                    |             |                   |          | 2       |        |       |

No vowel errors

Note. Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.

Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 2          |
| (e) Total consonants correct (c) – (d)            | 139        |
| (f) PCC: (e) ÷ (c) x 100                          | 99         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 0         |
| (e) Total vowels correct (c) – (d)            | 88        |
| (f) PVC: (e) ÷ (c) x 100                      | 100       |



# Speaker with DS 29

PARTICIPANT ID: DS29

## Sounds-in-Words (Ages 2:0-21:11)

| Item                 | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|----------------------|-------------|-------------------|----------|---------|--------|-------|
| 1                    | house       | haʊs              |          | h       |        | s     |
| 2                    | door        | dɔː               |          | d       |        |       |
| 3                    | pig         | pɪɡ               |          | p       |        | g     |
| 4                    | cup         | kʌp               |          | k       |        | p     |
| 5                    | boy         | bɔɪ               |          | b       |        |       |
| 6                    | apple       | æpəl              |          |         | p      | l     |
| 7                    | go          | ɡo                |          | ɡ       |        |       |
| 8                    | duck        | dʌk               |          | d       |        | k     |
| 9                    | quack       | kwæk              |          | kw      |        | k     |
| 10                   | table       | təbəl             |          | t       | b      | l     |
| 11                   | monkey      | mʌŋki             |          | m       | ŋ k    |       |
| 12                   | hammer      | hæmə              |          | h       | m      | ə     |
| 13                   | fish        | fɪʃ               |          | f       |        | ʃ     |
| 14                   | watch       | wɒtʃ              |          | w       |        | tʃ    |
| 15                   | spider      | spɑɪdə            |          | sp      | d      | ə     |
| 16                   | web         | wɛb               |          | w       |        | b     |
| 17                   | drum        | drʌm              |          | dr      |        | m     |
| 18                   | plate       | plet              |          | pl      |        | t     |
| 19                   | knife       | naɪf              |          | n       |        | f     |
| 20                   | shoe        | ʃuː               |          |         |        | ʃ     |
| 21                   | slide       | slaɪd             |          |         |        | d     |
| 22                   | swing       | swɪŋ              |          | sw      |        | ŋ     |
| 23                   | guitar      | ɡeɪtər            |          | ɡ       | t      | r     |
| 24                   | lion        | laɪən             |          |         |        | n     |
| 25                   | chair       | tʃeər             |          | tʃ      |        | r     |
| 26                   | soap        | sɒp               |          | s       |        | p     |
| 27                   | glasses     | ɡlæsɪz            |          | ɡ       | s      | z     |
| 28                   | tiger       | taɪɡər            |          | t       | ɡ      | ər    |
| 29                   | puzzle      | pʌzəl             |          | p       | z      | l     |
| Items 1-29 Subtotals |             |                   |          | 5       | 0      | 3     |

No vowel errors

| Item                               | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|------------------------------------|-------------|-------------------|----------|---------|--------|-------|
| 30                                 | finger      | fɪŋɡər            |          | f       | ŋ ɡ    | ər    |
| 31                                 | ring        | rɪŋ               |          | r       |        | ŋ     |
| 32                                 | thumb       | θʌm               |          | θ       |        | m     |
| 33                                 | elephant    | ələfənt           |          |         | l f    | nt    |
| 34                                 | vacuum      | vækjʊm            | (i)      | v       | k j    | m     |
| 35                                 | shovel      | ʃəvəl             |          | ʃ       | v      | l     |
| 36                                 | teacher     | ti:tʃər           |          | t       | tʃ     | ər    |
| 37                                 | zebra       | zɪbrə             |          | z       | br     | ər    |
| 38                                 | giraffe     | dʒərəf            |          | dʒ      | r      | f     |
| 39                                 | vegetable   | vɛdʒtəbəl         |          | v       | dʒ t b | l     |
| 40                                 | brushing    | brʌʃɪŋ            |          | br      | ʃ      | ɪŋ    |
| 41                                 | blue        | bluː              |          |         |        | bluː  |
| 42                                 | yellow      | jələʊ             |          | j       |        | ləʊ   |
| 43                                 | brother     | brʌðər            |          | br      | ð      | ər    |
| 44                                 | frog        | fɹɒɡ              |          | fr      |        | ɡ     |
| 45                                 | green       | ɡriːn             |          | gr      |        | n     |
| 46                                 | that        | ðæt               | (i)      | ð       |        | t     |
| 47                                 | leaf        | liːf              |          |         |        | liːf  |
| 48                                 | cookie      | kʊki              |          | k       |        | ki    |
| 49                                 | cheese      | tʃiːz             |          | tʃ      |        | z     |
| 50                                 | pajamas     | pədʒəmeɪz         |          | p       | dʒ m   | z     |
| 51                                 | teeth       | tiːθ              |          | t       |        | θ     |
| 52                                 | princess    | prɪnsɪs           |          | pr      | n s    | s     |
| 53                                 | crown       | kraʊn             |          | kr      |        | n     |
| 54                                 | truck       | trʌk              |          | tr      |        | k     |
| 55                                 | red         | red               |          | r       |        | d     |
| 56                                 | juice       | dʒuːs             |          |         |        | dʒuːs |
| 57                                 | zoo         | zuː               |          | z       |        |       |
| 58                                 | star        | stɑː              |          | st      |        | r     |
| 59                                 | five        | faɪv              |          | f       |        | v     |
| 60                                 | seven       | sevn              |          | s       | v      | n     |
| Items 30-60 Subtotals              |             |                   |          | 4       | 4      | 0     |
| Transfer Items 1-29 Subtotals here |             |                   |          | 5       | 0      | 3     |
| Total Raw Score                    |             |                   |          | 16      |        |       |

Note. Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.

Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 16         |
| (e) Total consonants correct (c) – (d)            | 125        |
| (f) PCC: (e) ÷ (c) x 100                          | 89         |

Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 0         |
| (e) Total vowels correct (c) – (d)            | 88        |
| (f) PVC: (e) ÷ (c) x 100                      | 100       |

# Speaker with DS 30

PARTICIPANT ID: DS30

## Sounds-in-Words (Ages 2:0-21:11)

| Item                               | Target Word | IPA Transcription | Response | Initial | Medial | Final |
|------------------------------------|-------------|-------------------|----------|---------|--------|-------|
| 1                                  | house       | haus              |          | h       |        | s     |
| 2                                  | door        | dɔr               |          | d       |        | r     |
| 3                                  | pig         | pɪg               |          | p       |        | g     |
| 4                                  | cup         | kʌp               |          | k       |        | p     |
| 5                                  | boy         | bɔɪ               |          | b       |        |       |
| 6                                  | apple       | æpəl              |          |         | p      | l     |
| 7                                  | go          | go                |          | g       |        |       |
| 8                                  | duck        | dʌk               |          | d       |        | k     |
| 9                                  | quack       | kwæk              |          | kw      |        | k     |
| 10                                 | table       | tebəl             |          | t       | b      | l     |
| 11                                 | monkey      | mʌŋki             |          | m       | ŋ k    |       |
| 12                                 | hammer      | hæmə              |          | h       | m      | ə     |
| 13                                 | fish        | fɪʃ               |          | f       |        | ʃ     |
| 14                                 | watch       | wɒʃ               |          | w       |        | ʃ     |
| 15                                 | spider      | spɑɪdər           |          | sp      | d      | ər    |
| 16                                 | web         | wɛb               |          | w       |        | b     |
| 17                                 | drum        | drʌm              |          | dr      |        | m     |
| 18                                 | plate       | plet              |          | pl      |        | t     |
| 19                                 | knife       | naɪf              |          | n       |        | f     |
| 20                                 | shoe        | ʃu                |          | ʃ       |        |       |
| 21                                 | slide       | slaɪd             |          | sl      |        | d     |
| 22                                 | swing       | swɪŋ              |          | sw      |        | ŋ     |
| 23                                 | guitar      | ɡetər             |          | ɡ       | t      | ər    |
| 24                                 | lion        | laɪən             |          | l       |        | n     |
| 25                                 | chair       | tʃer              |          | tʃ      |        | r     |
| 26                                 | soap        | sop               |          | s       |        | p     |
| 27                                 | glasses     | ɡlæsɪz            |          | ɡl      | s      | z     |
| 28                                 | tiger       | taɪɡər            |          | t       | ɡ      | ər    |
| 29                                 | puzzle      | pʌzəl             | (i)      | p       | z      | l     |
| Items 1-29 Subtotals               |             |                   |          | 0       | 0      | 0     |
| 30                                 | finger      | fɪŋɡər            |          | f       | ŋ ɡ    | ər    |
| 31                                 | ring        | rɪŋ               |          | r       |        | ŋ     |
| 32                                 | thumb       | θʌm               |          | θ       |        | m     |
| 33                                 | elephant    | ələfənt           |          |         | l f    | nt    |
| 34                                 | vacuum      | vækjʊm            | (i)      | v       | k j    | m     |
| 35                                 | shovel      | ʃʌvəl             |          | ʃ       | v      | l     |
| 36                                 | teacher     | ti:tʃər           |          | t       | tʃ     | ər    |
| 37                                 | zebra       | zɪbrə             |          | z       | br     |       |
| 38                                 | giraffe     | dʒərəf            |          | dʒ      | r      | f     |
| 39                                 | vegetable   | vɛdʒəbəl          |          | v       | dʒ b   | l     |
| 40                                 | brushing    | brʌʃɪŋ            |          | br      | ʃ      | ɪŋ    |
| 41                                 | blue        | blu               |          | bl      |        |       |
| 42                                 | yellow      | jələ              |          | br      | ə      | ər    |
| 43                                 | brother     | brʌðər            |          | fr      |        | g     |
| 44                                 | frog        | fɹɒɡ              |          | gr      |        | n     |
| 45                                 | green       | ɡrɪn              |          | ð       |        | t     |
| 46                                 | that        | ðæt               | (i)      | l       |        | f     |
| 47                                 | leaf        | li:f              |          | k       | k      |       |
| 48                                 | cookie      | kʊki              |          | tʃ      |        | z     |
| 49                                 | cheese      | tʃi:z             |          | p       | dʒ m   | z     |
| 50                                 | pajamas     | pəˈdʒɑməz         |          | t       |        | ə     |
| 51                                 | teeth       | ti:θ              |          | pr      | n s    | s     |
| 52                                 | princess    | prɪnsɪs           |          | kr      |        | n     |
| 53                                 | crown       | kraʊn             |          | tr      |        | k     |
| 54                                 | truck       | trʌk              | (i)      | r       |        | d     |
| 55                                 | red         | rɛd               |          | dʒ      |        | s     |
| 56                                 | juice       | dʒʊs              |          | z       |        |       |
| 57                                 | zoo         | zu                |          | st      |        | r     |
| 58                                 | star        | stɑr              |          | f       |        | v     |
| 59                                 | five        | faɪv              |          | s       | v      | n     |
| 60                                 | seven       | sevn              |          |         |        |       |
| Items 30-60 Subtotals              |             |                   |          | 1       | 1      | 0     |
| Transfer Items 1-29 Subtotals here |             |                   |          | 0       | 0      | 0     |
| Total Raw Score                    |             |                   |          | 2       |        |       |

No vowel errors

Note: Misarticulation or omission of one or more phonemes in a cluster counts as one error. Distortions are counted as errors.



Percent Consonants Correct

|                                                   |            |
|---------------------------------------------------|------------|
| (a) Total number of target consonants             | <b>141</b> |
| (b) Number of consonants not elicited             | 0          |
| (c) Total number of consonants elicited (a) – (b) | 141        |
| (d) Total number of consonants in error           | 2          |
| (e) Total consonants correct (c) – (d)            | 139        |
| (f) PCC: (e) ÷ (c) x 100                          | 99         |

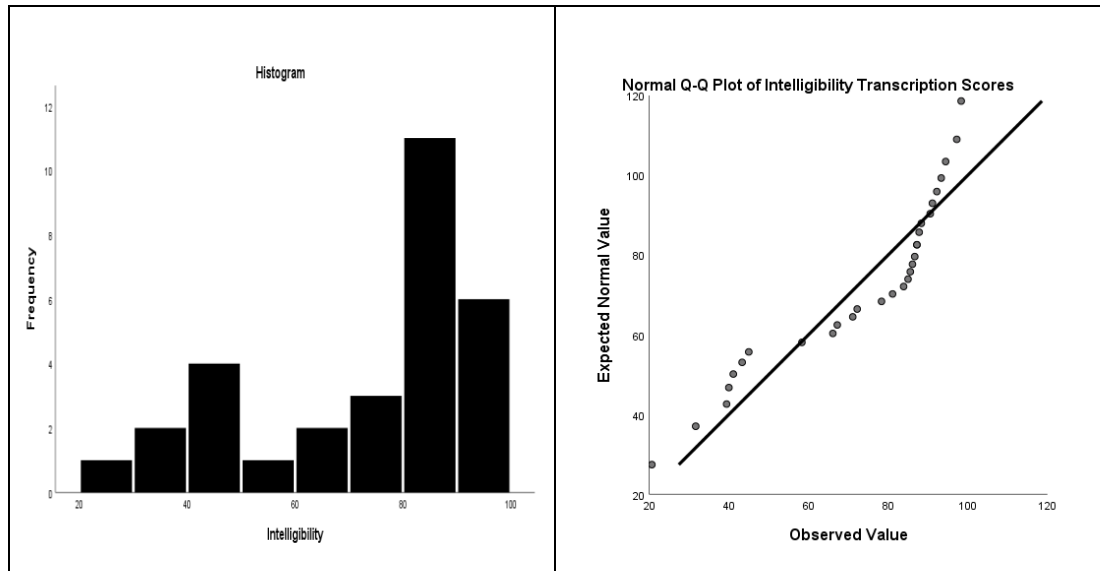
Percent Vowels Correct

|                                               |           |
|-----------------------------------------------|-----------|
| (a) Total number of target vowels             | <b>88</b> |
| (b) Number of vowels not elicited             | 0         |
| (c) Total number of vowels elicited (a) – (b) | 88        |
| (d) Total number of vowels in error           | 0         |
| (e) Total vowels correct (c) – (d)            | 88        |
| (f) PVC: (e) ÷ (c) x 100                      | 100       |

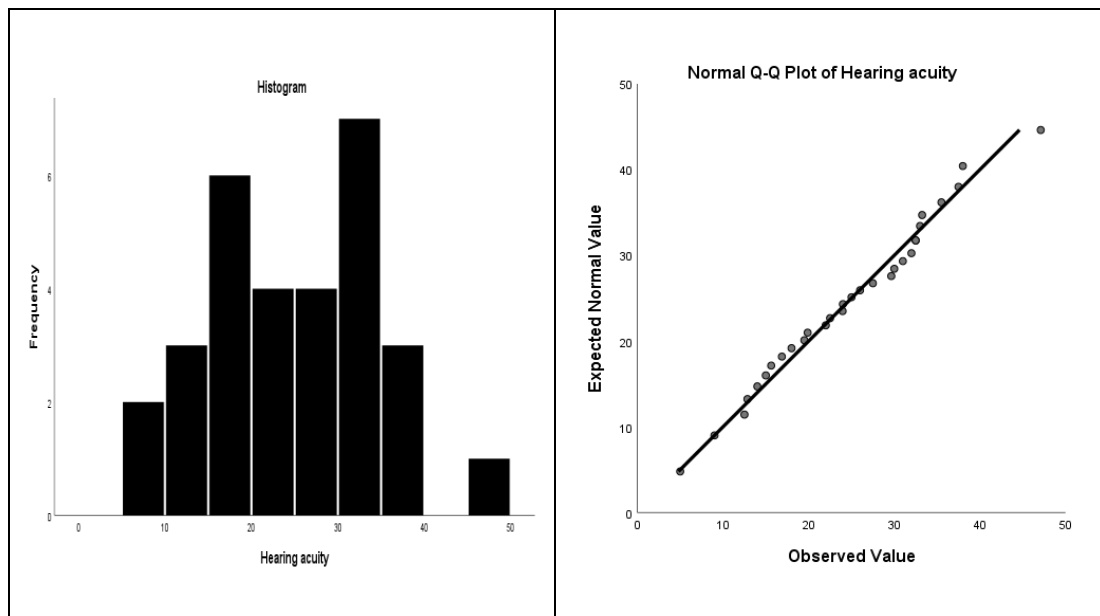
## Appendix F

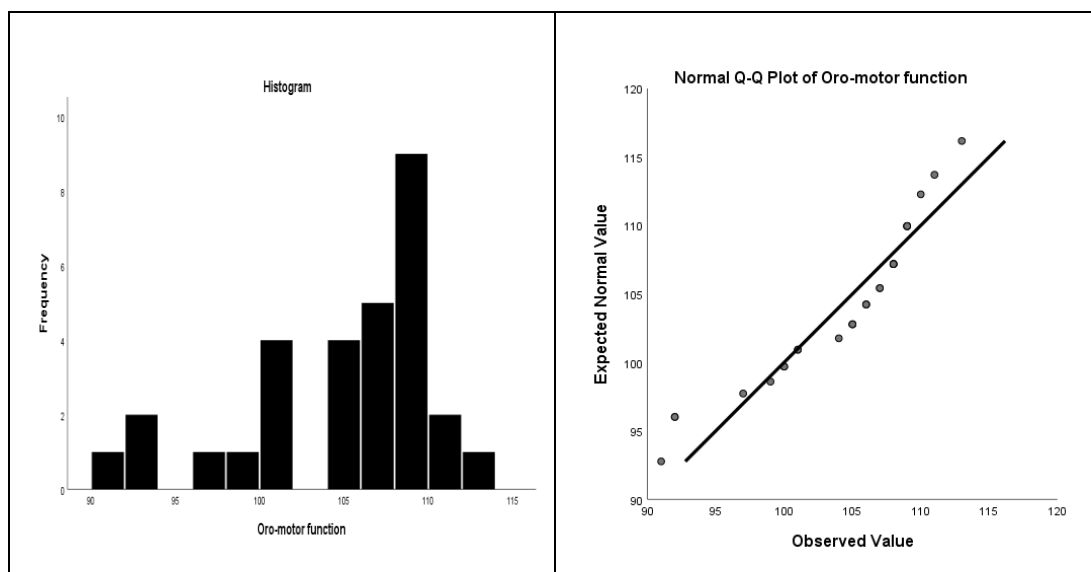
### Histograms and Q-Q plots for speech intelligibility, hearing acuity, and each perceptual parameter in Study 1

#### Speech intelligibility



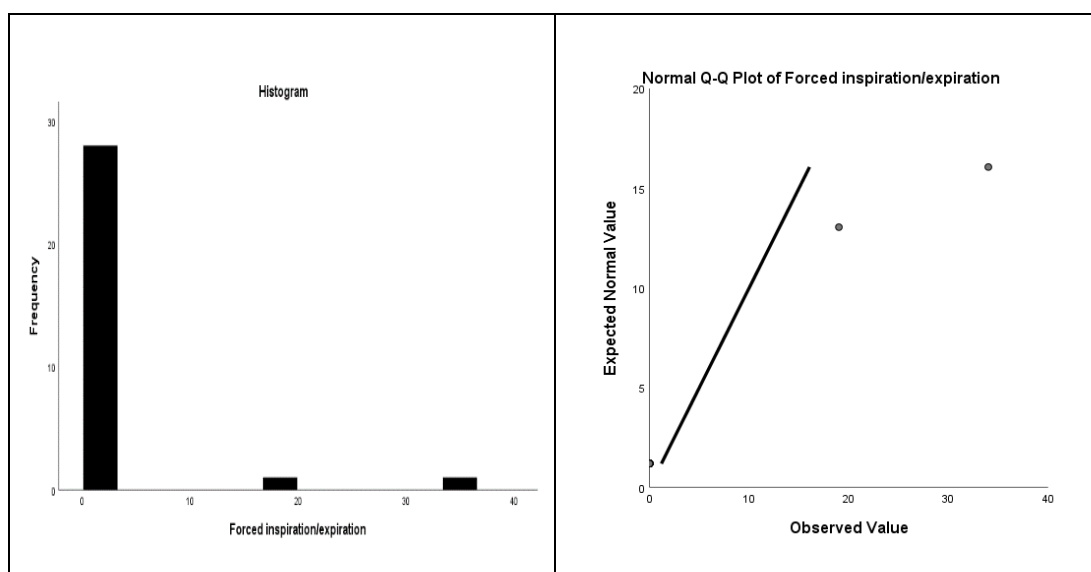
#### Hearing acuity

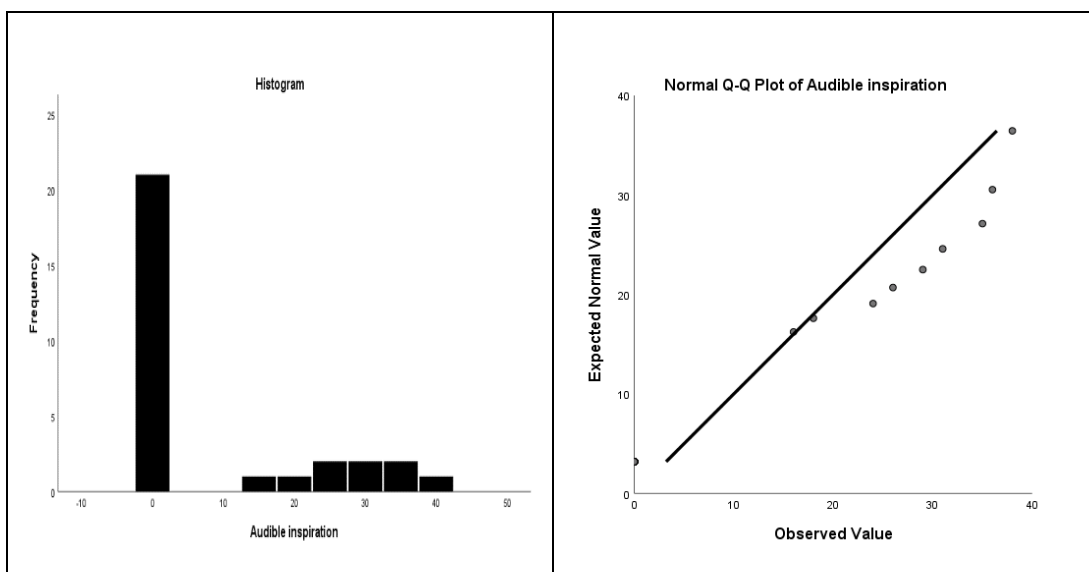




## Perceptual parameters

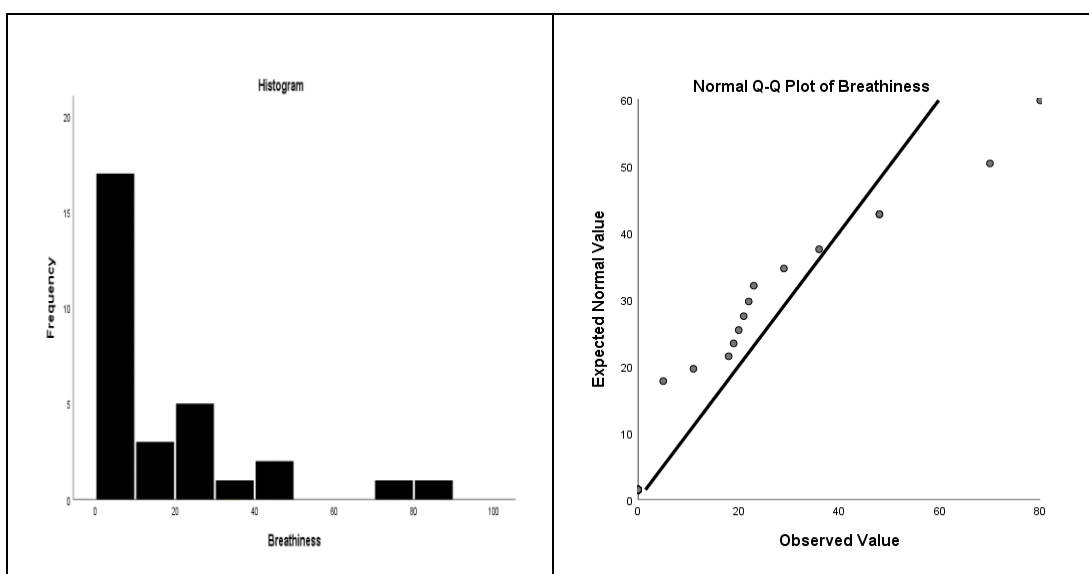
### Respiration

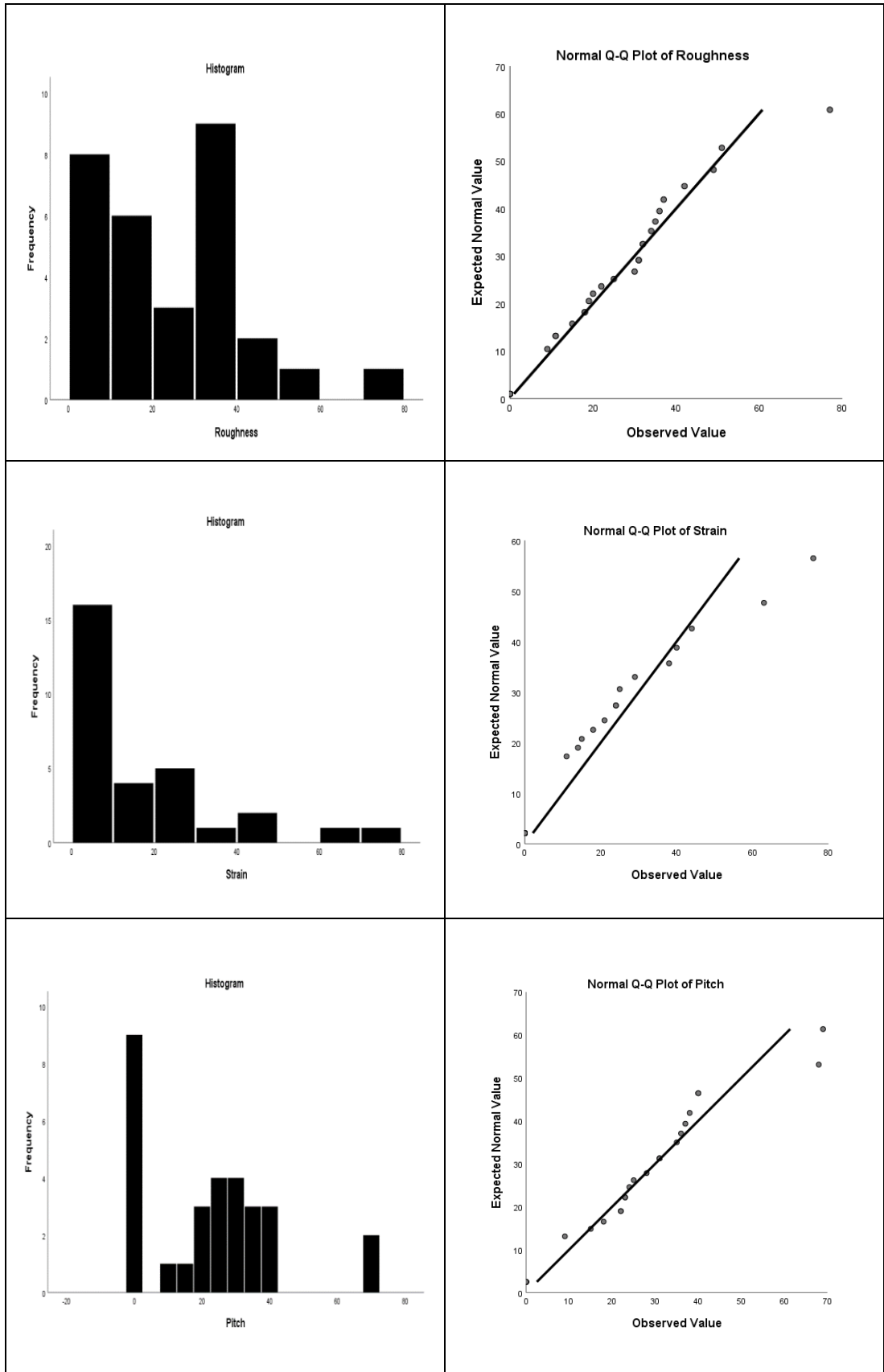


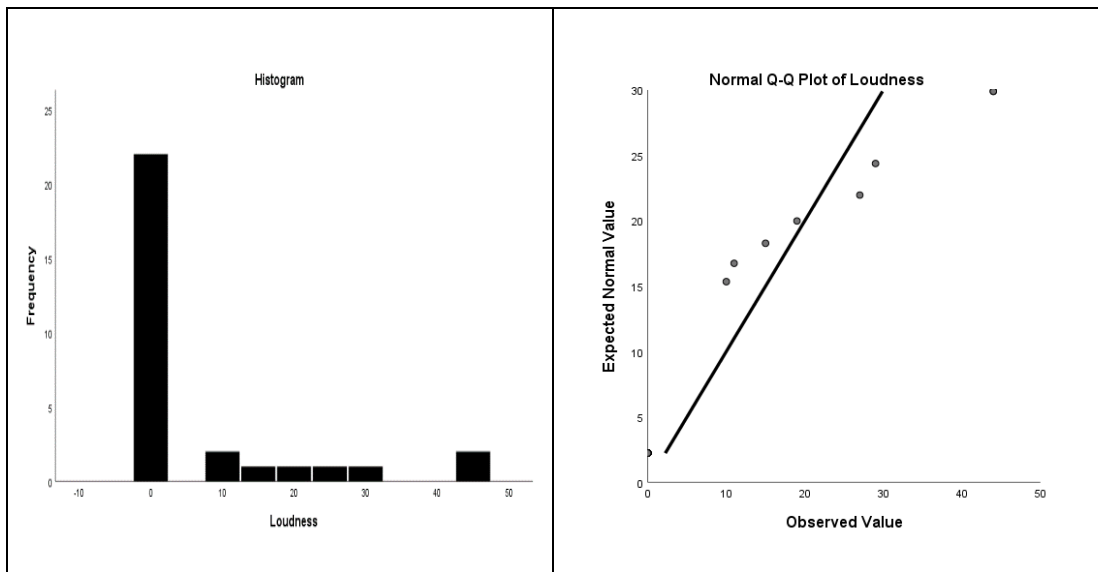


The “Grunt at end of expiration” variable was not analysed as all speakers were given a score of zero.

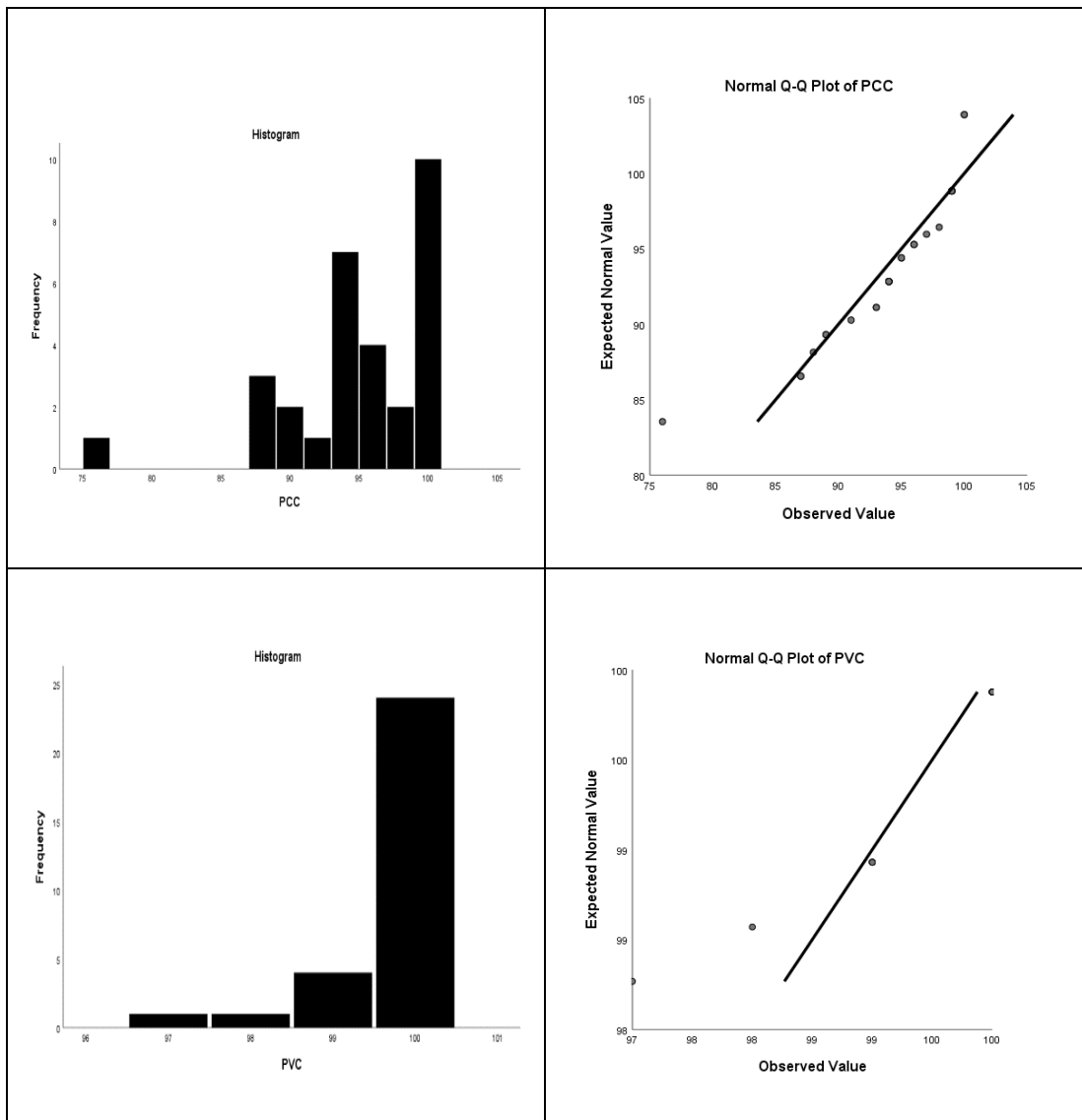
## Phonation



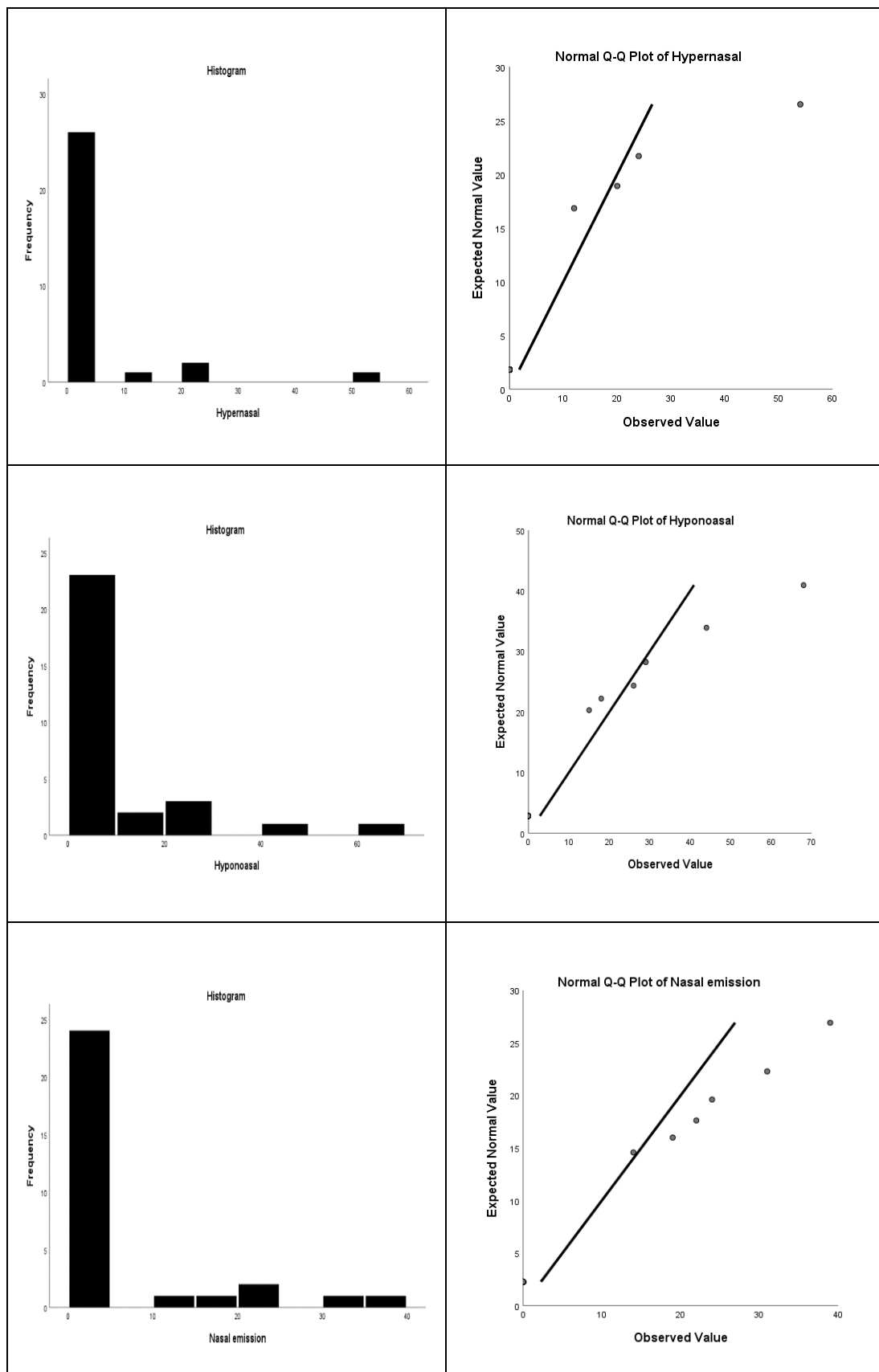




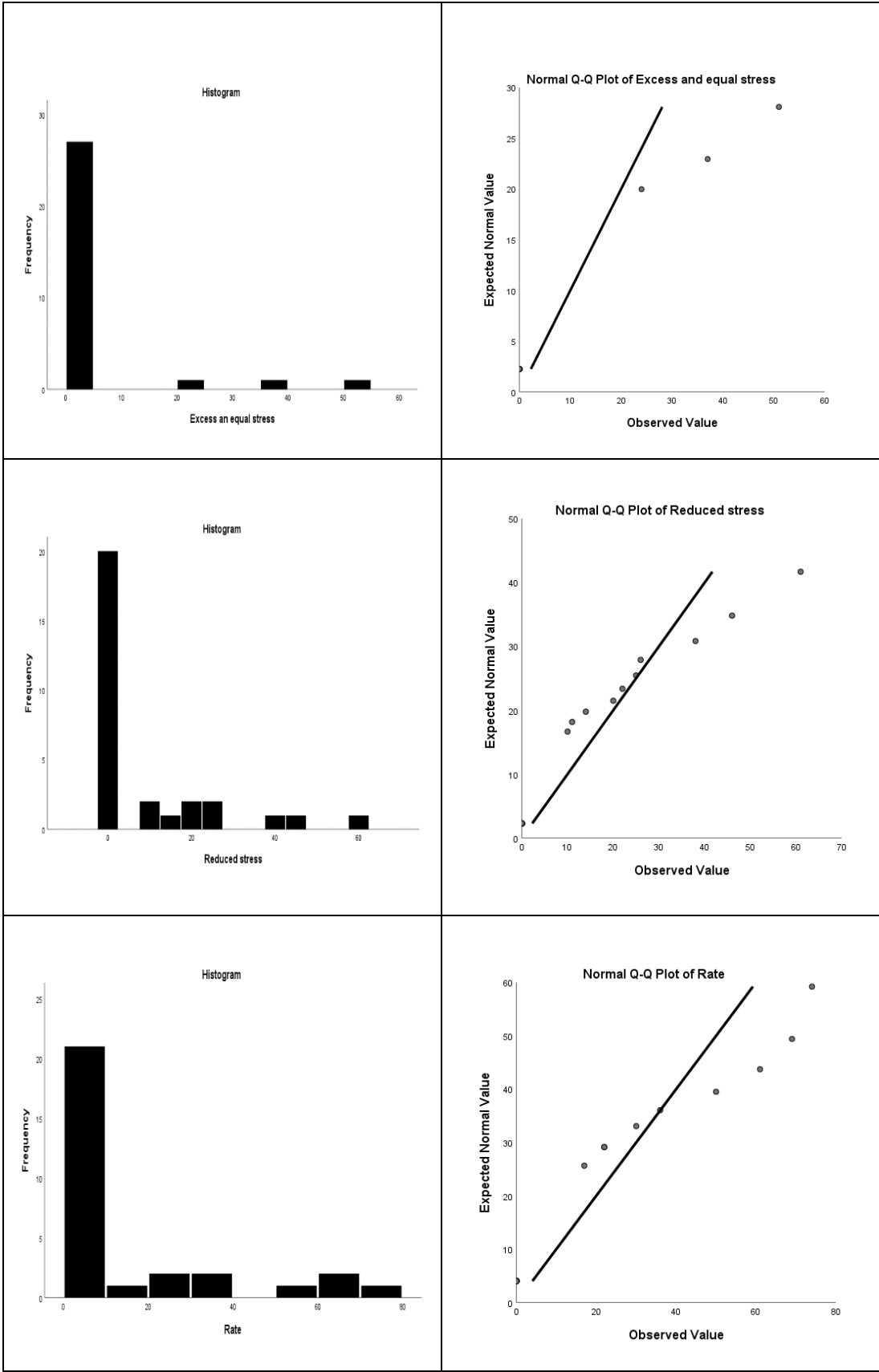
## Articulation



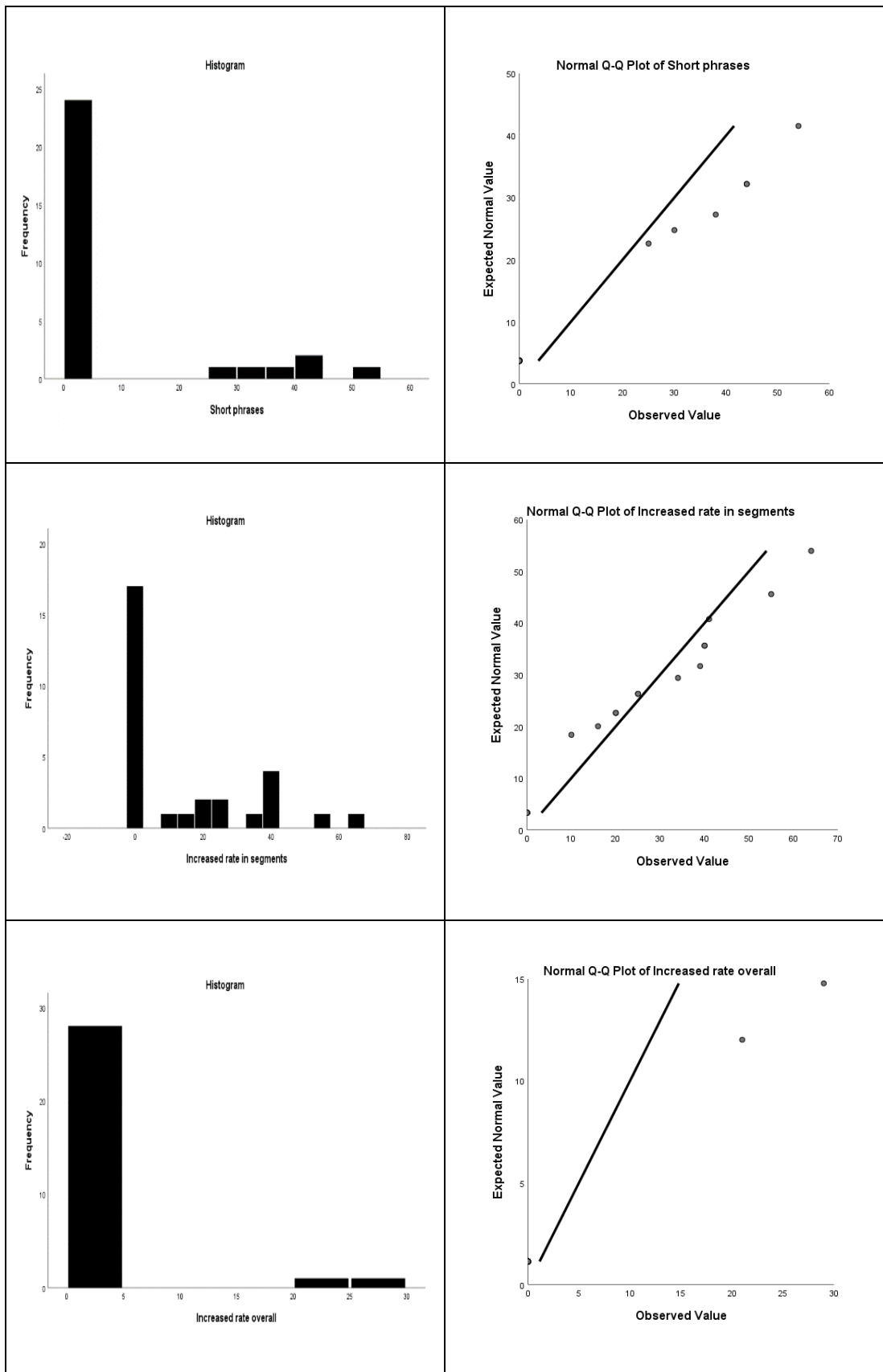
## Resonance

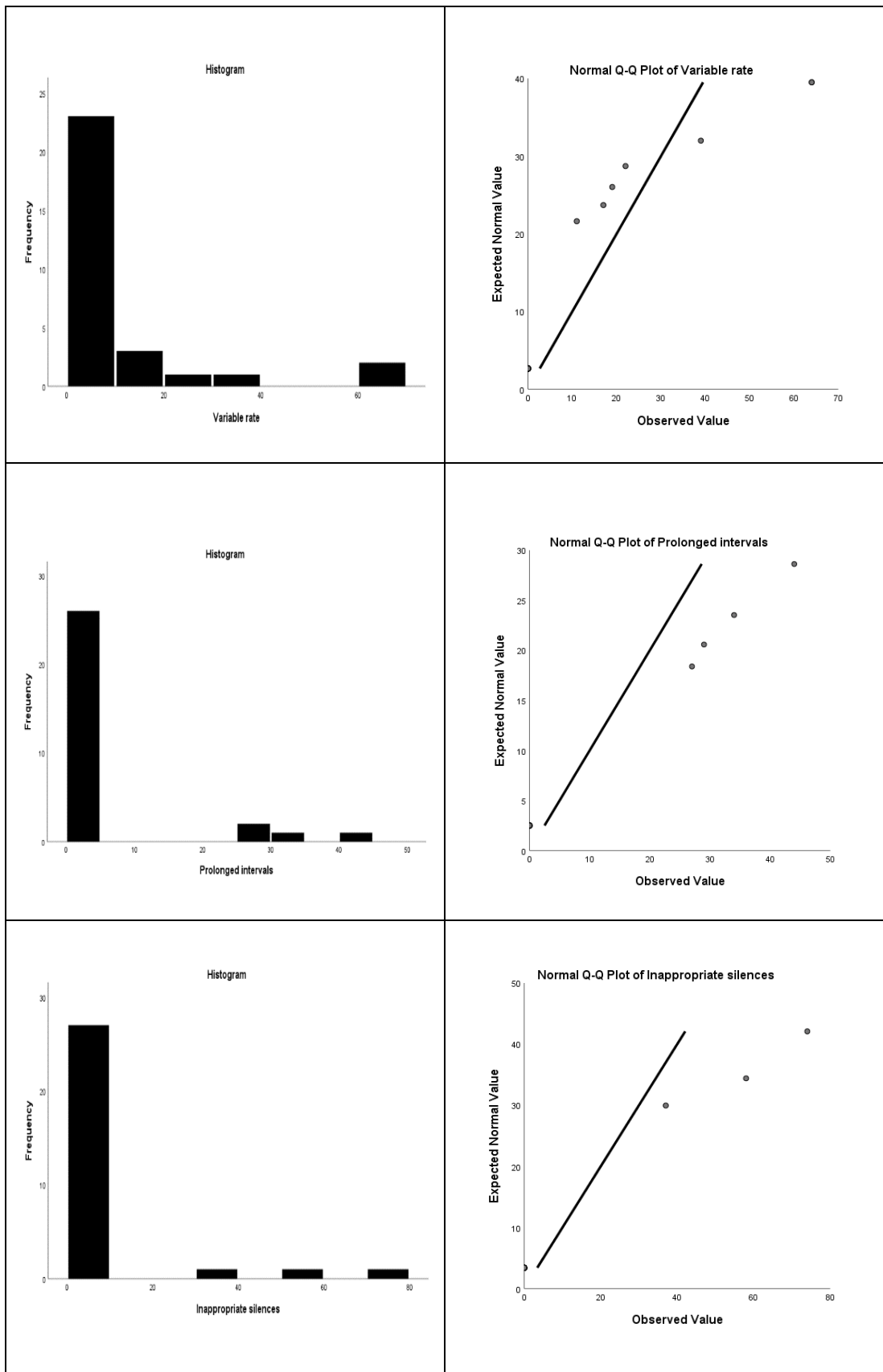


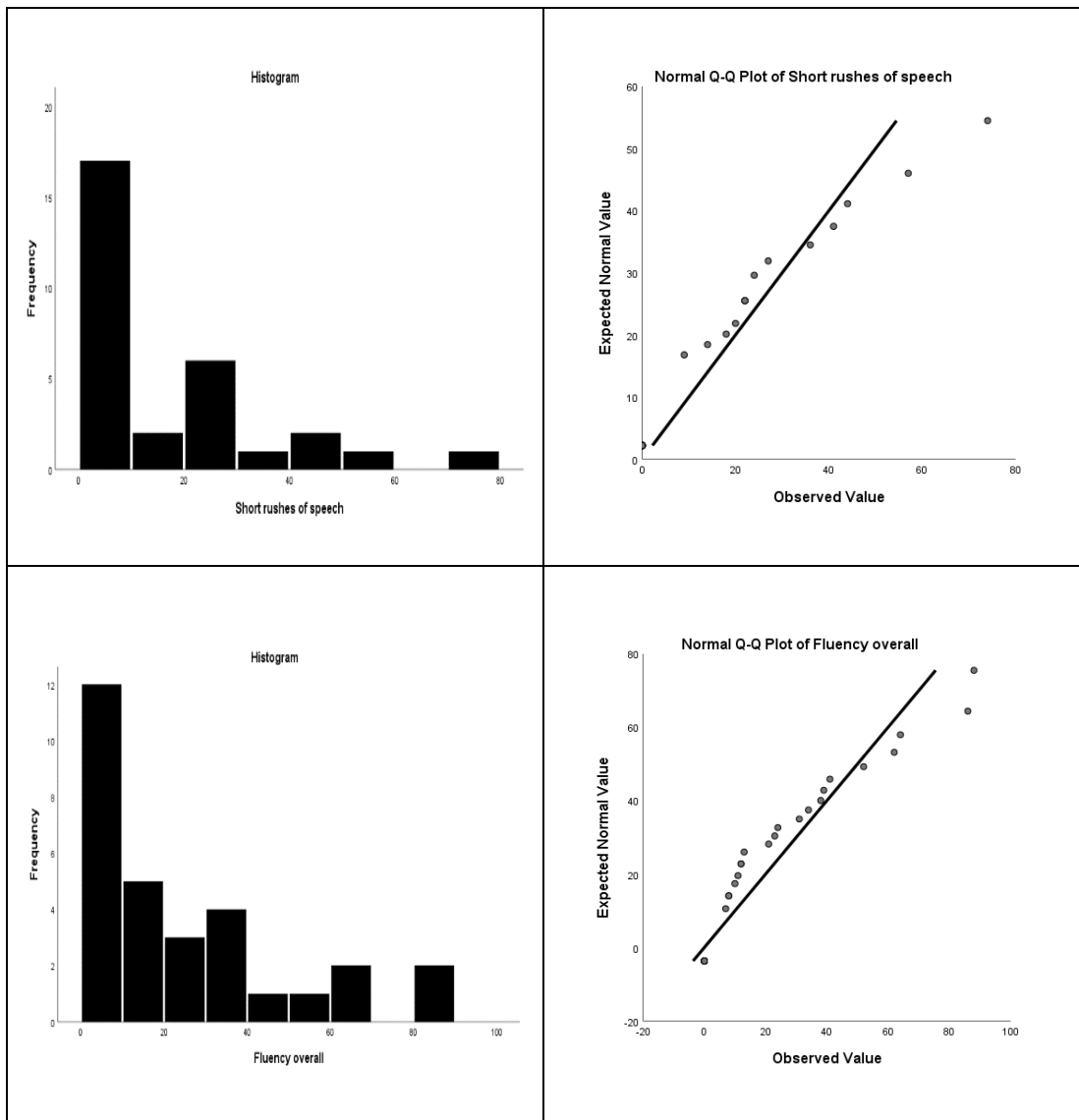
Prosody











## Appendix G

### Spearman rank-order correlations between each perceptual parameter in Study 1

|                            | Roughness | Breathiness | Audible<br>inspiration | Forced ins/<br>ex-piration | Intelligibility |
|----------------------------|-----------|-------------|------------------------|----------------------------|-----------------|
| Intelligibility            | 0.06      | -0.28       | 0.14                   | -0.07                      |                 |
| Forced ins/expiration      | -0.02     | 0.29        | -0.17                  |                            | -0.01           |
| Audible inspiration        | 0.23      | 0.38*       |                        | -0.17                      | 0.14            |
| Breathiness                | -0.09     |             | 0.38*                  | 0.29                       | -0.28           |
| Roughness                  |           | -0.09       | 0.23                   | -0.02                      | 0.06            |
| Strain                     | 0.25      | 0.15        | 0.15                   | 0.07                       | -0.09           |
| Pitch                      | 0.45*     | -0.27       | 0.22                   | -0.20                      | 0.04            |
| Loudness                   | 0.242     | 0.09        | -0.01                  | -0.16                      | -0.17           |
| PCC                        | 0.15      | 0.07        | .046*                  | -0.11                      | 0.63**          |
| PVC                        | 0.25      | -0.16       | 0.32                   | -0.17                      | 0.11            |
| Hypernasality              | -0.31     | 0.00        | -0.11                  | -0.10                      | 0.06            |
| Hyponasality               | 0.09      | -0.19       | -0.14                  | -0.15                      | -0.13           |
| Nasal Emission             | -0.03     | -0.08       | 0.06                   | 0.19                       | -0.09           |
| Excess Stress              | -0.05     | -0.01       | 0.11                   | -0.09                      | -0.23           |
| Reduced Stress             | 0.15      | 0.04        | 0.04                   | 0.06                       | -0.16           |
| Rate                       | 0.18      | 0.49**      | 0.2                    | 0.20                       | -0.30           |
| Short phrases              | -0.00     | 0.17        | 0.07                   | -0.13                      | -0.47**         |
| Increased rate in segments | 0.14      | 0.44*       | -0.02                  | 0.11                       | -0.27           |
| Increased rate overall     | 0.24      | 0.31        | 0.47**                 | -0.07                      | -0.08           |
| Variable rate              | -0.36     | 0.07        | -0.24                  | -0.15                      | -0.10           |
| Prolonged intervals        | -0.19     | 0.06        | -0.09                  | -0.10                      | -0.27           |
| Inappropriate silences     | -0.28     | 0.21        | 0.11                   | -0.09                      | -0.33           |
| Short rushes of speech     | -0.27     | 0.37*       | 0.04                   | 0.02                       | -0.35           |
| Fluency                    | -0.21     | 0.03        | -0.26                  | 0.16                       | -0.32           |

| Hypernasality | PVC     | PCC    | Loudness | Pitch  | Strain |                            |
|---------------|---------|--------|----------|--------|--------|----------------------------|
| 0.06          | 0.11    | 0.63** | -0.17    | 0.04   | -0.09  | Intelligibility            |
| -0.10         | -0.17   | -0.11  | -0.16    | -0.20  | 0.07   | Forced ins/expiration      |
| -0.11         | 0.32    | 0.46*  | -0.01    | 0.22   | 0.15   | Audible inspiration        |
| 0.00          | -0.16   | 0.07   | 0.09     | -0.27  | 0.15   | Breathiness                |
| -0.31         | 0.25    | 0.15   | 0.24     | 0.45*  | 0.25   | Roughness                  |
| -0.23         | 0.44*   | 0.18   | 0.44*    | 0.27   |        | Strain                     |
| -0.24         | 0.04    | 0.01   | 0.38*    |        | 0.27   | Pitch                      |
| 0.015         | 0.073   | -0.118 |          | 0.378* | 0.439* | Loudness                   |
| -0.09         | 0.33    |        | -0.12    | 0.01   | 0.18   | PCC                        |
| -0.12         |         | 0.33   | 0.08     | 0.04   | 0.44*  | PVC                        |
|               | -0.12   | -0.09  | 0.02     | -0.24  | -0.23  | Hypernasality              |
| -0.21         | -0.10   | -0.19  | 0.39*    | 0.32   | 0.06   | Hyponasality               |
| -0.19         | 0.09    | -0.01  | -0.29    | -0.02  | 0.01   | Nasal Emission             |
| -0.13         | -0.14   | -0.22  | -0.19    | 0.32   | -0.00  | Excess Stress              |
| -0.04         | -0.01   | -0.33  | 0.61**   | 0.42*  | 0.29   | Reduced Stress             |
| -0.25         | 0.18    | 0.02   | 0.07     | -0.06  | 0.57** | Rate                       |
| 0.29          | -0.39*  | -0.31  | 0.34     | 0.00   | -0.08  | Short phrases              |
| -0.21         | -0.08   | -0.07  | -0.09    | -0.21  | 0.12   | Increased rate in segments |
| -0.10         | 0.13    | 0.18   | 0.16     | -0.13  | 0.25   | Increased rate overall     |
| 0.23          | -0.18   | -0.30  | 0.22     | -0.15  | 0.01   | Variable rate              |
| 0.13          | -0.59** | -0.28  | -0.03    | -0.03  | -0.34  | Prolonged intervals        |
| 0.23          | -0.44*  | -0.31  | 0.06     | 0.21   | -0.00  | Inappropriate silences     |
| -0.16         | -0.22   | -0.21  | 0.02     | -0.23  | 0.26   | Short rushes of speech     |
| -0.32         | -0.27   | -0.36* | -0.11    | 0.05   | 0.07   | Fluency                    |





| Fluency |                            |
|---------|----------------------------|
|         | Intelligibility            |
| -0.29   | Forced ins/expiration      |
| 0.16    | Audible inspiration        |
| -0.26   | Breathiness                |
| 0.03    | Roughness                  |
| -0.21   | Strain                     |
| 0.07    | Pitch                      |
| 0.05    | Loudness                   |
| -0.11   | PCC                        |
| -0.36*  | PVC                        |
| -0.27   | Hypernasality              |
| -0.32   | Hyponasality               |
| 0.17    | Nasal Emission             |
| 0.01    | Excess Stress              |
| 0.39*   | Reduced Stress             |
| 0.05    | Rate                       |
| 0.08    | Short phrases              |
| -0.07   | Increased rate in segments |
| 0.18    | Increased rate overall     |
| -0.33   | Variable rate              |
| 0.21    | Prolonged intervals        |
| 0.41*   | Inappropriate silences     |
| 0.26    | Short rushes of speech     |
| 0.17    | Fluency                    |

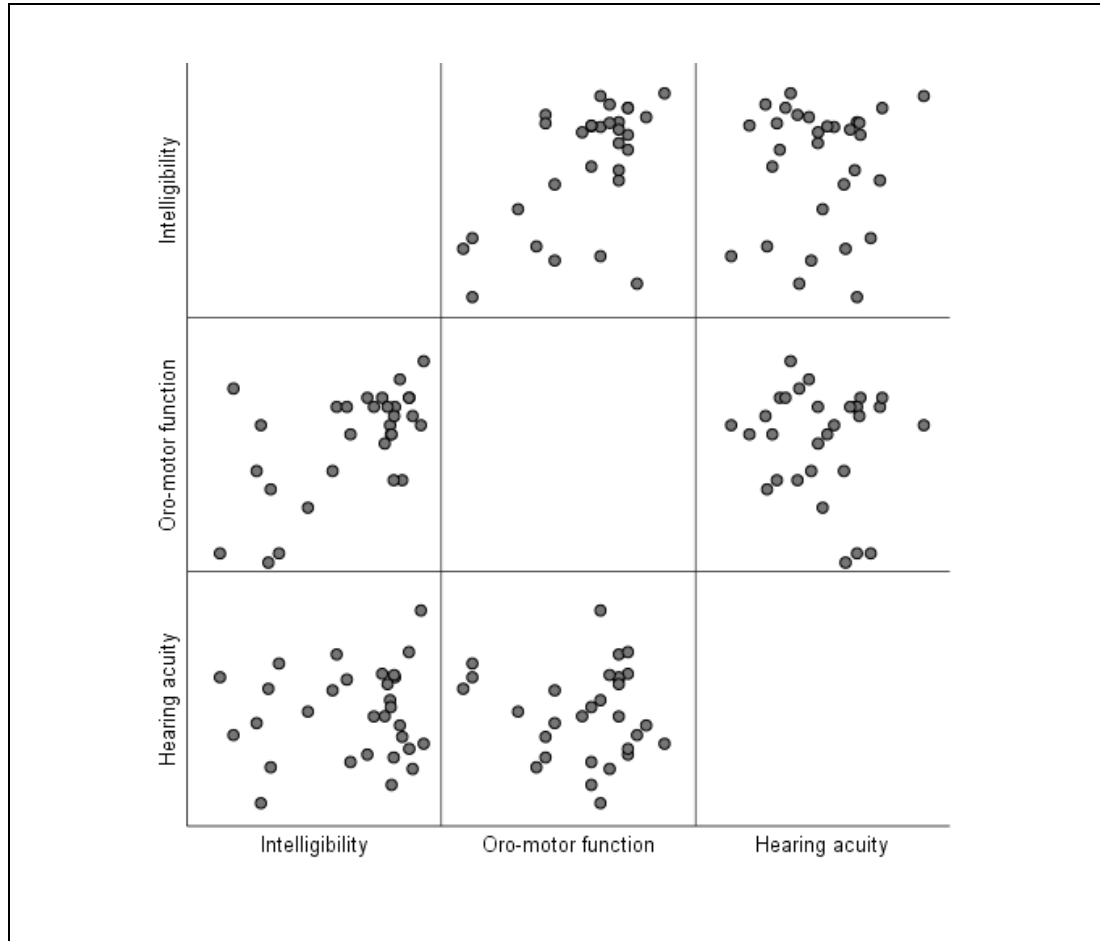
Note. \* $p < .05$ . \*\* $p < .01$ . \*\*\* $p < .001$ .



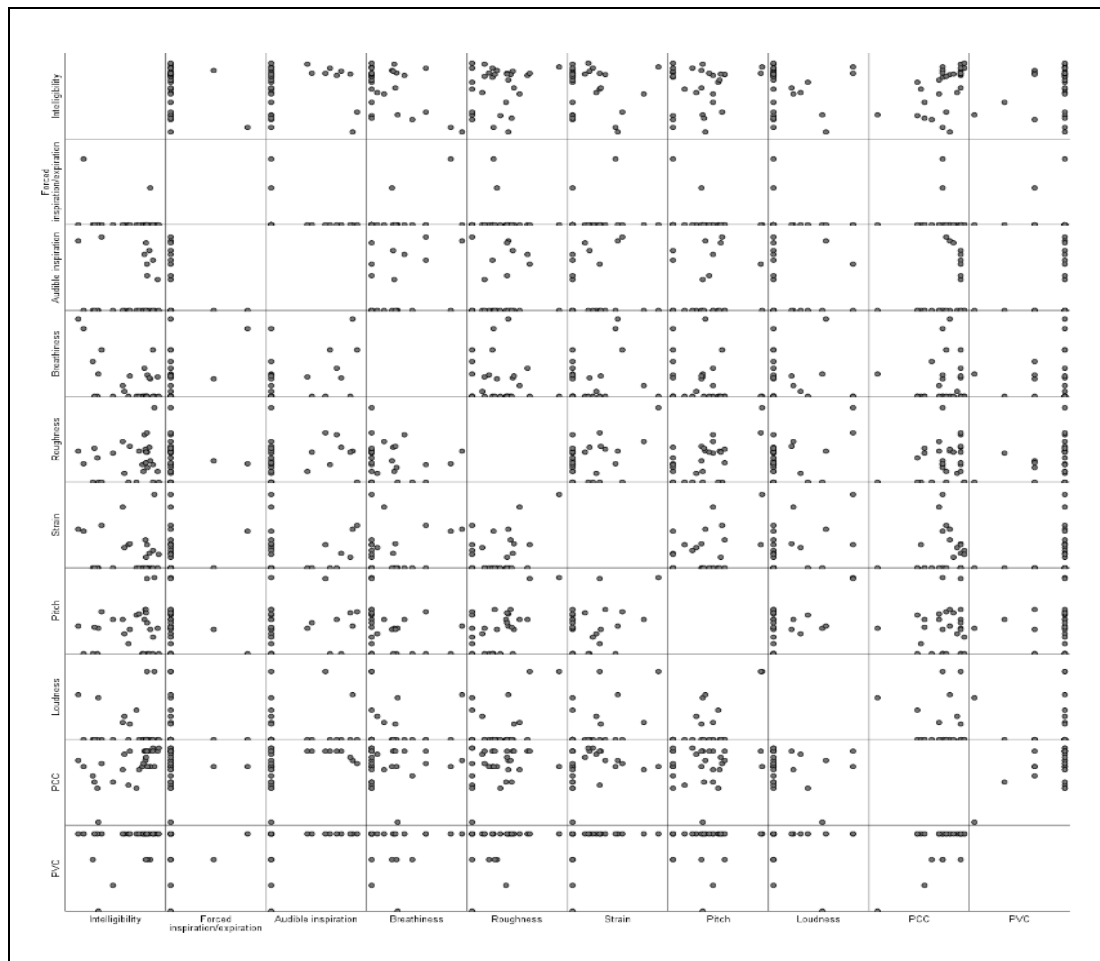
## Appendix H

### Scatterplots showing relationship between each perceptual parameter and speech intelligibility in Study 1

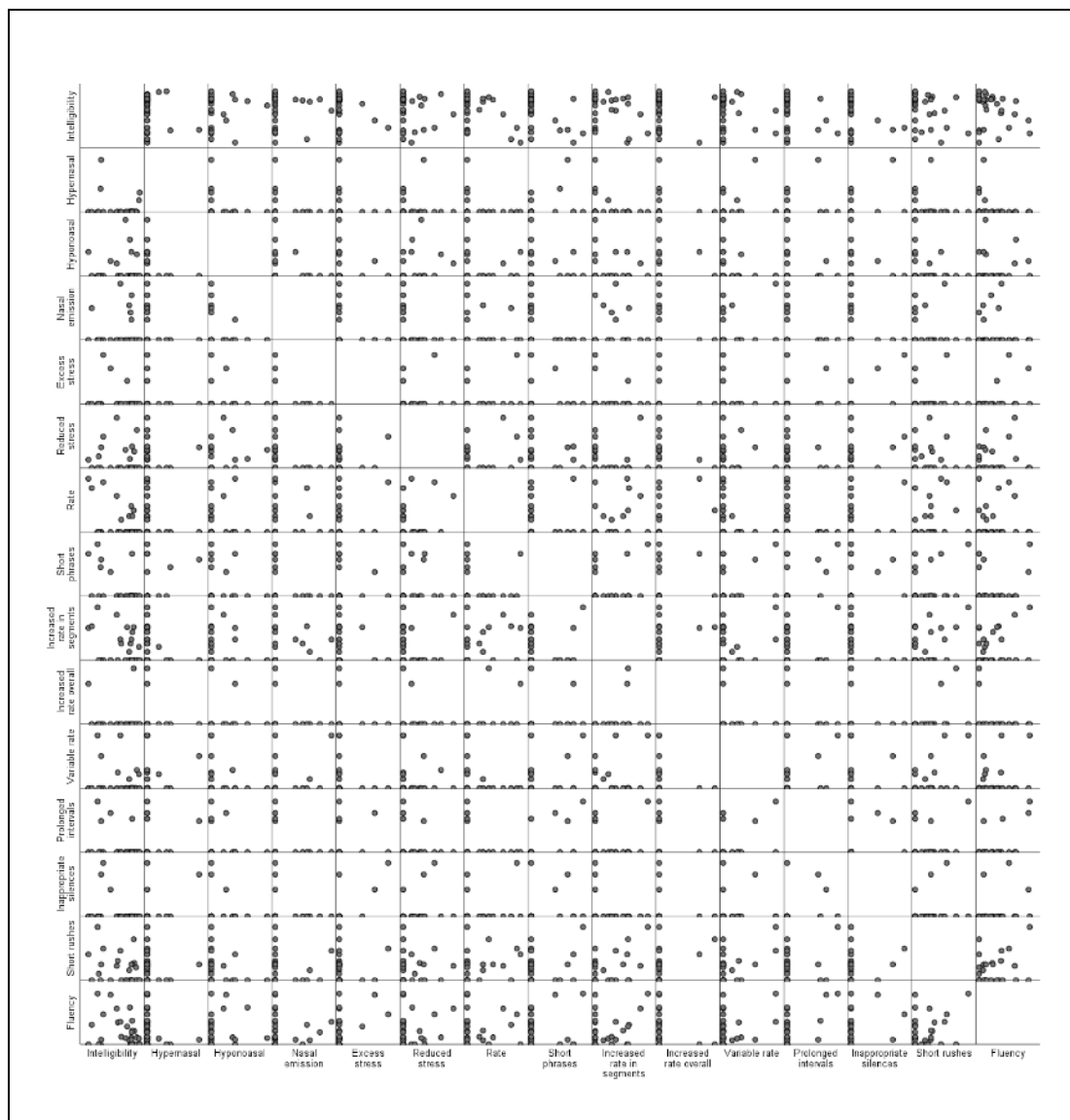
Intelligibility, hearing acuity, oro-motor function



## Parameters pertaining to respiration, phonation, and articulation



## Parameters pertaining to resonance and prosody



## Appendix I

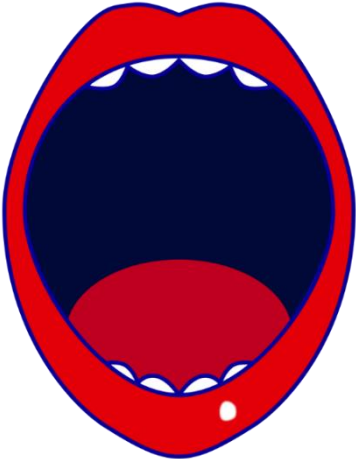
### Percentage agreement scores between the first and second investigator for each acoustic parameter in Study 1

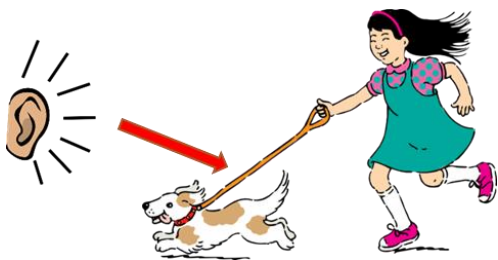
| Variable                       | Percentage agreement |
|--------------------------------|----------------------|
| Respiration                    |                      |
| Forced inspiration/ expiration | 66%                  |
| Audible inspiration            | 100%                 |
| Grunt at end of expiration     | 100%                 |
| Phonation                      |                      |
| Breathiness                    | 83%                  |
| Roughness                      | 53%                  |
| Strain                         | 86%                  |
| Pitch                          | 98%                  |
| Loudness                       | 47%                  |
| Articulation                   |                      |
| PCC < 100                      | 99%                  |
| PVC < 100                      | 100%                 |
| Resonance                      |                      |
| Hypernasality                  | 100%                 |
| Hyponasality                   | 73%                  |
| Nasal emission                 | 100%                 |
| Prosody                        |                      |
| Excess and equal stress        | 46%                  |
| Reduced stress                 | 50%                  |
| Rate slow/fast                 | 55%                  |
| Short phrases                  | 85%                  |
| Increased rate in segments     | 67%                  |
| Increased rate overall         | 90%                  |
| Variable rate                  | 61%                  |
| Prolonged intervals            | 100%                 |
| Inappropriate silences         | 100%                 |
| Short rushes of speech         | 95%                  |
| Fluency                        | 93%                  |

## Appendix J

### Visual cues for speech elicitation tasks

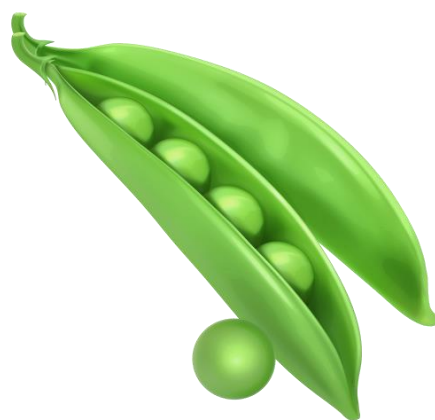
Prolonged vowels

|        |                                                                                     |
|--------|-------------------------------------------------------------------------------------|
| eeeeee |   |
| ahhh   |  |

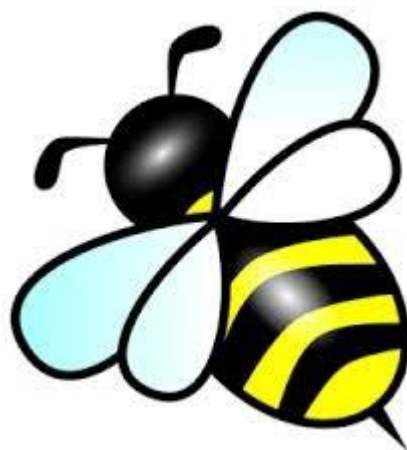
|       |                                                                                      |
|-------|--------------------------------------------------------------------------------------|
| heed  |    |
| hod   |   |
| who'd |  |
| had   |  |

Plosives /p/, /b/, /t/, /d/, /k/, /g/

pea



bee



tea



dee



key



gee





see

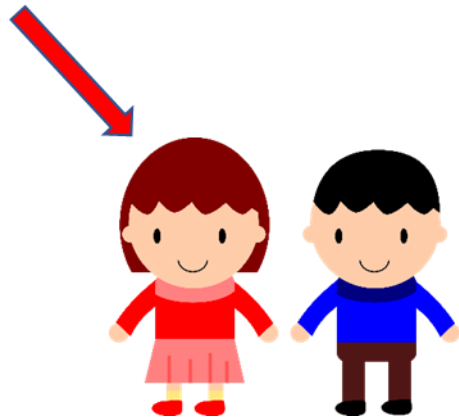
c



fee



she

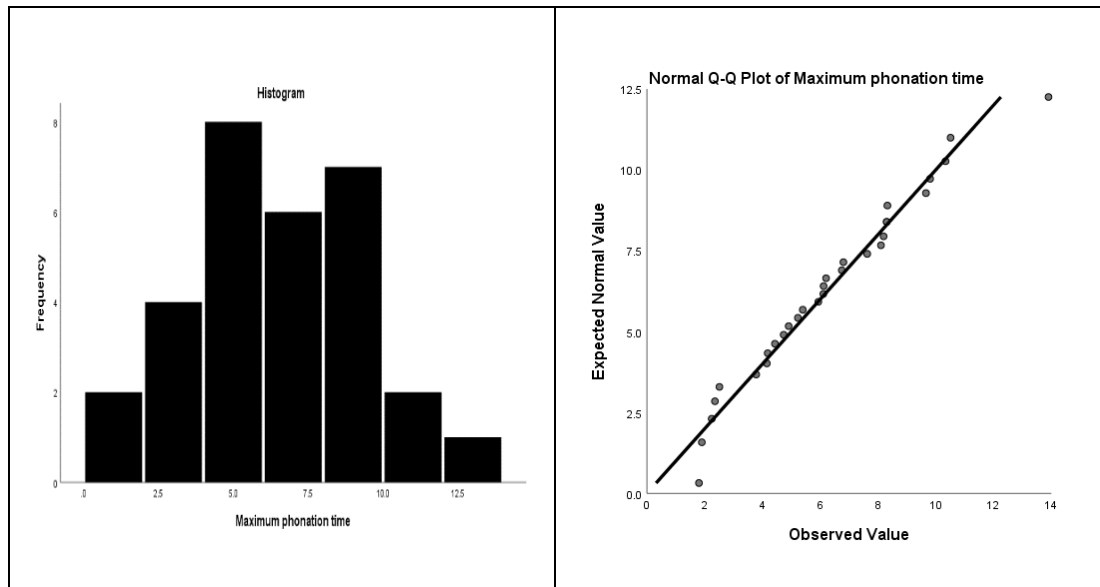


## Appendix K

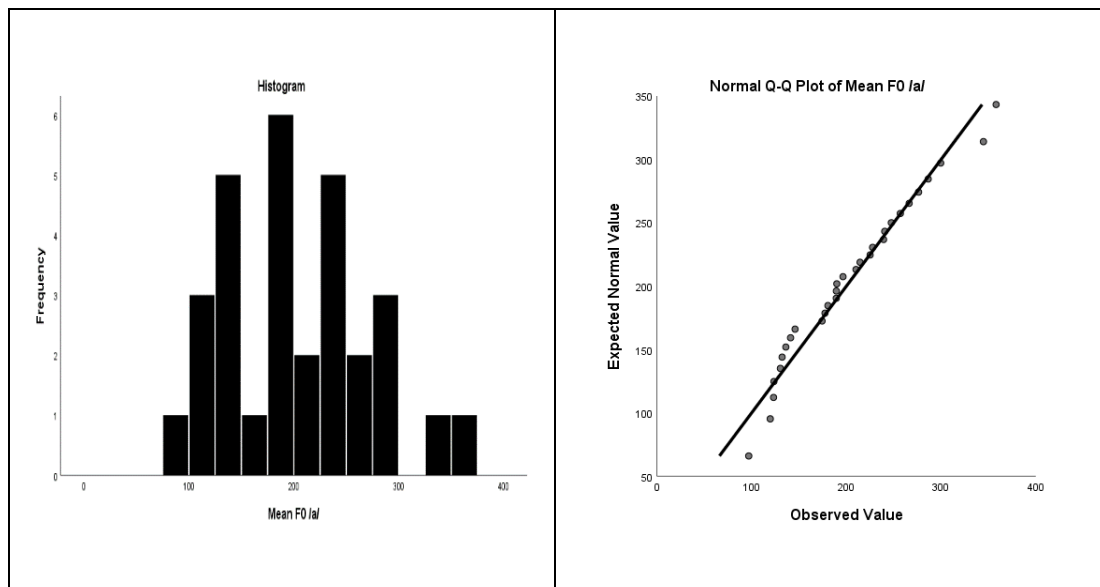
### Histograms and Q-Q plots for each acoustic parameter in Study 2

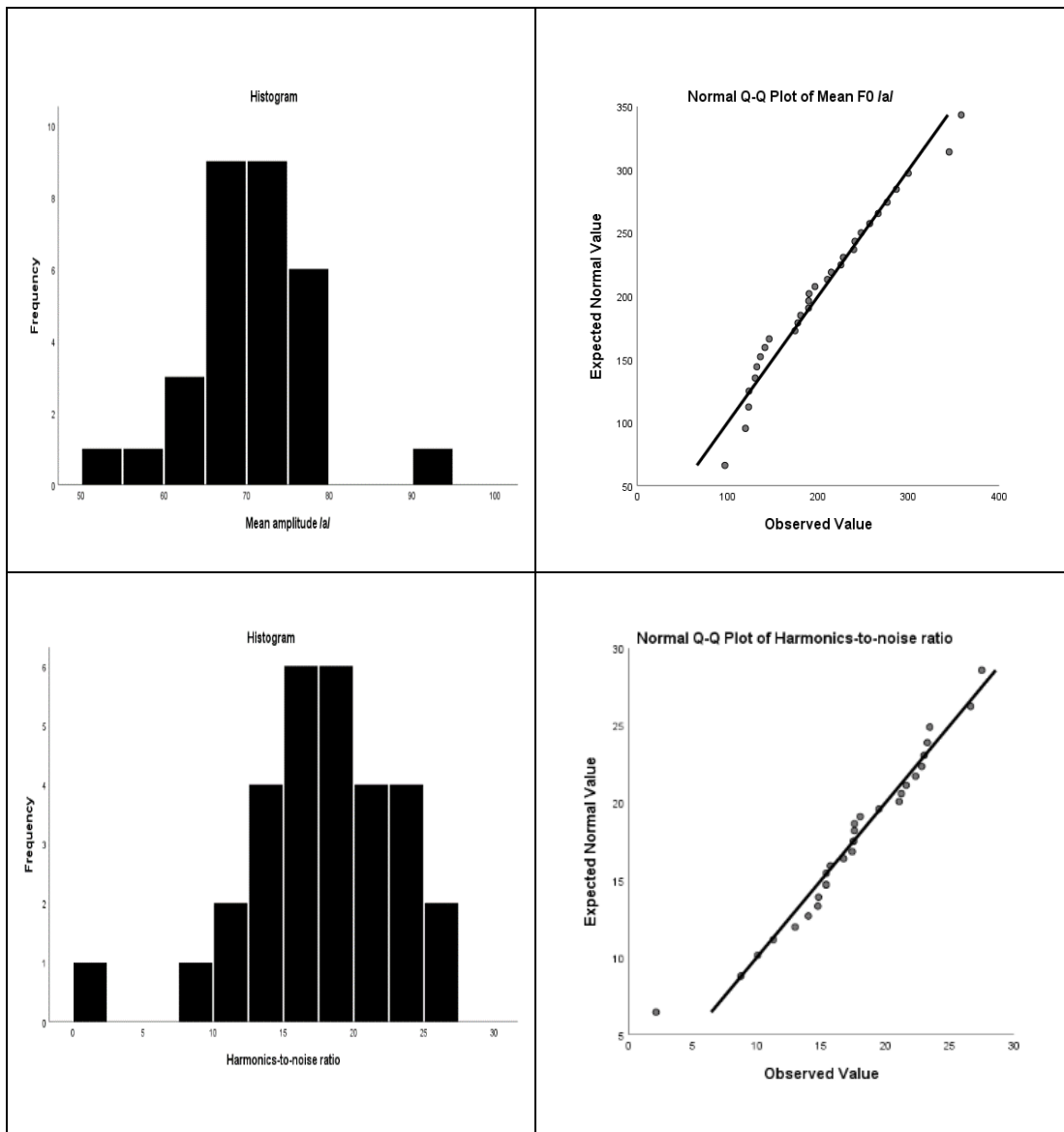
#### Speakers with DS

##### Respiration

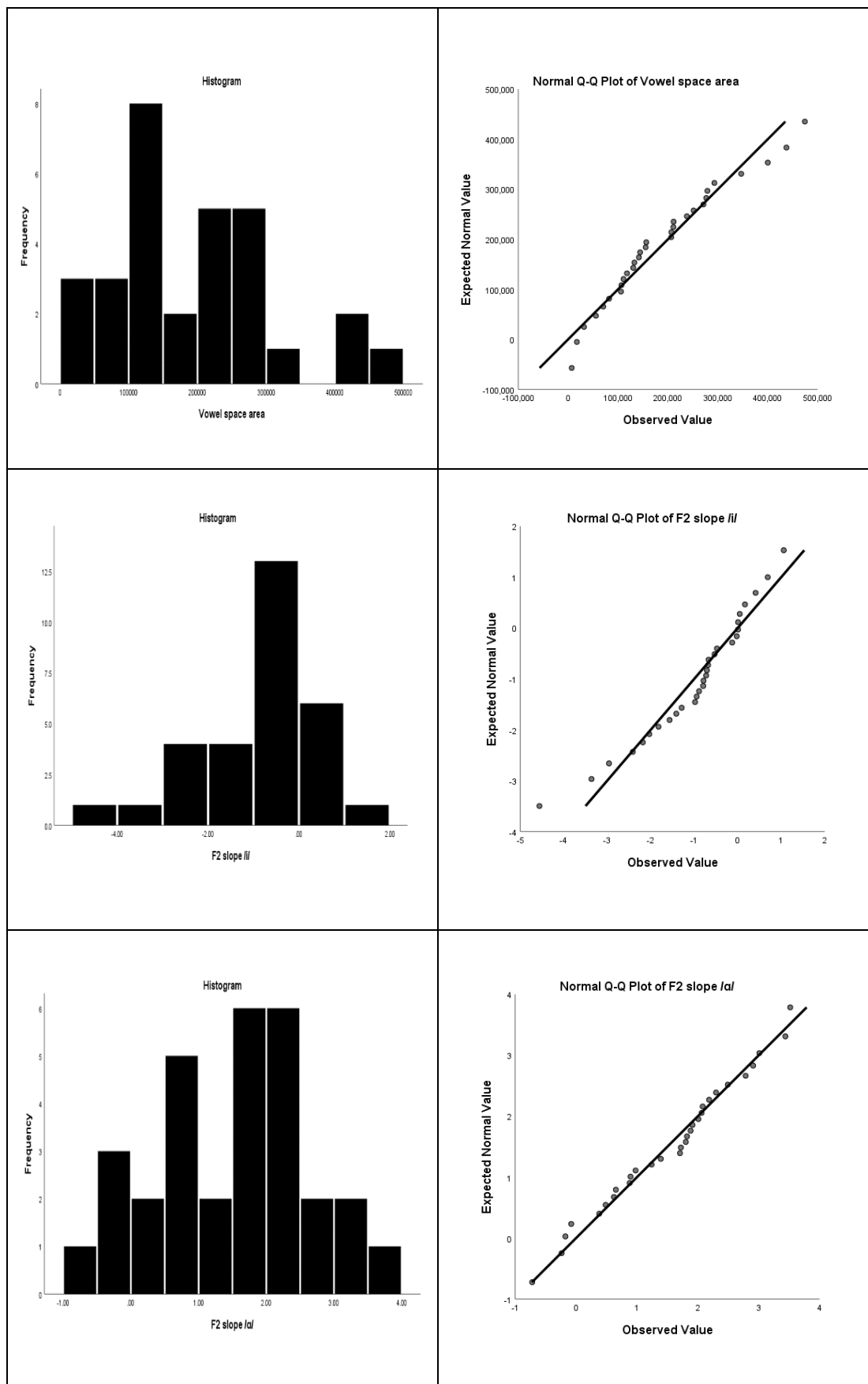


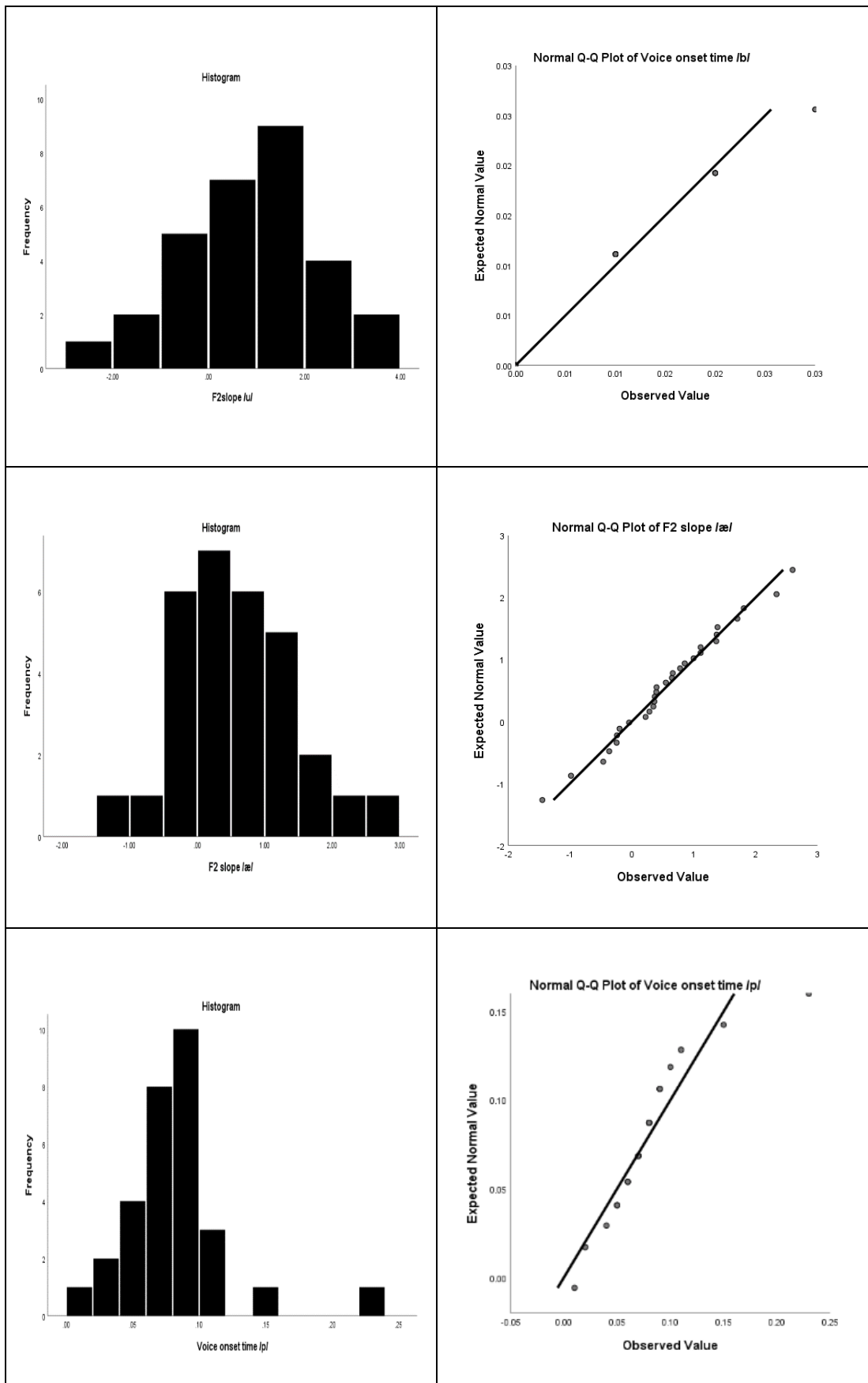
##### Phonation

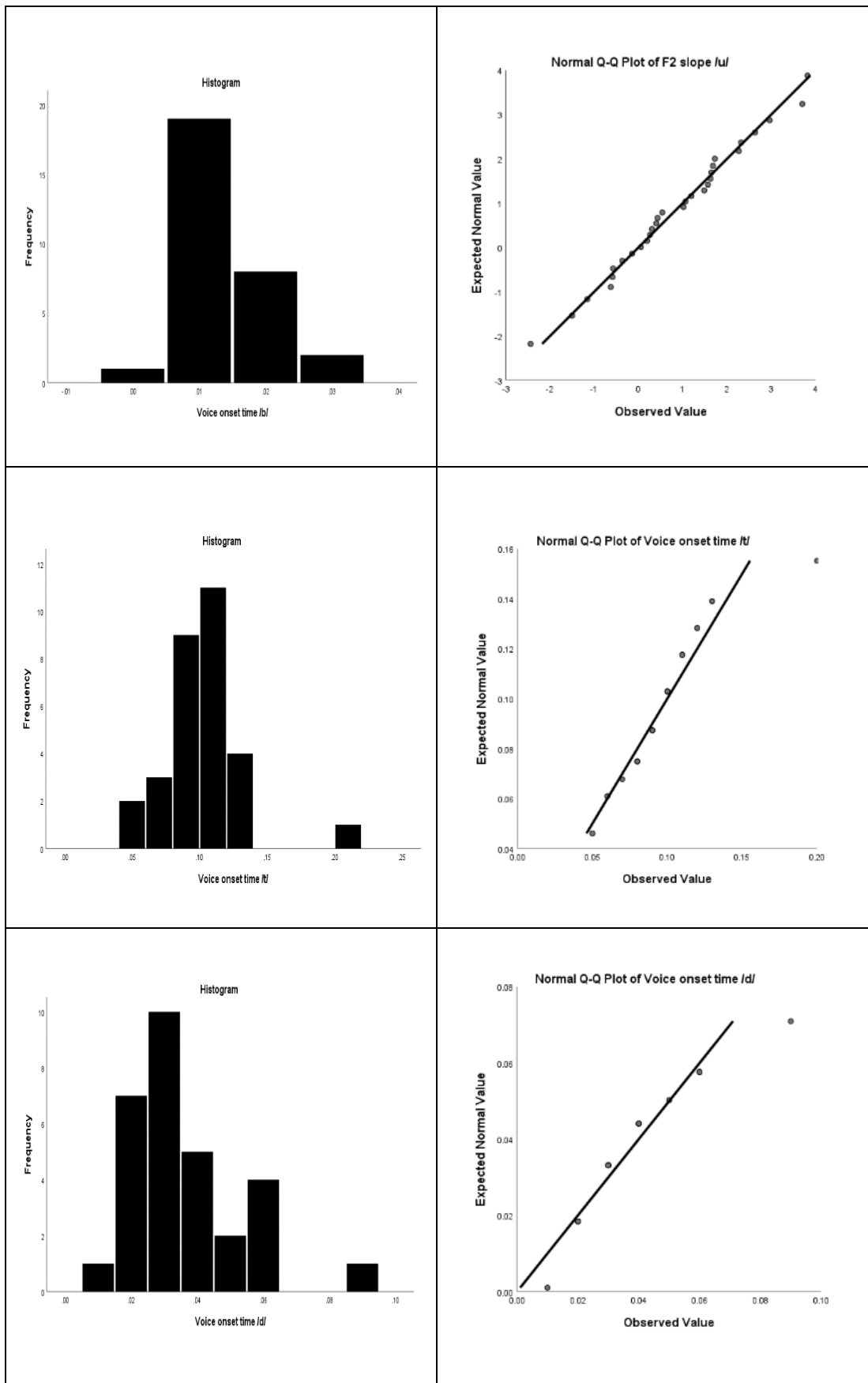


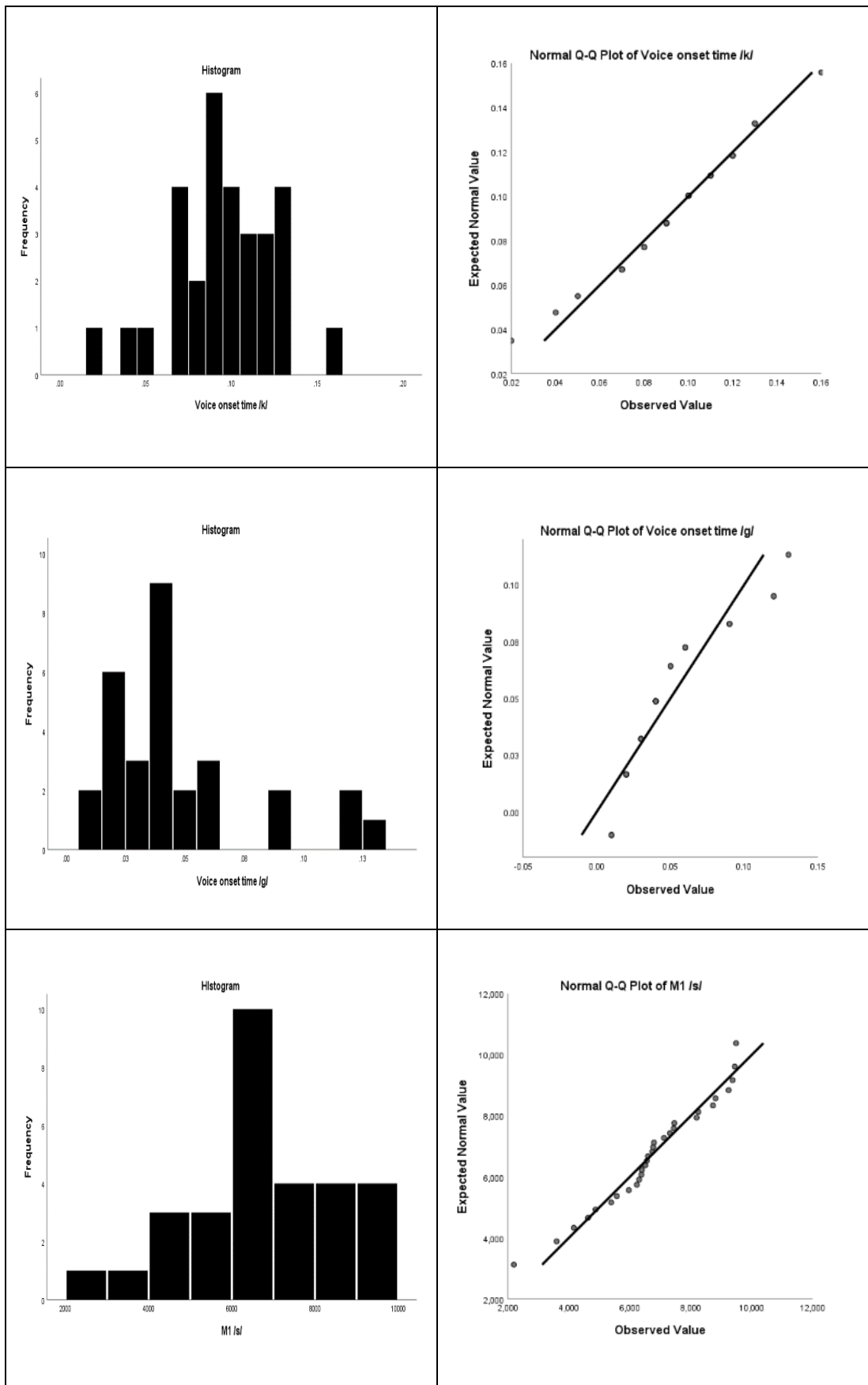


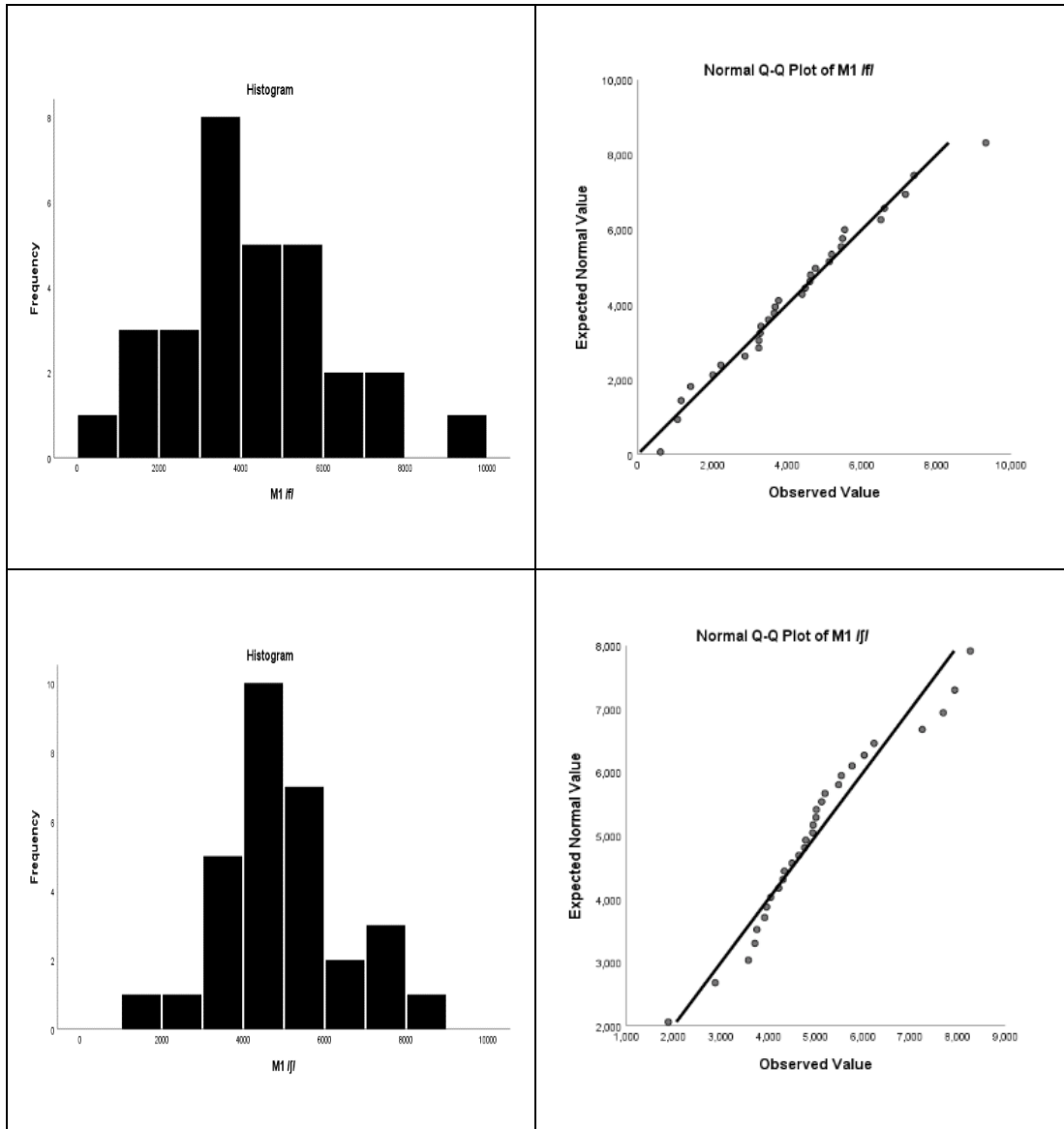
## Articulation





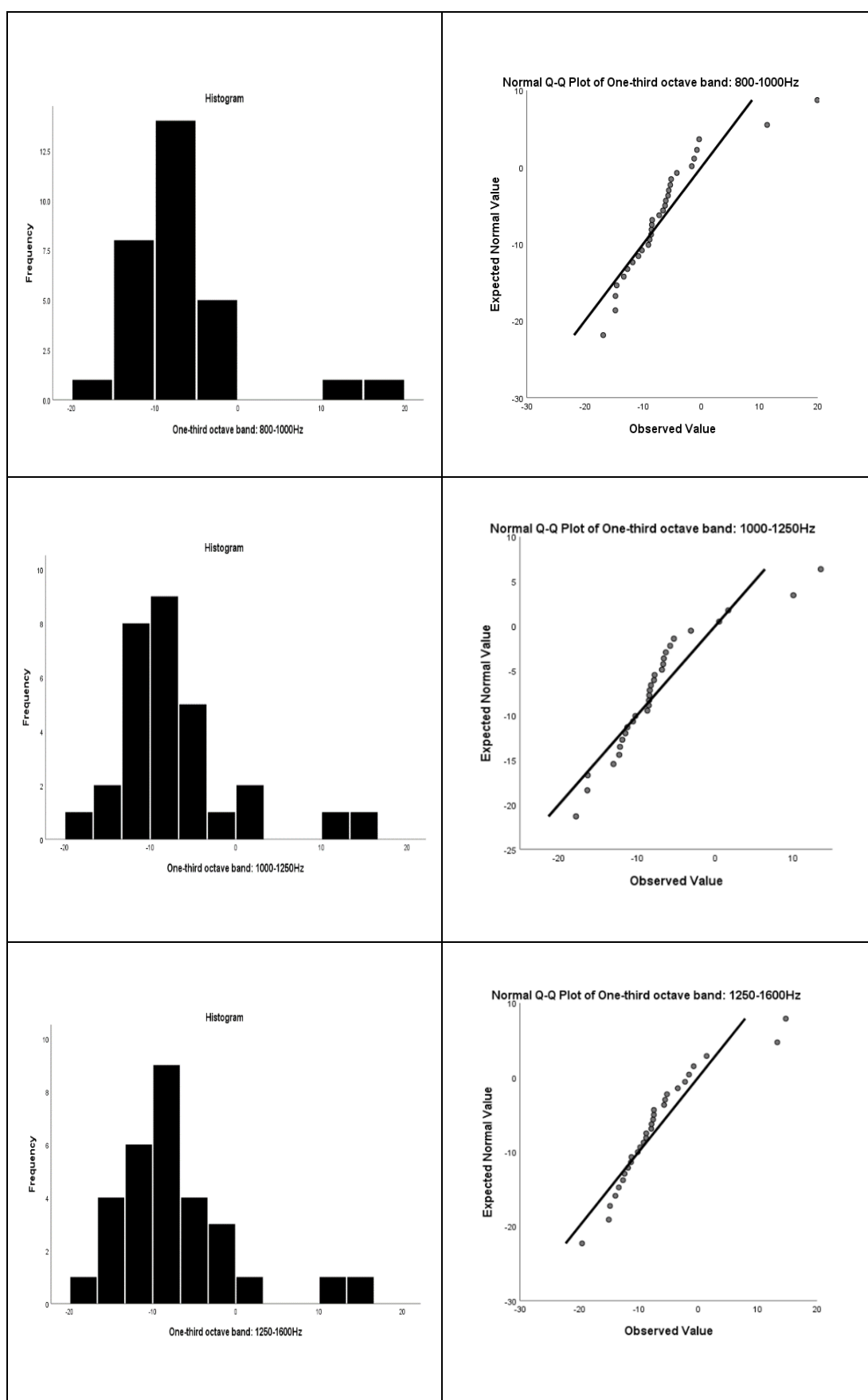


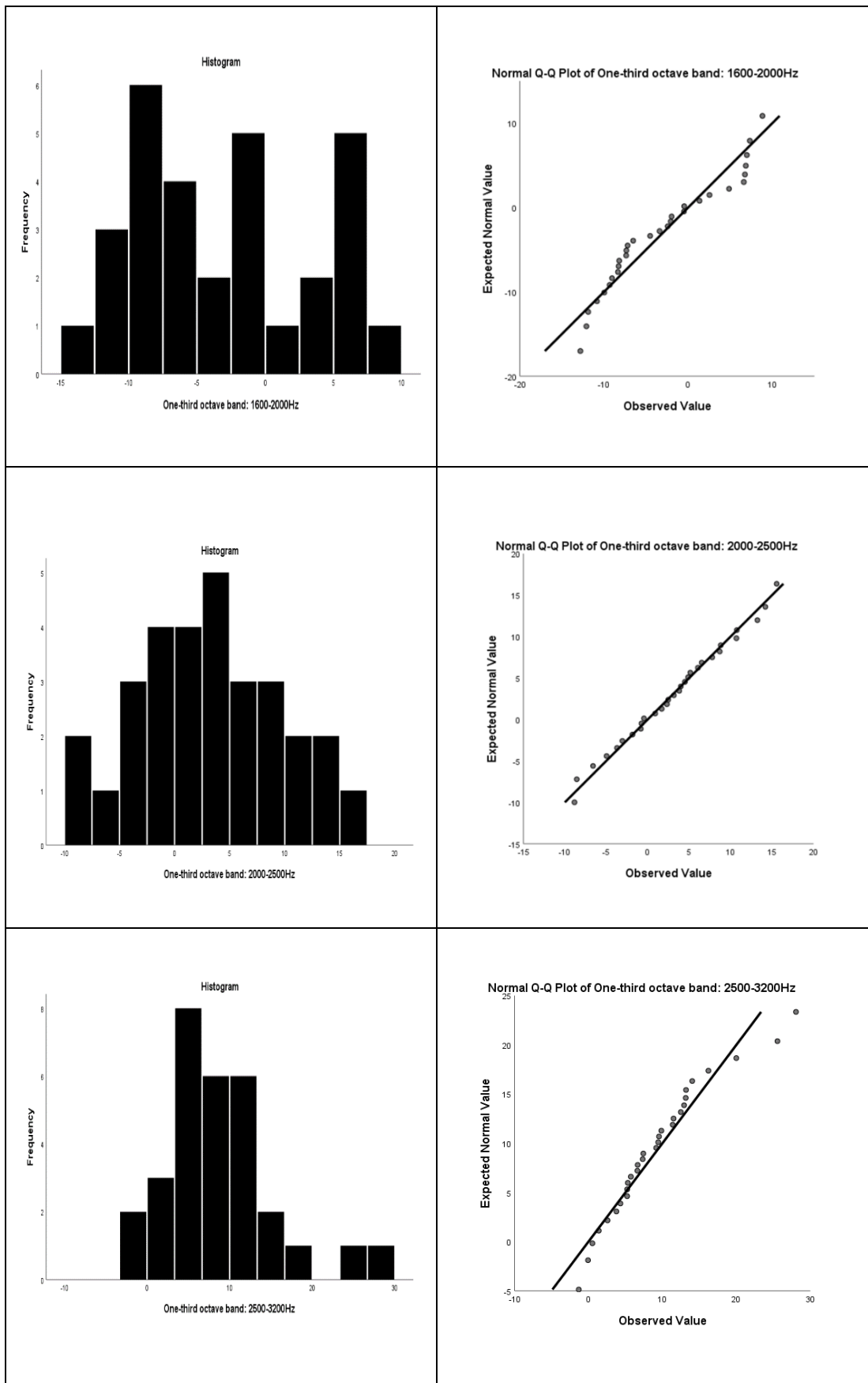




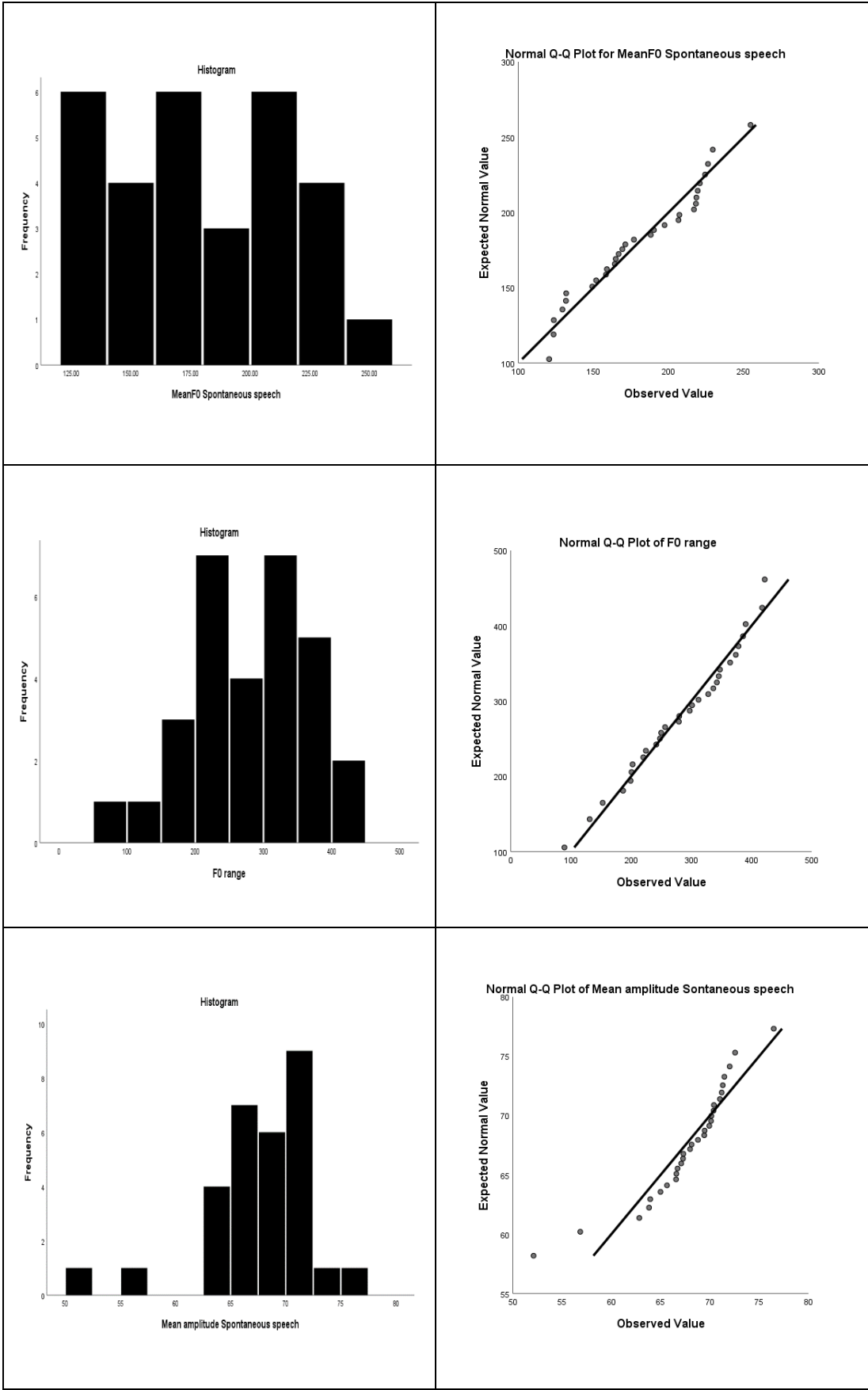


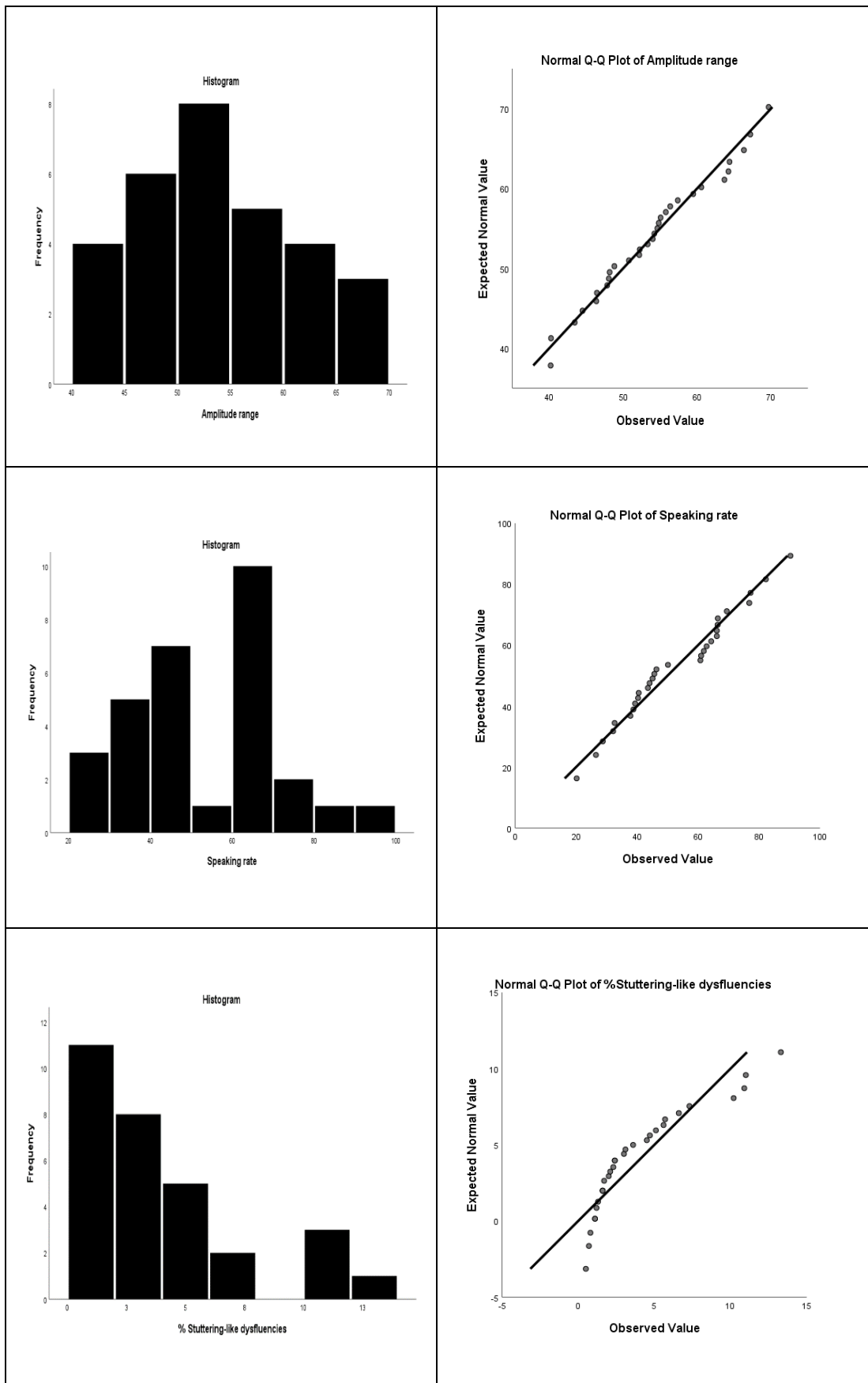
## Resonance





Prosody

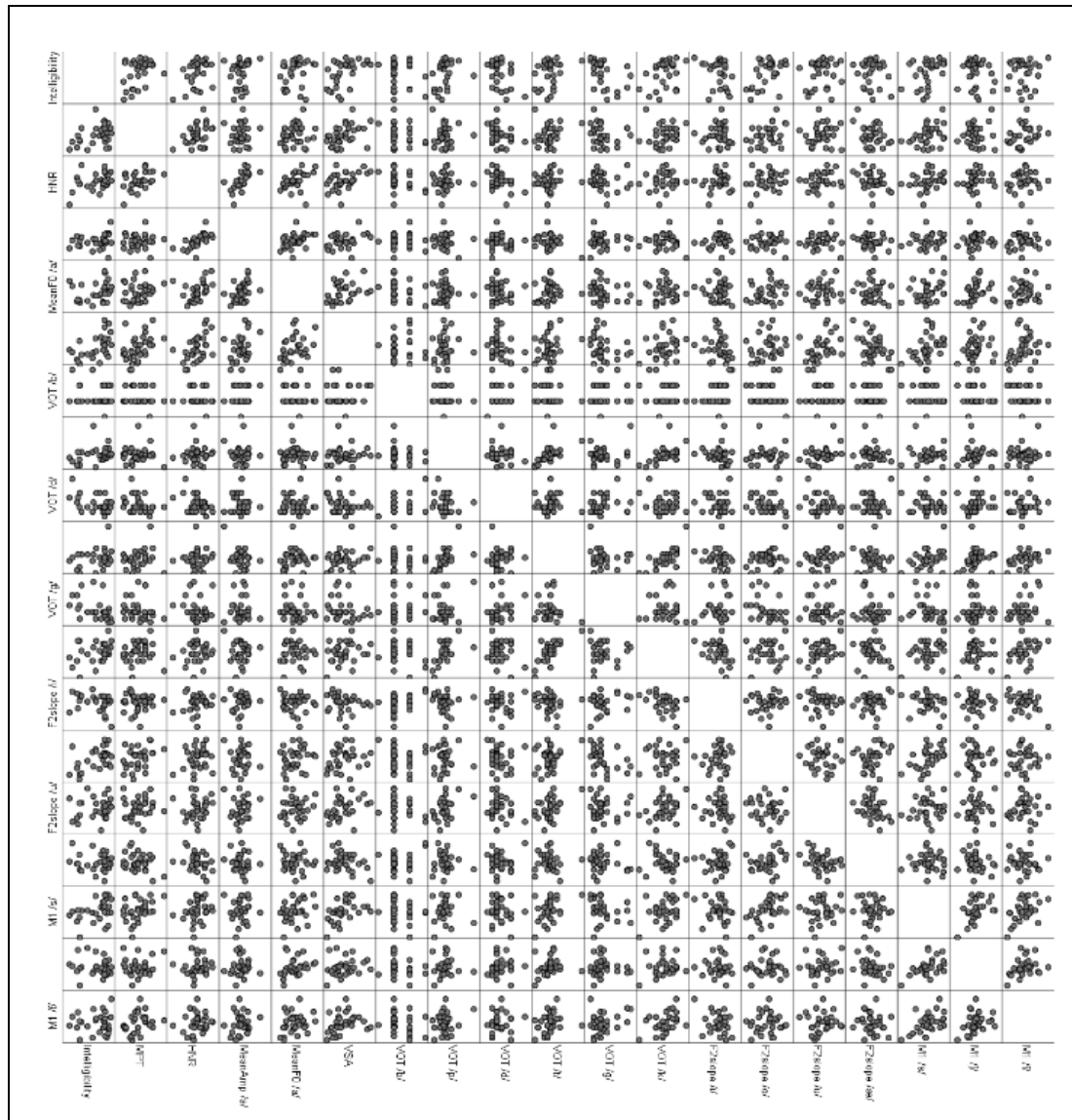




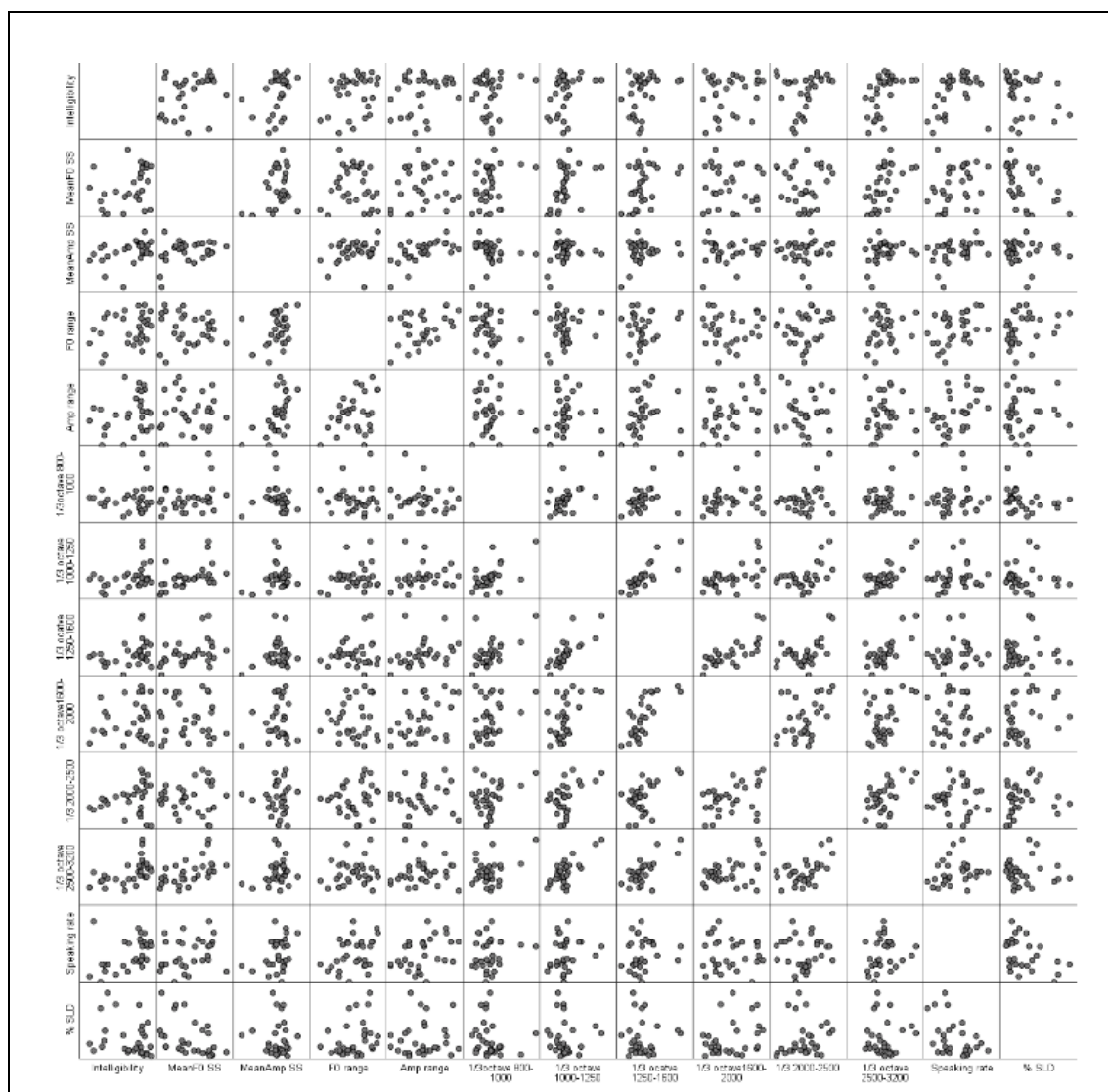
## Appendix L

### Scatterplots showing the relationship between each acoustic parameter and speech intelligibility in Study 2

Respiration, phonation, and articulation



## Resonance and prosody



## Appendix M

### Spearman rank-order correlations between acoustic parameters for Study 2

| VSA     | HNR    | Mean amp /a/ | Mean F0 /a/ | MPT   | Intelligibility | Intelligibility |
|---------|--------|--------------|-------------|-------|-----------------|-----------------|
| 0.44*   | 0.39*  | 0.33         | 0.28        | 0.26  | Intelligibility |                 |
| 0.43*   | 0.45*  | 0.01         | 0.14        |       | MPT             | 0.26            |
| 0.35    | 0.49** | 0.48**       |             | 0.14  | Mean F0 /a/     | 0.28            |
| 0.31    | 0.72** |              | 0.48**      | 0.13  | Mean amp /a/    | 0.33            |
| 0.45*   |        | 0.72**       | 0.49**      | 0.45* | HNR             | 0.39*           |
|         | 0.45*  | 0.31         | 0.35        | 0.43* | VSA             | 0.44*           |
| 0.01    | 0.06   | -0.11        | -0.27       | 0.01  | VOT /p/         | 0.35            |
| -0.01   | -0.23  | 0.04         | 0.05        | -0.18 | VOT /b/         | -0.01           |
| 0.16    | 0.13   | -0.07        | 0.18        | 0.17  | VOT /t/         | 0.20            |
| -0.16   | -0.21  | -0.01        | -0.03       | -0.37 | VOT /d/         | -0.35           |
| 0.19    | 0.13   | -0.05        | 0.02        | 0.24  | VOT /k/         | 0.34            |
| -0.29   | -0.25  | -0.01        | -0.13       | -0.26 | VOT /g/         | -0.59           |
| -0.29   | 0.08   | 0.11         | -0.09       | 0.01  | F2slope /i/     | -0.32           |
| 0.18    | 0.19   | 0.07         | 0.13        | 0.34  | F2slope /a/     | 0.33            |
| 0.37*   | 0.18   | 0.19         | 0.14        | 0.21  | F2slope /u/     | 0.15            |
| -0.14   | -0.30  | -0.17        | -0.03       | -0.23 | F2slope /æ/     | 0.02            |
| 0.55**  | 0.34   | 0.16         | 0.29        | 0.32  | M1 /s/          | 0.38*           |
| 0.24    | 0.22   | 0.16         | 0.26        | 0.37* | M1 /f.          | -0.05           |
| 0.40*   | 0.16   | 0.07         | 0.45*       | -0.05 | M1 /j/          | -0.13           |
| -0.08   | 0.03   | 0.14         | 0.46*       | -0.03 | 1/3:800-1000Hz  | 0.08            |
| 0.48**  | 0.32   | 0.52**       | 0.62**      | 0.04  | 1/3:1000-1250Hz | 0.36            |
| 0.28    | 0.35   | 0.65**       | 0.54**      | 0.03  | 1/3:1250-1600Hz | 0.34            |
| 0.08    | 0.37*  | 0.59**       | 0.22        | -0.12 | 1/3:1600-2000Hz | 0.16            |
| 0.08    | 0.18   | 0.26         | 0.18        | -0.27 | 1/3:2000-2500Hz | 0.31            |
| 0.48*** | 0.46*  | 0.55**       | 0.52**      | 0.15  | 1/3:2500-3200Hz | 0.64**          |
| 0.36    | 0.22   | 0.20         | 0.69**      | 0.11  | Mean F0 SS      | 0.39*           |
| 0.13    | -0.03  | 0.18         | -0.15       | 0.02  | F0 range        | 0.25            |
| 0.78**  | 0.26   | 0.18         | 0.02        | 0.35  | Mean amp SS     | 0.40*           |
| 0.16    | 0.20   | 0.49**       | 0.13        | 0.11  | Amp range       | 0.20            |
| 0.19    | 0.10   | 0.18         | 0.18        | 0.39* | Speaking rate   | 0.45*           |
| -0.17   | -0.03  | 0.08         | -0.32       | -0.30 | % SLD           | -0.31           |

| F2slope /a/ | F2slope /i/ | VOT /g/ | VOT /k/ | VOT /d/ | VOT /t/ | VOT /b/ |                 |
|-------------|-------------|---------|---------|---------|---------|---------|-----------------|
| -0.32       | -0.594**    | 0.34    | -0.35   | 0.19    | -0.01   | 0.35    | Intelligibility |
| 0.01        | -0.259      | 0.24    | -0.37*  | 0.17    | -0.18   | 0.01    | MPT             |
| -0.09       | -0.130      | 0.02    | -0.03   | 0.18    | -0.27   | 0.05    | Mean F0 /a/     |
| 0.11        | -0.007      | -0.05   | -0.02   | -0.07   | 0.04    | -0.11   | Mean amp /a/    |
| 0.08        | -0.254      | 0.13    | -0.21   | 0.13    | -0.23   | 0.058   | HNR             |
| -0.29       | -0.288      | 0.19    | -0.16   | 0.16    | -0.01   | 0.01    | VSA             |
| -0.19       | 0.052       | 0.54**  | -0.12   | 0.69**  | -0.17   |         | VOT /p/         |
| 0.30        | 0.057       | -0.07   | -0.03   | -0.24   |         | -0.17   | VOT /b/         |
| -0.28       | 0.034       | 0.66**  | 0.21    |         | -0.24   | 0.69**  | VOT /t/         |
| -0.11       | 0.189       | 0.01    |         | 0.21    | -0.03   | -0.12   | VOT /d/         |
| -0.39*      | -0.003      |         | 0.01    | 0.66**  | -0.07   | 0.54**  | VOT /k/         |
| 0.05        |             | -0.00   | 0.19    | 0.03    | 0.06    | 0.05    | VOT /g/         |
|             | 0.049       | -0.39*  | -0.11   | -0.28   | 0.30    | -0.19   | F2slope /i/     |
| 0.14        | -0.398*     | -0.06   | -0.26   | 0.15    | -0.10   | 0.04    | F2slope /a/     |
| -0.18       | 0.005       | 0.30    | -0.10   | 0.35    | -0.13   | 0.24    | F2slope /u/     |
| 0.15        | -0.149      | -0.21   | -0.12   | -0.22   | -0.02   | -0.11   | F2slope /æ/     |
| -0.19       | -0.297      | 0.22    | -0.07   | 0.36*   | -0.26   | 0.09    | M1 /s/          |
| -0.12       | 0.127       | 0.14    | 0.35    | 0.42*   | -0.24   | 0.15    | M1 /f/          |
| -0.16       | 0.156       | 0.41*   | 0.19    | 0.37*   | -0.22   | 0.03    | M1 /j/          |
| 0.02        | -0.106      | 0.02    | 0.06    | -0.09   | -0.06   | -0.08   | 1/3:800-1000Hz  |
| -0.04       | -0.240      | -0.11   | 0.01    | 0.09    | -0.17   | -0.01   | 1/3:1000-1250Hz |
| -0.06       | -0.069      | -0.16   | -0.06   | -0.13   | -0.16   | -0.01   | 1/3:1250-1600Hz |
| 0.09        | 0.010       | -0.16   | 0.11    | -0.14   | -0.14   | -0.01   | 1/3:1600-2000Hz |
| -0.09       | -0.156      | -0.13   | -0.18   | -0.29   | 0.19    | 0.04    | 1/3:2000-2500Hz |
| -0.39*      | -0.305      | 0.14    | -0.25   | 0.03    | -0.03   | 0.04    | 1/3:2500-3200Hz |
| -0.26       | -0.245      | 0.07    | -0.08   | 0.18    | -0.28   | 0.04    | Mean F0 SS      |
| 0.05        | 0.058       | 0.16    | -0.51** | 0.03    | 0.24    | 0.27    | F0 range        |
| -0.15       | -0.194      | 0.08    | -0.25   | -0.10   | -0.23   | -0.08   | Mean amp SS     |
| 0.13        | 0.067       | -0.24   | -0.09   | -0.19   | -0.12   | -0.17   | Amp range       |
| -0.02       | -0.049      | 0.24    | -0.21   | 0.21    | 0.19    | 0.17    | Speaking rate   |
| 0.0         | 0.335       | -0.39*  | -0.19   | -0.32   | 0.03    | -0.12   | % SLD           |



| 1/3: 1000- | 1/3: 800-1000Hz | M1 /f/ | M1 /j/  | M1 /s/ | F2slope /æ/ | F2slope /u/ |                 |
|------------|-----------------|--------|---------|--------|-------------|-------------|-----------------|
| 0.36       | 0.08            | -0.05  | 0.38*   | 0.02   | 0.15        | 0.33        | Intelligibility |
| 0.04       | -0.03           | 0.37*  | 0.32    | -0.23  | 0.21        | 0.34        | MPT             |
| 0.62**     | 0.46*           | 0.26   | 0.29    | -0.03  | 0.14        | 0.13        | Mean F0 /a/     |
| 0.52**     | 0.14            | 0.07   | 0.16    | -0.17  | 0.19        | 0.07        | Mean amp /a/    |
| 0.32       | 0.03            | 0.16   | 0.35    | -0.30  | 0.18        | 0.19        | HNR             |
| 0.48**     | -0.08           | 0.40*  | 0.55**  | -0.14  | 0.37*       | 0.18        | VSA             |
| -0.01      | -0.08           | 0.03   | 0.09    | -0.11  | 0.24        | 0.04        | VOT /p/         |
| -0.17      | -0.06           | -0.22  | -0.26   | -0.02  | -0.13       | -0.12       | VOT /b/         |
| 0.09       | -0.09           | 0.37*  | 0.36*   | -0.22  | 0.35        | 0.15        | VOT /t/         |
| 0.01       | 0.06            | 0.19   | -0.07   | -0.12  | -0.10       | -0.26       | VOT /d/         |
| -0.11      | 0.02            | 0.41*  | 0.22    | -0.21  | 0.30        | -0.06       | VOT /k/         |
| -0.24      | -0.11           | 0.16   | -0.29   | -0.15  | 0.01        | -0.39*      | VOT /g/         |
| -0.04      | 0.02            | -0.16  | -0.19   | 0.15   | -0.18       | 0.14        | F2slope /i/     |
| 0.13       | -0.15           | 0.02   | 0.472** | 0.32   | -0.16       | -0.12       | F2slope /ɑ/     |
| 0.04       | -0.24           | 0.09   | 0.12    | -0.31  | -0.16       | -0.12       | F2slope /u/     |
| -0.01      | -0.02           | -0.13  | -0.06   | -0.06  | -0.31       | 0.32        | F2slope /æ/     |
| 0.30       | -0.06           | 0.45*  | 0.52**  | -0.06  | 0.11        | 0.47**      | M1 /s/          |
| 0.25       | 0.11            | 0.40*  | 0.45*   | -0.25  | 0.17        | 0.01        | M1 /f/          |
| 0.19       | 0.13            |        | 0.45*   | -0.13  | 0.09        | 0.02        | M1 /j/          |
| 0.46*      |                 |        | -0.06   | -0.02  | -0.24       | -0.15       | 1/3:800-1000Hz  |
|            | 0.46*           | 0.13   | 0.30    | -0.01  | 0.04        | 0.13        | 1/3:1000-1250Hz |
| 0.79**     | 0.47**          | 0.19   | 0.05    | 0.01   | 0.08        | 0.11        | 1/3:1250-1600Hz |
| 0.54**     | 0.32            | -0.02  | -0.07   | -0.09  | 0.06        | -0.20       | 1/3:1600-2000Hz |
| 0.34       | 0.20            | -0.02  | 0.03    | -0.03  | -0.27       | -0.12       | 1/3:2000-2500Hz |
| 0.52***    | 0.13            | 0.03   | 0.42*   | -0.03  | 0.05        | 0.36        | 1/3:2500-3200Hz |
| 0.51**     | 0.28            | 0.13   | 0.37*   | 0.11   | -0.00       | 0.48**      | Mean F0 SS      |
| 0.09       | -0.21           | 0.02   | -0.08   | 0.12   | 0.27        | -0.06       | F0 range        |
| 0.09       | -0.36           | 0.33   | 0.40*   | 0.14   | 0.04        | 0.27        | Mean amp SS     |
| 0.31       | -0.09           | 0.19   | 0.18    | 0.12   | 0.03        | 0.33        | Amp range       |
| 0.22       | 0.13            | 0.27   | 0.06    | 0.18   | -0.12       | 0.42*       | Speaking rate   |
| -0.18      | -0.31           | -0.25  | -0.21   | -0.06  | 0.13        | -0.42*      | % SLD           |

| Mean amp SS | F0 range | Mean F0 SS | 1/3: 2500- | 1/3: 2000- | 1/3: 1600- | 1/3: 1250- |                 |
|-------------|----------|------------|------------|------------|------------|------------|-----------------|
| 0.40*       | 0.25     | 0.39*      | .064**     | 0.32       | 0.16       | 0.34       | Intelligibility |
| 0.35        | 0.02     | 0.11       | 0.15       | -0.27      | -0.12      | 0.03       | MPT             |
| 0.02        | -0.15    | 0.69**     | 0.52**     | 0.18       | 0.22       | 0.54**     | Mean F0 /a/     |
| 0.18        | 0.18     | 0.20       | 0.55**     | 0.26       | 0.59**     | 0.65**     | Mean amp /a/    |
| 0.26        | -0.03    | 0.22       | 0.46*      | 0.18       | 0.37*      | 0.35       | HNR             |
| 0.48**      | 0.13     | 0.36       | 0.48**     | 0.08       | 0.08       | 0.28       | VSA             |
| -0.08       | 0.27     | 0.04       | 0.04       | 0.04       | -0.01      | -0.01      | VOT /p/         |
| -0.23       | 0.24     | -0.28      | -0.03      | 0.19       | -0.14      | -0.16      | VOT /b/         |
| -0.10       | 0.03     | 0.18       | 0.03       | -0.29      | -0.14      | -0.13      | VOT /t/         |
| -0.25       | -0.51**  | -0.08      | -0.25      | -0.18      | 0.11       | -0.06      | VOT /d/         |
| 0.08        | 0.16     | 0.07       | 0.14       | -0.13      | -0.16      | -0.16      | VOT /k/         |
| -0.19       | 0.06     | -0.25      | -0.31      | -0.16      | 0.01       | -0.07      | VOT /g/         |
| -0.15       | 0.05     | -0.26      | -0.39*     | -0.09      | 0.09       | -0.06      | F2slope /i/     |
| 0.27        | -0.06    | 0.48**     | 0.35       | -0.12      | -0.20      | 0.11       | F2slope /a/     |
| 0.04        | 0.27     | -0.00      | 0.05       | -0.27      | 0.06       | 0.08       | F2slope /u/     |
| 0.14        | 0.12     | 0.12       | -0.03      | -0.03      | -0.09      | 0.01       | F2slope /æ/     |
| 0.40*       | -0.07    | 0.37*      | 0.42*      | 0.03       | -0.07      | 0.05       | M1 /s/          |
| 0.05        | -0.34    | 0.31       | 0.11       | 0.07       | -0.04      | 0.09       | M1 /f/          |
| 0.33        | 0.02     | 0.13       | 0.03       | -0.20      | -0.02      | -0.02      | M1 /j/          |
| -0.36       | -0.21    | 0.28       | 0.13       | 0.20       | 0.32       | 0.47**     | 1/3:800-1000Hz  |
| 0.09        | 0.09     | 0.51**     | 0.52**     | 0.34       | .054**     | 0.79**     | 1/3:1000-1250Hz |
| 0.05        | 0.01     | 0.41*      | 0.58**     | 0.36*      | 0.72**     |            | 1/3:1250-1600Hz |
| -0.04       | 0.06     | -0.08      | 0.32       | 0.40*      |            | .721**     | 1/3:1600-2000Hz |
| 0.02        | 0.18     | 0.03       | 0.15*      |            | 0.40*      | 0.36*      | 1/3:2000-2500Hz |
| 0.24        | 0.09     | 0.61**     |            | 0.41*      | 0.32       | 0.58**     | 1/3:2500-3200Hz |
| 0.19        | -0.17    |            | 0.61**     | 0.03       | -0.08      | 0.41*      | Mean F0 SS      |
| 0.27        |          | -0.17      | 0.09       | 0.18       | 0.06       | 0.01       | F0 range        |
| 1           | 0.27     | 0.19       | 0.24       | 0.02       | -0.04      | 0.05       | Mean amp SS     |
| 0.59**      | 0.32     | 0.09       | 0.18       | 0.11       | 0.37*      | 0.42*      | Amp range       |
| 0.33        | 0.35     | 0.30       | 0.27       | -0.01      | -0.01      | 0.23       | Speaking rate   |
| -0.05       | 0.34     | -0.56**    | -0.17      | 0.26       | 0.32       | -0.07      | % SLD           |

| % SLD   | Speaking rate | Amp range |                        |
|---------|---------------|-----------|------------------------|
| -0.31   | 0.45*         | 0.20      | Intelligibility        |
| -0.30   | .39*          | 0.10      | MPT                    |
| -0.32   | 0.18          | 0.13      | Mean F0 /a/            |
| 0.08    | 0.18          | .049**    | Mean amp /a/           |
| -0.03   | 0.10          | 0.19      | HNR                    |
| -0.17   | 0.19          | 0.16      | VSA                    |
| -0.12   | 0.17          | -0.17     | VOT /p/                |
| 0.03    | 0.19          | -0.12     | VOT /b/                |
| -0.32   | 0.21          | -0.19     | VOT /t/                |
| -0.19   | -0.21         | -0.09     | VOT /d/                |
| -0.39*  | 0.24          | -0.24     | VOT /k/                |
| 0.34    | -0.05         | 0.07      | VOT /g/                |
| 0.07    | -0.02         | 0.13      | F2slope /i/            |
| -0.42*  | 0.42*         | 0.33      | F2slope /ɑ/            |
| 0.13    | -0.12         | 0.03      | F2slope /u/            |
| -0.06   | 0.17          | 0.12      | F2slope /æ/            |
| -0.21   | 0.06          | 0.18      | M1 /s/                 |
| -0.13   | -0.22         | -0.08     | M1 /f/                 |
| -0.25   | 0.27          | 0.19      | M1 /ʃ/                 |
| -0.31   | 0.13          | -0.09     | 1/3:800-1000Hz         |
| -0.18   | 0.22          | 0.31      | 1/3:1000-1250Hz        |
| -0.07   | 0.23          | 0.43*     | 1/3:1250-1600Hz        |
| 0.32    | -0.01         | 0.37*     | 1/3:1600-2000Hz        |
| 0.26    | -0.01         | 0.12      | 1/3:2000-2500Hz        |
| -0.17   | 0.27          | 0.18      | 1/3:2500-3200Hz        |
| -0.56** | 0.30          | 0.09      | Mean F0 SS             |
| 0.34    | 0.35          | 0.32      | F0 range               |
| -0.05   | 0.33          | .059**    | Mean amp SS            |
| 0.08    | 0.49**        | 0.49**    | Amp range              |
| -0.38*  | -0.38*        | 0.08      | Speaking rate<br>% SLD |

*Note.* MPT = maximum phonation time; F0 = fundamental frequency; Amp = amplitude; HNR = harmonics-to-noise ratio; VSA = vowel space area; VOT = voice onset time; F2 = second formant; M1 = first spectral moment; 1/3 = 1/3 octave band; SS = spontaneous speech; SLD = stuttering-like dysfluencies.

\* $p < .05$ . \*\* $p < .01$ . \*\*\* $p < .001$ .

## Appendix N

### Percentage agreement scores between the first and second investigator for each acoustic parameter in Study 2

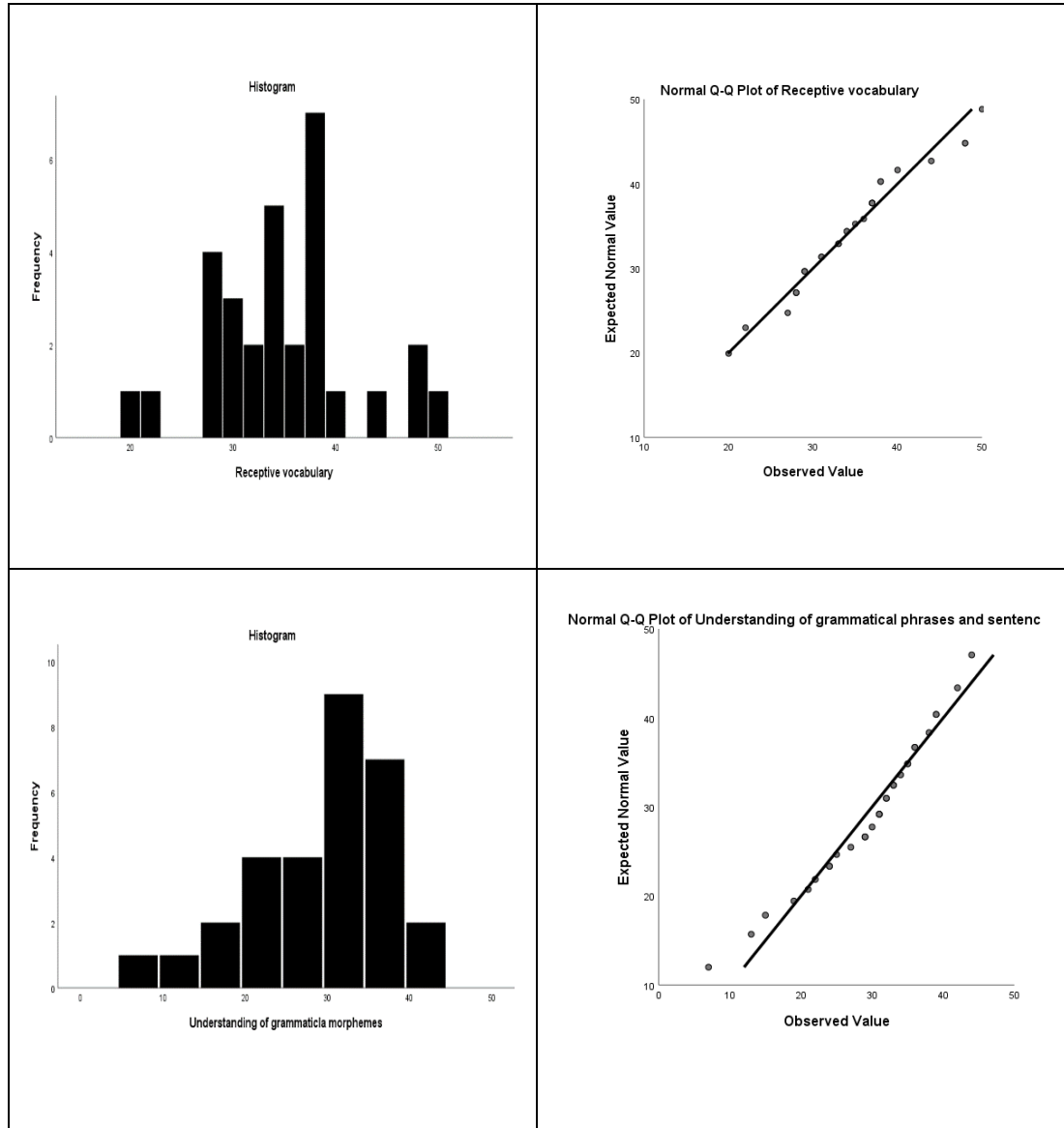
| Acoustic parameter                   | % Agreement |
|--------------------------------------|-------------|
| Respiration                          |             |
| MPT                                  | 85%         |
| Phonation                            |             |
| Mean F0 of /a/                       | 99%         |
| Mean amplitude of /a/                | 99%         |
| HNR                                  | 99%         |
| Articulation                         |             |
| VSA                                  | 87%         |
| F2 slope /i/                         | 95%         |
| F2 slope /ɑ/                         | 97%         |
| F2 slope /u/                         | 95%         |
| F2 slope /æ/                         | 79%         |
| VOT /p/                              | 81%         |
| VOT /b/                              | 97%         |
| VOT /t/                              | 98%         |
| VOT /d/                              | 80%         |
| VOT /k/                              | 93%         |
| VOT /g/                              | 79%         |
| M1 /s/                               | 99%         |
| M1 /ʃ/                               | 99%         |
| M1 /f/                               | 95%         |
| Resonance                            |             |
| 1/3 octave band: 800-1000 hertz      | 93%         |
| 1/3 octave band: 1000-1250 hertz     | 96%         |
| 1/3 octave band: 1250-1600 hertz     | 97%         |
| 1/3 octave band: 1600-2000 hertz     | 98%         |
| 1/3 octave band: 2000-2500 hertz     | 89%         |
| 1/3 octave band: 2500-3200 hertz     | 99%         |
| Prosody                              |             |
| Mean F0 of spontaneous speech        | 99%         |
| F0 range                             | 97%         |
| Mean amplitude of spontaneous speech | 98%         |
| Amplitude range                      | 96%         |
| Speaking rate                        | 99%         |
| % SLD                                | 86%         |

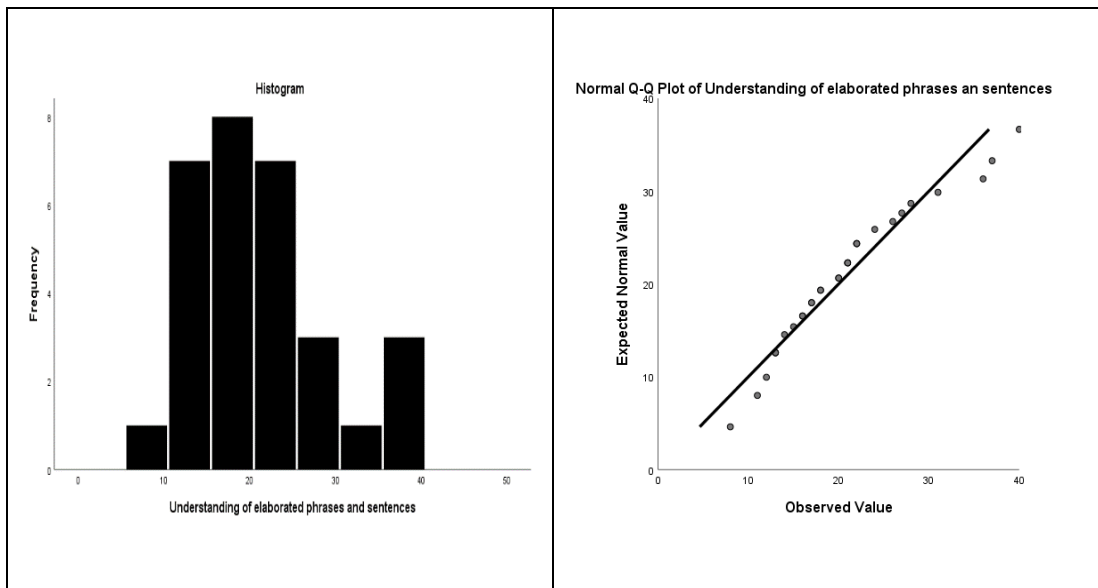
*Note.* MPT = maximum phonation time; F0 = fundamental frequency; HNR = harmonics-to-noise ratio; VSA = vowel space area; F2 = second formant; VOT = voice onset time; M1 = first spectral moment; SLD = stuttering-like dysfluencies.

## Appendix O

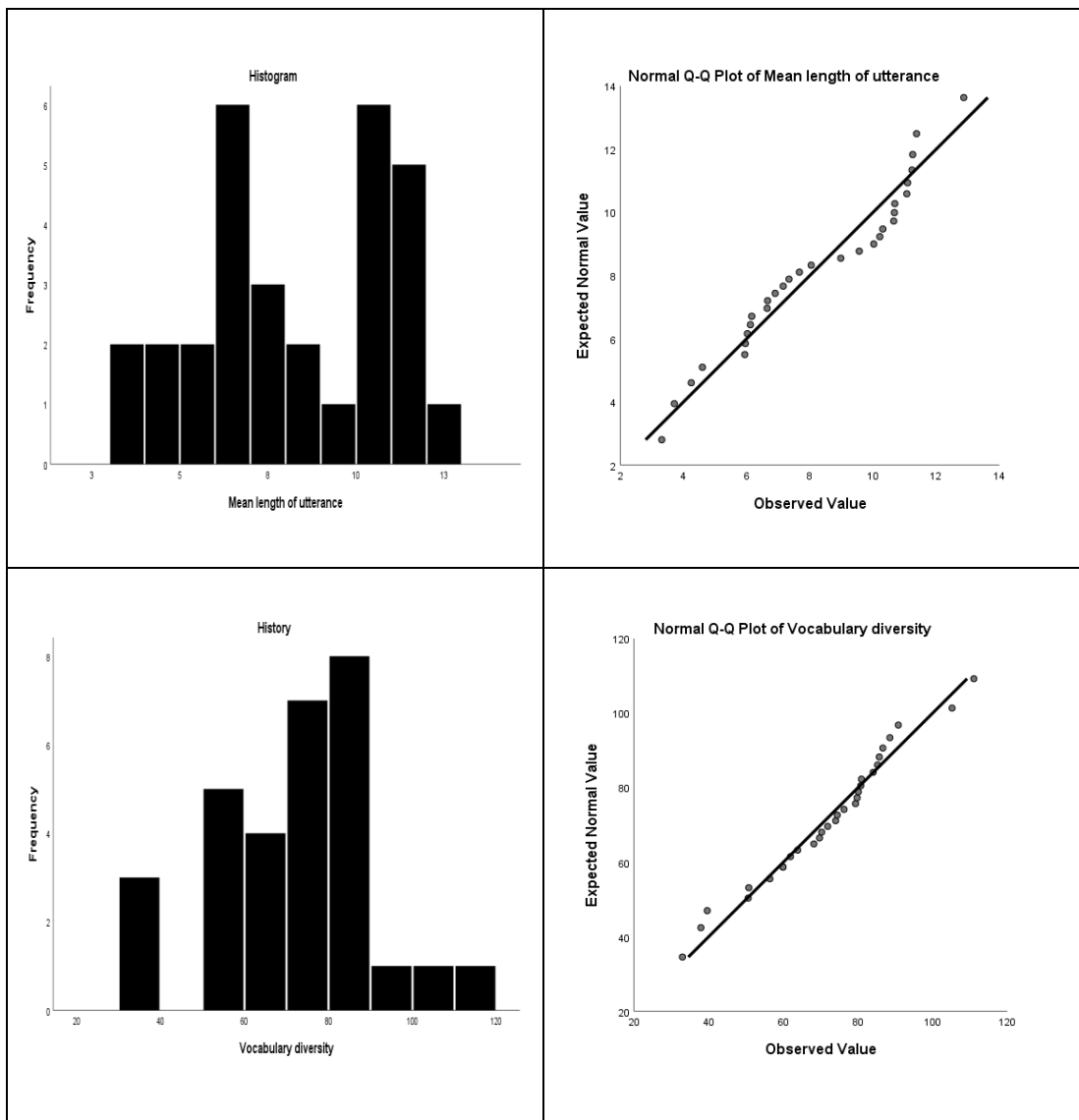
### Histograms and Q-Q plots for each language measure in Study 3

#### Receptive language





## Expressive language



## Appendix P

### Spearman rank-order correlations between speech intelligibility and receptive and expressive language measures in Study 3

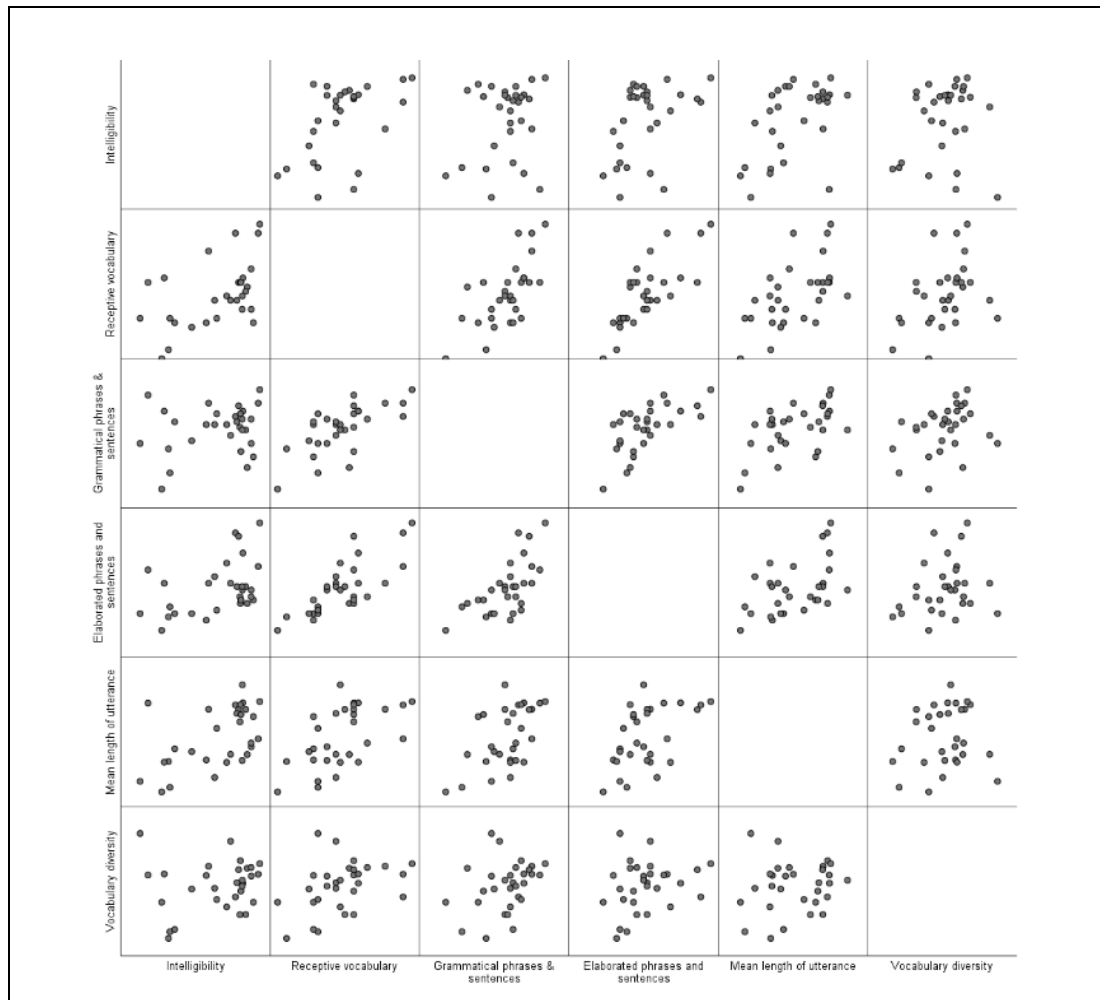
|                                    | Speech<br>intelligibility | Vocabulary | Grammatical<br>morphemes | Elaborate phrases<br>and sentences | MLU     | VocD  |
|------------------------------------|---------------------------|------------|--------------------------|------------------------------------|---------|-------|
| Speech intelligibility             |                           | 0.43*      | 0.12                     | 0.35                               | 0.53*** | 0.16  |
| Vocabulary                         | 0.43*                     |            | 0.67***                  | 0.76***                            | 0.59**  | 0.46* |
| Grammatical<br>morphemes           | 0.12                      | 0.67***    |                          | 0.65***                            | 0.53**  | 0.41* |
| Elaborate phrases and<br>sentences | 0.35                      | 0.76***    | 0.65***                  |                                    | 0.47**  | 0.29  |
| MLU                                | 0.53***                   | 0.59***    | 0.53**                   | 0.47**                             |         | 0.22  |
| VocD                               | 0.16                      | 0.46*      | 0.41*                    | 0.29                               | 0.22    |       |

*Note.* MLU = mean length of utterance; VocD = vocabulary diversity.

\* $p < .05$ . \*\* $p < .01$ . \*\*\* $p < .001$ .

## Appendix Q

Scatterplots showing relationship between each language measure and speech intelligibility in Study 3





## Appendix R

### Instructions and response sheet for listening task

# Rating Task

## Rating Task Instructions

- You are going to hear 45 sentences spoken by different people - some have clearer speech while some have speech that could be difficult to understand.
- Listen to the sentences through the headphones attached to your computer.
- Each slide contains one sentence. Please click on the speaker symbol to play each sentence.

## Rating Task Instructions

- After listening to a sentence, use the Visual Analogue Scale printed on the response sheets to rate how intelligible each sentence is. Intelligibility is defined as “how much of the speaker’s speech that you can understand.”
- The scale is a 10cm straight line, where the left end of the scale represents “0% intelligibility” and the right end represents “100% intelligibility”. Please mark on the straight line to indicate how intelligible the sentence sounds to you.
- When you are finished rating one sentence, move onto the next slide to listen to the next sentence. You are allowed to listen to each sentence **twice**.
- Let’s complete one practice trial to familiarize yourself with the procedure.

## Practice



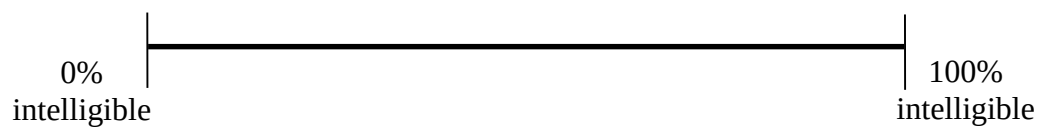
## Any Questions?

- How did it go?
- Is the sound loud enough for you?
- Do you know how to complete the rating task now?
- If there are any concerns during the task, please pause and let me know right away.
- If you are happy to continue, please go to the next slide to start the task.

Example from rating task response sheet

1.

Place an **X** on the line to indicate how intelligible the speaker is



# Transcription Task

## Transcription Task Instructions

- You are going to hear 45 sentences spoken by different people - some have clearer speech while some have speech that could be difficult to understand.
- Listen to the sentences through the headphones attached to your computer.
- Each slide contains one sentence. Please click on the speaker symbol to play each sentence.

## Transcription Task Instructions

- After listening to a sentence, use the printed response sheets to write down everything you think that each speaker is saying.
- When you are finished transcribing one sentence, move onto the next slide and play the next sentence. You can listen to each sentence **twice**.
- Let's complete one practice trial to familiarize yourself with the procedure.

## Practice



## Any Questions?

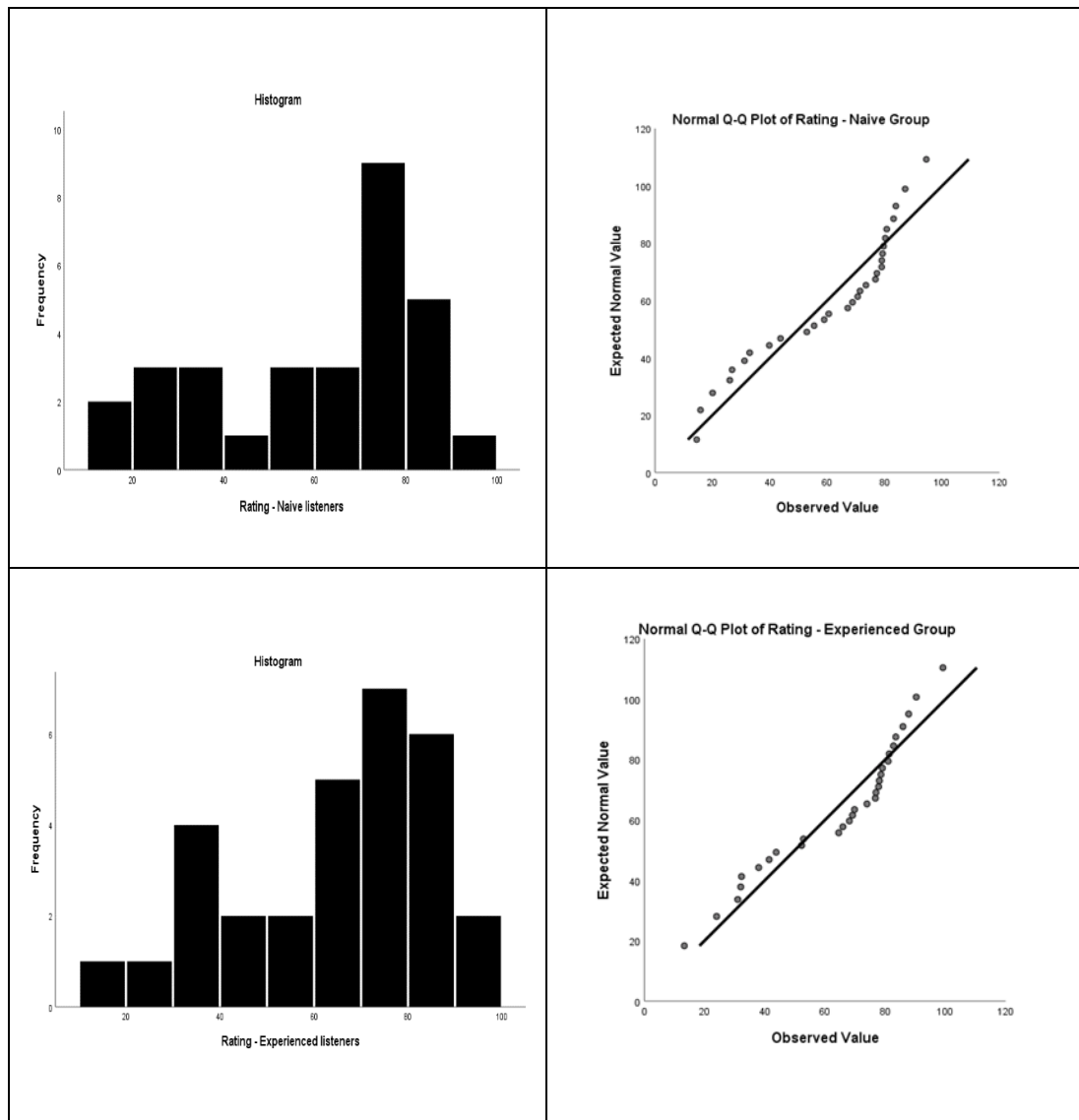
- How did it go?
- Is the sound loud enough for you?
- Do you know how to complete the transcription task now?
- If there are any concerns during the task, please pause and let me know right away.
- If you are happy to continue, please go to the next slide to start the task.

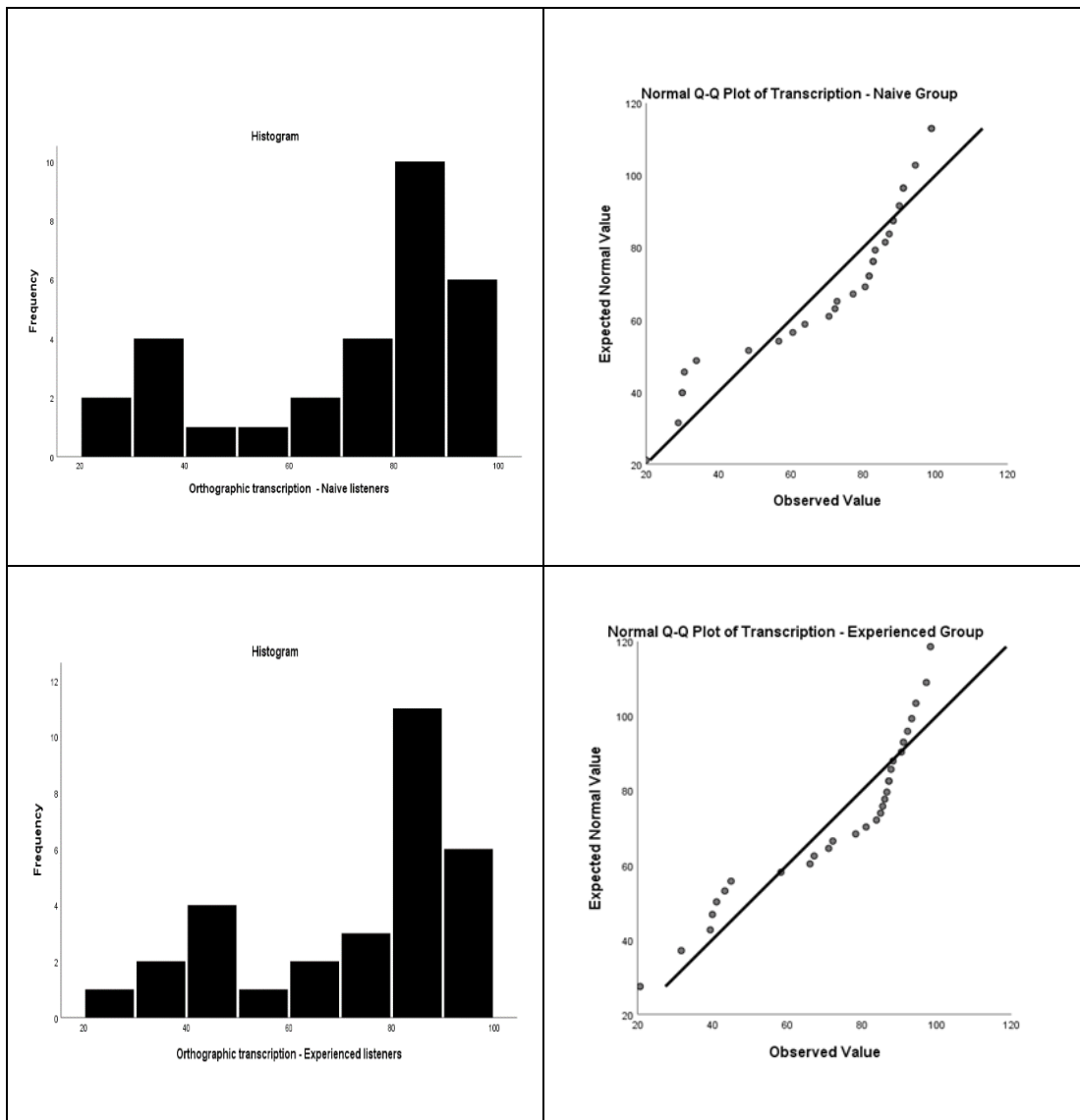
Example from transcription task response sheet

1. Write down what you think you hear.

## Appendix S

### Histograms and Q-Q plots for each test condition in Study 4





## Appendix T

### Publications arising from PhD Study

- O' Leary, D., Lee, A., O'Toole, C., & Gibbon, F. (online ahead of print). Intelligibility in Down syndrome: Effect of measurement method and listener experience. *International Journal of Language & Communication Disorders*. doi: 10.1111/1460-6984.12602.
- O' Leary, D., Lee, A., O'Toole, C., & Gibbon, F. (2021). *Acoustic features of speech in individuals with Down syndrome, and their impact on speech intelligibility*. The 18<sup>th</sup> (virtual) meeting of the International Clinical Phonetics and Linguistics Association, Scotland.
- O' Leary, D., Lee, A., O'Toole, C., & Gibbon, F. (2019). *Intelligibility in Down syndrome: Effects of analysis and listener experience*. The 2019 ASHA (American Speech-Language-Hearing Association) Convention, USA.
- O' Leary, D., Lee, A., O'Toole, C., & Gibbon, F. (2019). Perceptual and acoustic evaluation of speech production in Down syndrome: A case series. *Clinical Linguistics & Phonetics*. DOI: 10.1080/02699206.2019.1611925
- O'Leary, D., Lee, A., O'Toole, C., & Gibbon, F. (2018, October). *Perceptual and acoustic evaluation of speech production in Down syndrome: A case series*. Poster presented at the 17th meeting of the International Clinical Phonetics and Linguistics Association, Malta.
- O'Leary, D., Lee, A., O'Toole, C., & Gibbon, F. (2017, September). *Perceptual and acoustic features of speech in adolescents and adults with Down syndrome and their impact on intelligibility: A pilot study*. Paper presented at the meeting of the Down Syndrome Research Forum, London UK.
- O'Leary, D., Lee, A., O'Toole, C., & Gibbon, F. (2017, November). Speech intelligibility in Down syndrome. Paper presented at the meeting of the DELAD Initiative, Cork Ireland.

