Relationship between Subjective and Objective Measures of Speech Intelligibility in Children with Speech Sound Disorders

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JULY, 2024

CERTIFICATE

This is to certify that this dissertation entitled "**Relationship between Subjective and Objective Measures of Speech Intelligibility in Children with Speech Sound Disorders**" is a bonafide work submitted in part fulfilment for the degree of Masters in Science (Speech-Language Pathology) of the student Registration number: P01II22S123022. This has been carried out under the guidance of the faculty of this institute and has not been submitted earlier to any other University for an award of any other Diploma or Degree.

Mysuru
July, 2024

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DECLARATION

This is to certify that this dissertation entitled "**Relationship between Subjective and Objective Measures of Speech Intelligibility in Children with Speech Sound Disorders**" is the result of my own study under the guidance of Dr. Priya M. B., Assistant Professor in Speech Pathology, Centre for Speech and Language Disorders in Children, Adults and Senior Citizens, All India Institute of Speech and Hearing, Mysuru and has not been submitted earlier to any other University for an award of any other Diploma or Degree.

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Have I not commanded you? Be strong and courageous. Do not be frightened, and do not be dismayed, for the Lord your God is with you wherever you go".

Joshua: 1:9

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CHAPTER I

INTRODUCTION

The ability of a speaker to communicate effectively enough for a listener to understand them is known as speech intelligibility. Bernthal et al. (2017) defined intelligibility as a "perceptual judgment based on how much of the child's spontaneous speech the listener understands. Intelligibility can vary along a continuum ranging from intelligible (message is completely understood) to unintelligible (message is not understood)". Reduced speech understandability causes partners to become frustrated, lose interest, and misunderstand each other. Consequently, communication either declines or stays at a minimum.

Children's social engagement and successful functional communication depend on their ability to speak intelligibly. There is increasing evidence that a naive listener's assessment of speech intelligibility based on an orthographic transcription of speech corresponded highly with parents' ratings of their child's speech intelligibility (Hustad, 2012). Children use different forms of words and more coherent language when speaking with their parents than with other children (Hansson et al., 2000).

Speech intelligibility can be affected by a host of factors. The degree of complexity of an utterance (e.g., single words vs. conversational or connected speech), the number and frequency of different types of speech sound errors when it is present, the rate, inflection, stress patterns, pauses, voice quality, loudness, and fluency of the speaker can have either a positive or negative impact on the intelligibility. Similarly, linguistic factors (e.g., word choice and grammar), the listener's familiarity with the

speaker's speech pattern, the communication environment (e.g., familiar vs. unfamiliar communication partners, one-on-one vs. group conversation), communication cues for listeners (e.g., nonverbal cues from the speaker, including gestures and facial expressions), and signal-to-noise ratio (i.e., degree of background noise) can all affect an individual's intelligibility.

One drawback of closed-set testing for young children is the word being familiar. While developing an articulation or intelligibility test, it might be challenging to ensure that children are conversant with the terms selected and utilized to elicit speech. The use of repetition tasks instead of identification tasks may lessen the chance of being unfamiliar with target words (Kent et al., 1994). Utilizing lists of single words or other structured speech materials has the benefit of allowing for the inclusion of sounds that are especially highly susceptible to a particular kind of speech error. Additionally, these lists enable analysis of the relative contributions of various types of errors to a decrease of comprehensibility (Klein & Flint, 2006).

In common procedures for assessing intelligibility, listeners are asked to rate the level of intelligibility of various speech materials (word lists, sentences, and passages, for example) using a variety of measurement methods such as an orthographic transcription, a multiple-choice task, or a visual analog scale (VAS) (Hustad, 2008). There are two common methods used to evaluate speech intelligibility, one strategy for identification allows the listener to identify the words spoken while the other method is the scaling approach (Schiavetti, 1992). The scaling approach requires the listener to hear a sample of the speech and rate the overall intelligibility of the speech using a scale (Ansel & Kent, 1992). Scaling processes are not considered a reliable measure of

comprehensible speech as they do not provide information on specific error patterns. However, they provide a more realistic image of a speaker's communication skills in everyday speaking contexts (Beukelman & Yorkston, 1980). The rating indicates the degree to which the listener finds it challenging to understand the context of the speech sample because it is based on perceptual judgment and is regarded as a qualitative measure (Dukart, 1996). Additionally, scaling processes give the examiner a useful tool for assessing young children's speech intelligibility.

Subjective intelligibility tests require the listener to rate their level of understanding. On the other hand, objective procedures depend on the tester assessing the listener's comprehension. Usually, they require the recognition or repetition of speech test material. An objective method for measuring a child's intelligibility is by collecting a connected speech sample, orthographically transcribing each word, and then estimating the percentage of words that are comprehended out of the words spoken. However, this approach is time-consuming (Dukart, 1996) and hence, may not always be used in routine clinical practice. Estimating the percentage of words that are comprehendible from a child's utterance and then using that percentage to indicate how understandable they are is a more effective method that continues to be frequently used by practicing speech-language pathologists (Dukart, 1996).

Comparing subjective speech intelligibility estimation to the majority of objective measuring methods reveals several benefits. Subjective assessments are less time-consuming and can be completed in a few minutes in contrast to the longer duration required for an objective test to be scored. While most objective speech tests use speech that is unusual in everyday listening - like single monosyllables - the

subjective method enables quick measurement of the intelligibility of speech sequences that are similar to spontaneous speech (Dukart, 1996).

On the other hand, Kwiatkowski and Shriberg (1992) emphasize that connected speech assessment is the only accurate way to measure intelligibility in children with phonological disorders of unknown cause, regardless of even if they were chosen by imitation or spontaneous speech. Since connected speech evaluation is more like real-world speaking scenarios than word production in isolation, it is also seen to be a superior measure of functional performance than isolated speech production (Beukelman & Yorkston, 1980). In addition, an assessment based on connected speech has two key advantages over an evaluation based on feature lists: first, it considers supra-segmental features, which have been demonstrated to influence intelligibility; and second, it is believed to be a more accurate indicator of the individual's abilities for speech communication in natural environments, meaning that it has a higher ecological validity than an evaluation based on lists of words or sentences read aloud (Kwiatkowski & Shriberg, 1992). However, the primary disadvantage of connected speech is that, particularly in cases when the speaker has a significant speech impairment, it may be challenging to understand what they are saying. This complicates the estimation of adequately comprehended words.

However, even though both objective and subjective methods of assessing speech intelligibility are commonly used in clinical and research contexts, the relationship between them is yet to be understood completely. Cox et al. (1991) reported only a .58 correlation between an objective multiple-choice test, that produced a percentage score, and a subjective intelligibility evaluation of connected speech on a

seven-point equal-appearing interval scale. An equal-appearing scaling method can be used to calculate the percentage that indicates the speech intelligibility level (Kent, 1992). Instead of providing a range of 1, 5, 7, or 9, the listener provides a numerical number based on a continuum that ranges from zero percent (unintelligible) to one hundred percent (perfectly intelligible). For example, the spoken sample is deemed 50% understandable if the listener comprehends half of the speaker's words.

1.1 Need for the study

Intelligibility is crucial for understanding a person's speech and conversing with a communication partner. It also refers to how clearly the listener can comprehend the pronunciation or dialect of the speaker, which facilitates building a friendly one-on-one conversation. According to standard norms, a child's speech should be 26–50% understandable by the age of two years, 75–75% by age three, and 90–99% by age four (American Speech-Language-Hearing Association, 2003).

One of the children's most commonly seen speech impairments is Speech Sound Disorder (SSD) (Broomfield & Dood, 2004). “SSD is described as difficulties in using age-appropriate speech sounds for a particular dialect” (Diagnostic and Statistical Manual of Mental Disorders (DSM-5), American Psychiatric Association, 2013). SSD, characterized by abnormalities in speech sound production linked to phonological, articulation, and cognitive processing problems, has a profound impact on intelligibility. SSD is frequently observed in children and is linked to deficiencies in reading and writing as well as language difficulties (Kim et al., 2019).

According to McCauley (1996), the three commonly used criterion-referenced metrics for SSD assessment are PCC (Percentage of Consonants Correct), percentage of intelligibility (Brannan et al, 2000), PCC-R (Percentage of Consonants Correct–Revised, Shriberg & Kwiatkowski, 1994), and percentage of occurrence of phonological patterns (Preston et al., 2013). The PCC-R assesses children's overall accuracy with consonants. PCC-R was assessed in hundreds of preschoolers by Shriberg and Kwiatkowski (1994), who also provided cutoff scores that distinguish children with SSDs from typically developing children.

The availability of normative data on speech intelligibility measures is limited. The estimation of speech intelligibility needs to be more consistent based on subjective and objective measures in regular clinical practice. Further, there is also considerable variability in the sample type used to calculate speech intelligibility measures, ranging from word repetitions to connected speech. Considering that the severity of SSD is based on speech intelligibility measures, it is essential to understand the relationship between these measures and the influence of the type of sample.

1.2 Aim of the study

The study aimed to study the relationship between subjective and objective measures of speech intelligibility in children with SSD.

1.3 Objectives of the study

The objectives of the study were as follows:

- To study the relationship between subjective and objective measures of speech intelligibility in children with SSD for words

- To study the relationship between subjective and objective speech intelligibility measures in children with SSD for connected speech.

1.4 Hypotheses of the study

The study assumed a null hypothesis for the objectives as follows:

- There is no significant correlation between the subjective and objective measures of speech intelligibility in children with SSD for words
- There is no significant correlation between the subjective and objective speech intelligibility measures in children with SSD for connected speech.

CHAPTER 2

REVIEW OF LITERATURE

Speech Sound Disorder (SSD) is defined as a condition characterized by difficulties in producing speech sounds correctly, which can impact the intelligibility of speech and may involve problems with articulation and / or phonological processing (Shriberg & Kwiatkowski, 1994). SSDs are a group of disorders affecting the articulation and phonological processing of speech sounds.

2.1 Characteristics of SSD

SSD encompass a range of difficulties children face in pronouncing specific sounds correctly, often leading to sound substitutions, omissions, or distortions. These disorders not only involve challenges in articulation but also affect the ability to systematically produce and organise sounds, thereby impacting the phonological system (Shriberg & Kwiatkowski, 1982). Standard phonological processes observed in children with SSD include consonant cluster reduction, fronting, and stopping. These processes often follow predictable patterns but may persist beyond the typical age of suppression. Early identification and intervention are crucial to prevent these patterns from becoming entrenched and more difficult to remediate over time (Dodd & Crosbie, 2003).

SSD often reflects deviations from typical speech sound development. These deviations can vary significantly in severity, impacting both intelligibility and communication effectiveness. Children with SSD may struggle to be understood by listeners, leading to frustration and social challenges (Bowen, 2011). The severity of

the disorder is a critical factor, as it influences the degree of intelligibility and the subsequent impact on daily communication (Flipsen, 2006). The repercussions of SSD extend beyond speech production. Children with SSD often experience difficulties in overall communication skills, which can affect language development and social interactions and academic performance. The link between SSD and literacy skills is particularly concerning; children with speech sound difficulties may face challenges in learning to read and write, which can have long-term educational implications (Nathan & Stackhouse, 2004).

The presentation of SSD can vary widely among individuals. Some children may exhibit only mild distortions, while others may have more severe errors affecting multiple speech sounds. This variability necessitates individualizes assessment and intervention strategies to address each child's unique needs (McLeod, 2017). Understanding these differences is essential for clinicians to develop effective treatment plans that cater to the specific patterns of sound errors observed in each child. SSDs frequently co-occur with other developmental disorders, such as language disorders, attention-deficit/hyperactivity disorder (ADHD), and developmental coordination disorder. This comorbidity can complicate the diagnosis and treatment of SSD, as multiple areas of development may need to be addressed simultaneously (Lewis & Taylor, 2004).

2.2 Speech Intelligibility in SSD

Speech intelligibility is the extent to which speech is understood by a listener in a specific environment, given the speech material and context (Nabelek & Harker, 1988). Speech intelligibility is the measure of how well speech can be understood by

a listener, often quantified by the percentage of correctly identified words or sentences (Kryter, 1962). Intelligibility, or how well-spoken words are understood, is crucial because deficits can lead to misunderstanding and frustrations. Poor speech intelligibility can hinder classroom participation and social integration, with research indicating that poor classroom acoustics negatively affect speech intelligibility and the teaching-learning process in primary schools (Murgia et al., 2020). Additionally, children with SSD often have reduced intelligibility, leading to difficulties in academic achievement and peer relationships (Shriberg et al., 2010). These children may also struggle with literacy skills such as reading and spelling (Shriberg et al., 2017).

2.3 Need for assessing intelligibility in SSD

Assessing speech intelligibility in individuals with SSD is crucial for several reasons: Speech intelligibility assessments help in quantifying the extent of the disorder, thereby helping in the determination of the severity. This enables clinicians to understand how much the SSD is impacting the individual's ability to communicate effectively. Evaluating intelligibility provides insights into the specific types and patterns of speech errors (e.g., articulation vs, phonological errors), which are essential for accurate diagnosis and appropriate intervention plan.

McLeod and Baker (2014) emphasise the importance of using both objective measures (e.g., percentage of consonants correct) and subjective measures (e.g., listener judgements) in the assessment of speech intelligibility based on the review of multiple studies involving children with SSD ranged from 3 to 10 years. Moreover, they highlighted that different methods of assessing intelligibility provide complementary information. Objective measures help identify specific speech errors,

while subjective measures capture the listener's overall perception of speech clarity. The authors stress that the comprehensive assessment of speech intelligibility is necessary for setting appropriate therapy goals and monitoring progress. Kent (1992) highlighted the benefits of combining multiple assessment methods to comprehensively understand a child's speech abilities.

2.4 Methods used to assess speech intelligibility

Speech intelligibility can be assessed using variety of measures that are generally categorized as subjective or objective (Hustad, 2012). Subjective measures include listeners ratings and use of rating scales. The method of listeners rating is often used in a clinical setting to provide a quick and practical estimate of intelligibility wherein listeners rate the percentage of words understood from a sample of speech (Flipsen, 2006). Similarly, using rating scales, listeners rate speech on a scale, often ranging from "completely unintelligible" to "completely intelligible". Rating scales are commonly reported to be useful for capturing overall impressions of speech intelligibility (Gordon-Brannan & Hodson, 2000).

In contrast, objective measures offer more specific information about speech intelligibility and error patterns. The results typically yield a proportion of words accurately identified relative to the target words the speaker intended to produce. One of the objective intelligibility measures is transcription analysis (Shriberg & Kwiatkowski, 1982) in which speech samples are transcribed, and the percentage of correctly understood words or phonemes is calculated. Another objective measure is Automated Speech Recognition, a software used to analyse speech samples and provide an intelligibility score based on how well the speech matches expected

patterns. This approach leverages technological advancements for more precise measurements (Green & Nip, 2010).

In addition to the subjective and objective measures, acoustic analysis is also used to measure speech intelligibility. Detailed phonetic analysis gives specific phonetic errors and patterns that might affect intelligibility, such as substitutions, omissions, distortions, and additions (Bankson & Flipsen, 2017). Prosody plays a crucial role in the naturalness and intelligibility of speech and on these lines, prosodic analysis evaluates elements like stress, rhythm, and intonation that can influence how easily speech is understood (Vance & Stackhouse, 2006).

Clinical assessments usually include administration of standardized tests and speech sample analysis. Standardized tests such as Goldman-Fristoe Test of Articulation or the Hodson Assessment of phonological Patterns can be used to assess speech sound production and its impact on intelligibility (Goldman & Fristoe, 2000). Clinicians collect and analyse speech samples in different contexts (e.g., conversation, storytelling) to evaluate intelligibility in natural settings. This method of speech sample analysis provides insights into everyday communication abilities (McLeod & McCormack, 2012).

Subjective ratings by listeners are valuable tool for assessing intelligibility and understanding the impact of various disorders. Children with articulation or phonological disorders exhibited significantly lower intelligibility ratings compared to their typically developing peers (Shriberg & Kwiatkowski, 1994). Strand and McCauley (2008) explored the relationship between the severity of SSD and speech

intelligibility in children between four to eight years of age. Listeners rated intelligibility and the severity of the disorder was assessed using standardized measures. The results revealed a significant negative correlation between the severity of SSD and speech intelligibility scores, indicating that severity directly affect how well their speech is understood by others.

There are research evidences supporting the clinical usefulness of objective measures of speech intelligibility. Research studies collectively demonstrate the effectiveness of the percentage of consonants correct (PCC) as an objective measure for assessing speech intelligibility in children with SSD. PCC reliably distinguishes between children with and without speech impairments, with those affected showing significantly lower scores (Shriberg & Kwiatkowski, 1982). Furthermore, PCC scores correlate with the severity of the disorder, overall speech intelligibility, and related skills such as phonological awareness (Preston & Edwards, 2010).

Based on a study carried out on 60 children aged 3-8 years diagnosed with phonological disorders, Shriberg and Kwiatkowski (1982) reported that children with phonological disorders had significantly lower PCC scores compared to the control group. Further, lower PCC scores were strongly correlated with greater severity of phonological disorders, indicating that PCC is a reliable measure of speech sound accuracy and severity. Similarly, Flipsen (2006) reported a significant positive correlation between PCC scores and overall speech intelligibility ratings by unsophisticated listeners in a study based on 30 children with SSD aged 4 -10 years. Lower PCC scores were associated with various risk factors, including male gender, low socioeconomic status, and family history of speech and language disorders

(McLeod & Harrison, 2009). Given its robustness and the strong correlations found across different studies, PCC serves as a valuable tool for both diagnostic and treatment progress evaluation in speech-language pathology.

The purpose of the assessment also influences the choice of method. For some situations, a general assessment of intelligibility, such as conversational speech with an unfamiliar listener in a quiet context, may be sufficient. However, for more specific purposes, a detailed or diagnostic approach is needed. When planning interventions for children with severe unintelligibility, spending time on intelligibility testing is beneficial to identify all factors affecting intelligibility. These factors may include the accuracy of distinct phonetic contrasts, the naturalness and appropriateness of prosodic variations, and the use of clarification and repair strategies. Typically, rating scales are used to assess speech intelligibility, with listeners providing a numerical value (0 to 100), a percentage, or descriptors like" standard", "sometimes", "mainly", or" always" to indicate how well the speech is understood (Ertmer, 2010). Coplan and Gleason (1988) developed a standardized intelligibility screener based on parent assessments of their child's understandability to others.

Numerous studies have shown that various factors can affect a person's intelligibility. These include the speaker's characteristics (e.g., motor skills, language abilities, cognitive abilities), the listener's attributes (e.g., familiarity with the speaker and experience understanding the child's speech), and the context (e.g., type of speech stimuli, elicitation technique, and listening environment). Due to these intricacies, intelligibility measures are best viewed as a snapshot of the speech signal's effectiveness in a specific situation. Nevertheless, they can provide strong indicators

of treatment progress and potential improvements in functional communication (Hustad, 2012).

Scoring intelligibility at the word level is a traditional method of intelligibility scoring that has been used by several investigators (Shriberg & Kwiatkowski, 1982), Smith et al., 1975); Weston & Shriberg, 1992); Yorkston & Beukelman, 1981). Word scoring can apply to conversational speech from speakers of varied ages and communication abilities (as long as there is some utterance intelligibility). Furthermore, the analysis is usually simple, requiring judges to identify terms in certain conversation samples, reading, or repetition. Intelligibility is measured simply by the percentage of words correctly detected.

Objective measures are considered as the "gold standard "for clinically assessing intelligibility because quantification is straightforward: lexical units are either correct or incorrect (Hustad, 2012). It is important to note that speech production can be phonetically accurate, allowing the listener to understand it phonetically and lexically correctly. However, to grade lexical elements correctly or incorrectly decoded, the speaker's target words must be specified. This requirement means that intelligibility is often assessed using elicited words and sentences through transcriptions or forced–choice recognition techniques. Despite the ecological validity of studying spontaneous speech, scoring orthographic transcription of spontaneous speech is frequently difficult or impossible due to the uncertainty of the amount and type of lexical targets.

One benefit of structured speech material, like word lists, is that it can be tailored to include phonemes that are especially prone to a particular kind of speech error. It can also be used to analyze the relative contributions of various error types to the reduction in intelligibility (Klein & Flint, 2006). However, an assessment based on spontaneous speech has two main advantages over one based on lists of words or sentences read aloud: first, it incorporates supra-segmental features, which have been shown to affect intelligibility; and second, it is believed to be more representative of the speaker's ability to use speech to communicate in everyday life, meaning that it has a higher ecological validity. The most common way is for listeners to score their intelligibility on an equal-appearing interval scale while listening to recordings of spontaneous speech (Whitehill, 2002).

2.5 Relationship between subjective and objective measures of speech intelligibility

Lohmander et al (2005) studied the speech intelligibility and consonant production of ten children with typical development and ten children with SSD in the age range of 4 to 8 years. The study involved two SLPs who are recently graduated and eighteen SLP students as listeners, with two additional students assessing PCC for single words and rated spontaneous speech for intelligibility. Correlation analysis were carried out and there was strong correlation between intelligibility ratings for spontaneous speech and PCC score for single words. In addition, the authors reported that intelligibility scores differed significantly between the two groups of participants.

Dukart (2000) explored the reliability and correlation of speech intelligibility ratings by unsophisticated listeners (with no formal training in phonology or

articulation) with that of orthographic transcription by student Speech – Language Pathologists. The speech samples were elicited via story telling task in children with different levels of speech intelligibility. The results indicated a strong positive correlation between the subjective ear estimation method and the orthographic transcription method.

In summary, the review of literature indicates that SSD can significantly affect a child's interactions, academic performance, and overall development. Accurate assessment of speech intelligibility is crucial for diagnosing SSD and planning effective interventions. Regular assessment of intelligibility helps in tracking the progress of interventions and modifying therapy goals as needed. Further, combining subjective and objective assessment methods provide a well–rounded view of a child's speech intelligibility. This approach helps accurately measure and address the complexities of SSD thereby ensuring that children with SSD receive the most effective support to improve their communication skills. However, the relationship between subjective and objective measures of speech intelligibility is not very clearly established for different types of speech samples, particularly in SSD. In this regard, the present study was taken up to explore the relationship between subjective and objective speech intelligibility measures for words and connected speech samples in children with SSD.

CHAPTER 3

METHODS

The study aimed to compare the relationship between subjective and objective speech intelligibility measures in children with Speech Sound Disorder (SSD) in the age range of 4 to 7 years.

3.1 Objectives of the study

The objectives of the study were as follows:

- To study the relationship between subjective and objective measures of speech intelligibility in children with SSD for words
- To study the relationship between subjective and objective measures of speech intelligibility in children with SSD for connected speech.

3.2 Research Design

Correlational research was used to understand the relationship between subjective and objective measures of speech intelligibility in children with SSD for words and sentences.

3.3 Participants

The participants included 20 children in the age range of 4 to 7 years with a clinical diagnosis of SSD. They were divided into two groups (Group 1 & Group II) randomly, with each group consisting of 10 children with SSD.

3.3.1 Participants Selection Criteria

The selection criteria for inclusion in the study were as follows:

- All participants selected for the study were native speakers of Kannada language (Mysore dialect)
- They belonged to middle socio-economic status (as per the revised NIMH Socio-Economic Status Scale) (Venkatesan, 2011)
- They had normal hearing acuity and normal/corrected vision
- All participants had a clinical diagnosis of Speech Sound Disorder based on evaluations by a Speech Language Pathologist and also correlated with the diagnosis of DSM -5 criteria.

In addition, participants had no history of problems like hearing loss or any structural deficits like cleft lip and palate. Participants with co-morbid conditions such as stuttering, specific language impairment, or any other neurological conditions were excluded from the study.

3.3 Informed Consent and Ethical Clearance

The study followed the ethical guidelines prescribed by the institutional review board (Venkatesan, 2009). Informed written consent was obtained from the caregivers/parents of each of the participants.

3.4 Procedure

All participants were comfortably seated and tested individually in a quiet, distraction-free environment with adequate lighting and good ventilation.

3.4.1. Stimuli and Tasks

The stimuli for assessing speech intelligibility were considered under two domains, i.e. word and connected speech.

Word level samples were obtained by administering a standardized word list, namely the Kannada Diagnostic Photo Articulation Test (Deepa & Savithri, 2010). The test included a total of 115 stimuli, each of which was presented in the form of a picture. The total number of consonants in the test was 316. The task required the participants to name the picture presented by the examiner, one after another through a laptop If the children failed to spontaneously name the pictures, they were provided with additional cues. If the children could not name the picture despite giving additional cues, they would be asked to repeat the word after the examiner.

Connected speech sample was obtained using a picture description task. The participants were presented with a picture of a "Market Scene" (Refer to Appendix 1) and asked to describe the events depicted in the same. If the participant failed to describe the picture using connected speech, probe questions were used to elicit responses while encouraging responses in simple sentences. A minimum of 50 words was considered for analysis.

The speech samples obtained from the participants were recorded using a digital audio recorder with unidirectional microphone placed at a distance of six inches from the participant. The recorded speech samples of participants in both group I and group II were coded and analyzed.

3.5 Data transcription and analyses

All recorded samples were transcribed verbatim using broad International Phonetic Alphabet (IPA) and analyzed using both subjective and objective assessment methods. Both subjective and objective assessments were carried out in group I by the

investigator of the study and by another Speech Language Pathologist in group II. The listeners were blinded to the details of the participants and were allowed to listen to the recorded samples a maximum of three times.

3.5.1 Subjective Assessment of Speech Intelligibility

The subjective assessments were carried out separately for word and connected speech samples. Subjective assessment of samples obtained by participants in group I was carried out by the investigator of the study while that of group II was done by a second investigator who was a Speech Language Pathologist with a minimum of 5 years of experience in the field. The listeners were asked to carefully listen to the recorded speech samples and rate the speech intelligibility between 0 and 100 using an equal-appearing scaling method, where '0' indicated completely unintelligible and '100' indicated completely intelligible.

3.5.2 Objective Assessment of Speech Intelligibility

Calculation of the percentage of consonants correct (PCC) was considered as the measure of objective assessment of speech intelligibility. Objective assessment of samples obtained by participants in group I was carried out by the investigator of the study while that of group II was done by the second Speech Language Pathologist with a minimum of 5 years of experience in the field. Similar to the subjective assessment, objective assessments were also carried out separately for word and connected speech samples. Therefore, PCC was calculated separately for the word and connected speech samples of each of the participants by dividing the total number of correct consonant productions by the total number of intended consonants and multiplying by 100 (Shriberg & Kwaitkowski, 1994). The specific rules followed while calculating the PCC

(Forslund et al., n.d.) are given in Appendix 2 for both word and connected speech samples.

3.6 Reliability measures

Owing to the subjective nature of analyses, intrajudge and interjudge reliability measures were established.

3.6.1 Intrajudge reliability

The first investigator repeated analyses of the samples from participants in group I (N = 10) within one month from the time of initial analyses. The results obtained on the two occasions was compared using suitable statistical measures to assess intrajudge reliability.

3.6.2 Interjudge reliability

Two investigators were asked to independently analyse the recorded speech samples of participants in group II (N=10). The results obtained by each of the investigators were compared using suitable statistical measures to assess interjudge reliability for both words and connected speech samples.

3.7 Statistical Analyses

The analyzed responses of individual participants were tabulated for further compilation of group data. The Statistical Package for Social Sciences (SPSS version 26) was utilized to carry out suitable statistical analysis of the group data (SPSS Inc, Chicago). A normality check using Shapiro-Wilk test revealed non-normal distribution of the data and hence, non-parametric tests were carried out. Spearman's correlation

analysis was carried out to study the relationship between subjective and objective measures of speech intelligibility. Reliability analyses were carried out using Cronbach's correlation co-efficients.

CHAPTER 4

RESULTS

The present study aimed to study the relationship between subjective and objective speech intelligibility measures in children with Speech Sound Disorder (SSD) between 4 and 7 years of age. Twenty participants were selected for the study, and the participants were divided into two groups, I and II with ten participants in each. The stimuli used to assess speech intelligibility included words and connected speech elicited using picture naming and picture description tasks respectively. The recorded speech samples were subjected to both subjective and objectives measures of speech intelligibility. Speech samples of participants in group I was analyzed by the investigator of the study while that of group II was analyzed by a second investigator.

Statistical analysis was carried out using SPSS software (version 26). Shapiro–Wilk's test was administered to check for normality, and the results indicated that the data did not follow normal distribution ($p<0.05$). Nonparametric tests were carried out to compare the subjective and objective measures of speech intelligibility within two groups of children on different speech intelligibility tasks. Descriptive statistics was computed for the subjective and objective measures of speech intelligibility obtained for the two groups of participants included in the study. The means, medians, standard deviations and interquartile ranges of the scores obtained by the participants are presented in Table 4.1.

Table 4.1

Means, Medians, Standard Deviations (SD) and Interquartile ranges (IQR) of the scores obtained by the two groups of participants for subjective and objective assessments

Group	Analysis	Subjective Assessment		Objective Assessment	
	Sample	Word	Connected Speech	Word	Connected Speech
Group I	Mean	66.50	59.50	90.47	87.04
	Median	75.00	70.00	91.45	87.37
	SD	24.04	30.95	5.89	5.29
	IQR	25.00	56.25	7.59	8.97
Group II	Mean	84.00	83.00	92.09	89.36
	Median	87.50	87.50	93.65	89.37
	SD	14.49	16.19	6.49	9.76
	IQR	31.25	25.00	11.48	12.97

From table 4.1, it can be seen that, both groups of participants obtained lower mean and median scores of intelligibilities for connected speech samples compared to that of words. It is also evident that the speech intelligibility scores were higher on objective assessment compared to the corresponding subjective ratings for both word and connected speech samples. This was found to be true for both groups of participants who were assessed by two different investigators.

The results of the study are described in the following sections:

4.1 Relationship between subjective and objective measures of speech intelligibility in children with SSD for words

4.2 Relationship between subjective and objective measures of speech intelligibility in children with SSD for connected speech

4.3 Intrajudge and Interjudge reliability analysis

4.1 Relationship between subjective and objective measures of speech intelligibility in children with SSD for word samples

Nonparametric Spearman's rho correlation analysis was carried out to study the correlations between subjective (ratings based on equal-appearing scale) and objective measures (PCC) of speech intelligibility for words. This was done separately for participants in group I and II whose samples were analysed by the first and second investigator, respectively. The results revealed significant correlation between subjective and objective measures for word samples in group II ($\rho = 0.969$, $p < 0.01$) indicating a high positive correlation but not in group I ($\rho = 0.424$, $p=0.222$).

4.2 Relationship between subjective and objective measures of speech intelligibility in children with SSD for connected speech samples

The correlations between subjective and objective measures of speech intelligibility for connected speech were analysed separately for participants in group I and II using nonparametric Spearman's rho correlation. The results revealed significant correlation between subjective and objective measures for connected speech samples in group II ($\rho = 0.899$, $p < 0.01$) indicating a high positive correlation but not in group I ($\rho = 0.142$, $p = 0.696$).

4.3 Intrajudge and Interjudge reliability analysis

The results are presented separately for intrajuge and interjudge reliability analysis in the following sections.

4.3.1 Intrajudge reliability

The first investigator repeated analyses of the samples from participants in group I (N = 10) within one month from the time of initial analyses. Cronbach’s alpha

was used to determine the intrajudge reliability of the two analyses. The results revealed high intrajudge reliability (α > .9) for both word and connected speech samples analysed using subjective and objective measures of speech intelligibility (Table 4.2).

4.3.2 Interjudge reliability

Two investigators were asked to independently analyse the recorded speech samples of participants in group II (N=10) and the results of the two investigators were assess for interjudge reliability for both words and connected speech samples. The results of Cronbach's alpha revealed low interjudge reliability (α < .5) for word sample and moderate reliability (.7 < α > .5) for connected speech assessed subjectively (Table 4.2).

Table 4.2

Results of reliability analysis using Cronbach's alpha

		Subjective Assessment		**Objective Assessment**	
		Word	**Connected Speech**	**Word**	**Connected Speech**
Intrajudge reliability	Cronbach's alpha (α)	.971	.983	.988	.949
Interjudge reliability	Cronbach's alpha (α)	.291	.533	.624	.802

On the other hand, reliability was found to be moderate (.7 < α > .5) and good (α > .7) for word and connected speech samples respectively, when analyzed using objective measures (Table 4.2).

CHAPTER 5

DISCUSSION

The present study aimed to study the relationship between subjective and objective speech intelligibility measures in children with Speech Sound Disorder (SSD) aged 4 – 7 years. The participants of the study were divided into two groups with 10 children with SSD in each group. Each participant was tested individually and both word and connected speech samples were obtained from them using picture naming and picture description tasks respectively. The samples were recorded and subjected to subjective and objective measures of speech intelligibility. Speech samples of participants in group 1 was analyzed by the investigator while those of group II was carried out by a second investigator.

The results of the study revealed significant correlation between subjective and objective measures for both word and connected speech samples in group II indicating a high positive correlation. However, results of correlation analysis in group I did not show significant correlation between subjective and objective measures of speech intelligibility for both word and connected speech samples. These findings indicate that speech intelligibility estimations differ significantly based on listeners. Speech samples were analysed by different investigators in group I and II.

A closer look at the individual data indicate that the speech intelligibility was found to be poor on subjective measures compared to objective measures in both groups of participants. These findings could be attributed to the large extent of subjectivity in rating speech intelligibility based on measures such as rating scales or

equal-appearing scaling methods. On the other hand, objective measures such as calculation of PCC involves forced-choice recognition techniques and the phonemes are to be identified as either correct or incorrect following a phonetic transcription, thereby reducing the extent of subjectivity in estimating speech intelligibility.

The results of reliability analysis revealed high intrajudge reliability ($\alpha > .9$) for both word and connected speech samples analysed using subjective and objective measures of speech intelligibility. However, results of interjudge reliability were found to be mixed with higher reliability observed for objective measures of speech intelligibility compared to subjective measures. On comparing the estimates of speech intelligibility obtained for word and connected speech samples, reliability was found to be higher for connected speech than word samples. These findings indicate that although there is consistency in the speech intelligibility estimation by a given examiner on two different points of time, the same may not hold good across different examiners.

The findings of the current study are in partial consonance with that reported in the literature. Dukart (2000) examined the reliability of speech intelligibility ratings by novice listeners compared to orthographic transcriptions by students of speech-language pathology. The author reported a strong positive correlation between listener's ear estimations and orthographic transcriptions. Similar findings were obtained in the present study, although in one group of participants, wherein subjective and objective measures of speech intelligibility were found to have a high positive correlation. Similarly, Lohmander et al (2005) carried out correlation analysis and

reported that there was strong correlation between intelligibility ratings for spontaneous speech and PCC score for single words.

The nature of the tasks used across studies as well as the measures considered for analysis could also influence the results of speech intelligibility. While the current study used picture naming tasks to elicit speech samples at the word level and picture description for connected speech, Dukart (2000) used story telling tasks to obtain spontaneous speech samples.

In consonance with the earlier literature, the findings of the present study highlights that various methods of assessing intelligibility provide complementary information. While objective measures help identify specific speech errors, subjective measures capture the listener's overall perception of speech clarity (Gordon-Brannan & Hodson, 2000; Kent, 1992; McLeod & Baker, 2014; Shriberg & Kwiatkowski, 1982; 1994). Overall, the present study showed varying degrees of correlation between subjective and objective speech intelligibility measures and highlighted strong intrajudge reliability but mixed results for interjudge reliability. Despite individual inconsistencies, the overall correlation with orthographic transcription was substantial, suggesting that collective simple judgements align well with more objective methods.

CHAPTER 6

SUMMARY AND CONCLUSIONS

The current study aimed to study the relationship between subjective and objective measures of speech intelligibility in children with Speech Sound Disorder (SSD) aged 4 to 7 years. The objectives of the study were to study the relationship between subjective and objective measures of speech intelligibility in children with SSD for words and connected speech.

The study included 20 children with a clinical diagnosis of SSD in the age range of 4 to 7 years. They were further divided into groups with ten participants in each. The stimuli used to assess speech intelligibility included both words and connected speech. The Kannada Diagnostic Photo Articulation Test (KDPAT) (Deepa & Savithri, 2010) was used to elicit word samples via picture naming task while connected speech samples were elicit using picture description task.

The recorded speech samples were subjected to both subjective and objectives measures of speech intelligibility, separately for word and connected speech. Speech samples of participants in group I was analyzed by the investigator of the study while that of group II was analyzed by a second investigator. Subjective assessments were carried out using an equal-appearing scaling method in which the speech samples were rated for intelligibility between 0 and 100, where ‘0’ indicated completely unintelligible and ‘100’ indicated completely intelligible. Objective assessment included calculation of PCC by dividing the total number of correct consonant productions by the total

number of intended consonants and multiplying by 100. In addition, intrajudge and interjudge reliability measures were established.

The results of the study indicated significant correlation between subjective and objective measures for both word and connected speech samples in group II that was assessed by the second investigator but not in group I. The results of reliability analysis revealed high intrajudge reliability ($\alpha > .9$) for both word and connected speech samples analysed using subjective and objective measures of speech intelligibility. However, results of interjudge reliability were found to be mixed with higher reliability observed for objective measures of speech intelligibility compared to subjective measures. In addition, reliability was found to be higher for connected speech compared to word samples.

These findings collectively emphasize the need to include different types of speech samples with varying levels of complexity in children with SSD for a better understanding of the nature and consistency of errors. Further, analysis of speech intelligibility should consider both subjective and objective measures by more than one examiner to obtain accurate estimation of the severity of the disorder.

6.1 Implications of the study

- The findings of the current study provides an insight into the relationship between subjective and objective measures of speech intelligibility in children with SSD
- The findings also sheds light on the similarities/differences obtained in speech intelligibility measures between word level and connected speech samples, which in turn have applications in estimating the severity of SSD in routine clinical situations.

6.2 Limitations of the study

- The sample size of the study was relatively small, which may limit the generalizability of the findings.
- The participants of the study included children with SSD irrespective of the severity of the condition, which could have influenced the findings.

6.3 Future directions

- Future research with larger and more diverse samples concerning types and severity of SSD would provide more robust insights into the subjective and objective measures of speech intelligibility in this population.
- Acoustic analysis could be carried out as an additional measure for objective analysis.

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APPENDIX 1

Stimulus for picture description

APPENDIX 2

Rules to be followed for calculation of Percentage of Consonants Correct (PCC)

1. Word samples

i. Score only the first production of consonants if a syllable is repeated (e.g., ba—balloon). Score only the first production of /b/.
ii. Do not score consonants if a word is unintelligible or only partially intelligible.
iii. Errors include substitution, deletions, distortions, and addition. Voicing errors are only scored for consonants in the initial position of words.
iv. If /ng/ is replaced with /n/ at the end of a word, do not score it as an error. Likewise, minor sound changes due to informal speech and selection of sounds in unstressed syllables are not scored as errors. Eg /fider/ for “feed her” , /dono/ for “don’t know”)
v. Dialectal variables are not scored as errors.
vi. While calculating geminated clusters (eg: a**pp**a), score two points (on lines similar to al Huneety et al., 2024)

2. Connected speech samples

i. Leave the starting ten words from the connected speech samples and the last ten words while calculating.
ii. Score only the first production of consonants if a syllable is repeated (e.g., ba-balloon). Score only the first production of /b/.
iii. Do not score consonants if a word is unintelligible or only partially intelligible.
iv. Errors include substitution, deletions, distortions, and addition. Voicing errors are only scored for consonants in the initial position of words.
v. If /ng/ is replaced with /n/ at the end of a word, do not score it as an error. Likewise, minor sound changes due to informal speech and selection of sounds in unstressed syllables are not scored as errors. E.g. /fider/ for “feed her”, /dono/ for “do not know”)
vi. Dialectal variables are not scored as errors.
vii. While calculating geminated clusters- score two points (on lines similar to al Huneety et al., 2024)