PROCESSING PREDICTORS OF SEVERITY OF SPEECH SOUND DISORDERS

A thesis submitted in partial fulfilment of the requirements for the Degree of Master of Science in the Department of Communication Disorders

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List of Abbreviations

CELF – Clinical Evaluation of Language Fundamentals

CELF Pre – 2 Australian – Clinical Evaluation of Language Fundamentals Preschool – Second Edition Australian Standardised Edition

DEAP – Diagnostic Evaluation of Articulation and Phonology

IPA – International Phonetic Alphabet

NRT – Nonword Repetition Test

PA – Phonological Awareness

PCC – Percentage of Consonants Correct

PPC – Percentage of Phonemes Correct

PRJT – Phonological Representation Judgement Task

PVC – Percentage Vowels Correct

QPR – Quality of Phonological Representations

SD – Standard Deviation

SRT – Syllable Repetition Task

SSD – Speech Sound Disorder

TD – Typically Developing

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Abstract

This study investigated whether or not variability in the severity of speech sound disorders is related to variability in phonological short-term memory and/or variability in the accuracy of phonological representations. The aim was to determine speech processing predictors of severity of speech sound disorders. A total of 33 children, aged three to six years of age, were assessed on measures of nonword repetition, accuracy of phonological representations, accuracy of speech production, and language. The tests administered included the Clinical Evaluation of Language Fundamentals Preschool – 2 Australian, the Diagnostic Evaluation of Articulation and Phonology, the Nonword Repetition Test (modified), and the Phonological Representation Judgement Task (modified). The relationships between the results of these tests were established using a correlation analysis. The relationship between accuracy of phonological representations and the percentage of consonants correct was found to be mediated by language. There was no significant relationship between nonword repetition and percentage consonants correct. These findings may have been the result of small sample size, age of the participants, or co-morbid language difficulties. These findings imply that variability in severity of speech sound disorders may be related to a variable not directly assessed in this study. This variable may be a constraint relating to the stored motor programs within children's speech processing systems. Implications for future research are discussed.

Chapter 1: Literature Review

Speech Sound Disorder

Speech sound disorder (SSD) has also been referred to as phonological impairment, speech disorder, speech delay, speech impairment, or functional articulation disorder. The term SSD describes a condition in which systematic errors in the production of words are made by young children when compared to correct adult productions (Munson, Baylis, Krause & Yim, 2009). Most children's speech production begins to approach an accurate match to adult speech production by approximately six years of age, and completes its development by approximately nine years of age (Smit, Hand, Freilinger, Bernthal & Bird, 1990). However, for a certain proportion of children these speech sound errors are persistent (Munson et al, 2009).

SSD is believed to have its roots in various aetiologies, including developmental disorders, cognitive impairments, and hearing impairments (Leonard, 1995). However, there is also a group of children with SSD to whom none of these potential aetiologies apply, and for whom the origin of the SSD is unknown.

Based on a population sample of 1,328 six-year-old monolingual English speaking children in the United States of America, it has been found that the prevalence rate for SSD is 3.8%, and that the prevalence is 1.5 times higher in boys than in girls (Shriberg, Tomblin and McSweeny, 1999). In the United Kingdom, it has been found, based on data gathered on 1,100 children who were referred to a speech and language therapy service over 15 months, that there was an estimated referral incidence of 6.4% (Broomfield and Dodd, 2004).

For children with SSD, speech production often resembles that of typically developing (TD) children at a younger age. This applies especially in terms of: segmental accuracy, distinctive features, phonological processes, implication laws, subphonemic distinctions, avoidance, and sensitivity to ambient language (Leonard, 1995). Segmental accuracy refers to the phonemes that are produced correctly. Distinctive features are the features that make phonemes distinct from each other. For example, /p/ and /b/ have the same place and manner of articulation and differ only in terms of voicing. Therefore, their distinctive feature is voicedness. The term phonological processes describes systematic patterns of errors. For example, the habitual production of /k/ as /t/, also referred to as fronting of velars, is a phonological process. Implication laws are laws governing the implied phonetic distinctions within a child's speech system. That is, that the presence of a phonetic distinction within the child's phonetic inventory implies that another type of distinction will be made. For instance, the presence of two distinct phonemes with the same place and manner of articulation, such as /t/ and /d/, implies that the child is making a distinction based on voicing within their inventory. Subphonemic distinctions refer to contextual changes made to a phoneme that do not alter it enough for it to become a different phoneme. An example of this is when a vowel is lengthened when followed by a voiced plosive, but not when it is followed by an unvoiced plosive. The term avoidance refers to the avoidance of speech forms that the child finds difficult to produce. Sensitivity to ambient language relates to the use of similar phonemes existent in the ambient language to substitute sounds that the child cannot produce.

However, children with SSD differ from younger TD children in several ways (Leonard, 1995). Firstly, children with SSD make fewer pre-vocalic voicing errors (e.g. producing the word "fan" as /væn/). Secondly, they display more atypical errors, such as substitution of presumably later developing sounds for earlier developing ones, or the use of phonemes not existent in the ambient language. Thirdly, children with SSD have an unsystematic application of sounds in speech. This is evidenced by increased variability in their speech production. Finally, children with SSD experience a lag between phonological and lexical development. That is, their lexical development is even slower than their phonological development. In addition to the variation between children with SSD and their TD peers, children with SSD also tend to be heterogeneous. That is, they differ from each other in terms of the types of errors that they make. Notably, children with SSD are also heterogeneous in terms of the severity of their SSD, which can range widely, and it is this factor which is of concern in the current study.

Severity of SSD

Several different conceptions of severity of SSD exist. These include normative comparison, intelligibility, levels of concern, prognosis, and accuracy of production. Normative comparison relates to the accuracy of the surface presentation of the child’s speech in relation to that of their peers, and is descriptive in nature. In this conception, severity is often derived from normative data in formal assessments, such as the Goldman-Fristoe Test of Articulation 2 (Goldman & Fristoe, 2000). However, it can be argued that these assessments do not always provide adequate qualitative information on the types of errors made, and also often include some degree of cultural bias (Dodd & Crosbie, 2005). Alternately, intelligibility may be used to indicate severity. Intelligibility relates to how much of a child’s speech can be understood by a novel listener. This novel listener then proceeds to subjectively rate the child’s unintelligibility as mild, moderate or severe (Dodd & Crosbie, 2005). This approach, however, is subjective and may not always provide enough rigour for scientific research. It has been suggested that both the degree of concern felt by stakeholders as a result of the disorder, as well as consequences of the disorder projected by a speech and language therapist (i.e. prognosis), should also factor into decisions of severity (Dodd & Crosbie, 2005). However, again, these measures are subjective in nature, and may not always be appropriate for use in research.

Severity can also be described by measuring the percentage of consonants correct (PCC) and the percentage of vowels correct (PVC) (Pascoe, Stackhouse & Wells, 2006). This is calculated by dividing the number of accurate productions of sounds by a child, by the number of opportunities for production of those sounds within a speech sample. PCC and PVC combined can then yield the percentage of phonemes correct (PPC). Commonly used guidelines for severity in relation to PCC are that a PCC score of more than 90% can be considered mild; a PCC score of 65-89% can be considered mild-moderate; a PCC score of 50-64% can be considered as moderate-severe; and a PCC score of less than 49% can be considered severe. PCC, PVC and PPC all avoid the confound of subjectivity, as they are calculated mathematically. Additionally, they can be derived from any speech sample, thereby allowing the examiner to avoid cultural bias by choosing appropriate stimulus items.

However, interpretations of PCC scores as described above are based on the speech skills of children over the age of five years. The concept of PCC was revisited in a study of 40 TD children (20 boys, 20 girls), who were followed longitudinally (Campbell, Dollaghan, Janosky & Adelson, 2007). Spontaneous speech samples were gathered from all the participants, and the mean PCC scores of the samples were calculated. This was done in order to find a way to apply PCC to younger children, as well as to account for the very rapid development of children’s speech skills. As a result, the PCC-R was produced. The PCC-R is a performance curve capable of distinguishing accurately between children with TD speech and children with SSD, controlling for age at one-month intervals. The curve includes a mean PCC score, as well as a standard deviation (SD) for each one-month age band, from 18 to 172 months.

When considering PCC as a measure of severity, and the variability of severity that is observed in children with SSD, it raises the question as to what might influence this severity. In order to consider this question, one must first have a framework outlining the possible influences. Potential frameworks to fulfil this need are discussed in detail below.

Frameworks for SSD

There are a number of frameworks in which SSD can be described. Three frameworks that are commonly used are described as follows. The first framework seeks to classify them by surface characteristics, as well as demographic and genetic data (Shriberg, Lewis, Tomblin, McSweeny, Karlsson & Scheer, 2005). The second framework also classifies SSD based on surface characteristics (Dodd & Crosbie, 2005). The third framework that will be discussed approaches SSD from a psycholinguistic perspective and seeks to describe the processing deficits underlying the surface presentation of the SSD (Stackhouse & Wells, 1997).

The first framework was described by analysing conversational speech samples from 72 preschool-aged children (Shriberg et al, 2005). The children all had a SSD of unknown aetiology, and the speech samples were analysed in terms of types of errors, demographic and genetic data, and speech accuracy. The framework consisted of seven SSD subtypes. This framework, however, has been challenged (Fox, Dodd & Howard, 2002). Information on potential risk factors was gathered from the parents of 65 children with SSD between the ages of two- and seven-years. An attempt was made to categorise the participants according to the presence of one of the aetiological factors described by this framework: genetic (measured through family history); history of otitis media with effusion; developmental apraxia of speech; or psychological influence. It was found that 59% of the participants were unable to be classified within this framework, with 12% of these exhibiting more than one of the risk factors and the remainder exhibiting none of the risk factors at all.

The second framework (Dodd & Crosbie, 2005) is a classification system of speech disorder based on linguistic symptomology. This system describes childhood apraxia of speech (CAS), which is defined as a motor-speech disorder, as well as four subgroups of speech disorders:

1. Articulation disorder, defined as difficulty accurately producing specific phonemes. This difficulty is present regardless of whether the phoneme is imitated or produced spontaneously, and the error for those specific phonemes is always the same;
2. Phonological delay, defined as when a child uses phonological processes in their speech, all of which occur in TD children, and with at least some of these processes typically occurring in children at a younger age;
3. Consistent phonological disorder, defined as the consistent use of phonological processes which do not occur in TD children, usually in conjunction with other processes which do occur in TD children;
4. Inconsistent phonological disorder is defined as when 40% variability is present in a child's phonological system. That is, when a child makes multiple errors for the same word.

This framework does suggest several causative or maintenance factors, divided into organic (e.g. hearing, auditory processing, oro-motor skills) and non-organic (i.e. related to the language-learning environment) factors (Dodd & Crosbie, 2005). However, the framework acknowledges that not all children with SSD can be accounted for by these factors. It states that, provided that these organic and non-organic factors have been excluded, further consideration is not strictly necessary for suitable intervention provision.

In addition to the first two frameworks, which classify SSD by surface presentation, there is a third framework which classifies SSD in terms of information processing. This is the psycholinguistic framework (Stackhouse & Wells, 1997), which describes a psycholinguistic approach to SSD. It is focused on identifying individual deficits within the speech processing system of a child in order to generate an individual profile of that child's system. It seeks to do this in order to account for the observed heterogeneity within the group. It has been argued that the psycholinguistic framework neither takes any causal or co-morbid relationships between deficits into account, nor more centralised deficits (e.g. learning), and that intervention based on identified deficits is not necessarily effective or efficient (Dodd, Holm, Crosbie & McCormack, 2005). However, this view was countered by evidence of the efficacy of providing intervention within this framework in a single-subject designed study on a six-year-old girl who had a SSD (Pascoe, Stackhouse and Wells, 2005). The subject's assessment was analysed using the psycholinguistic framework, and she received 30 hours of intervention based on the results of this. An assessment following intervention showed significant change in the subject's speech.

The psycholinguistic framework appears to offer significant promise as a method of investigating the phonological processing abilities of young children, and it is the framework employed in the current study. To illustrate the framework of phonological processing, a hierarchical speech processing model is described (Stackhouse & Wells, 1997). This model is organised along two axes: input vs. output, and denying lexical access vs. requiring lexical access. Speech and phonological awareness elements are organised along these axes according to the processing requirements of each element (Figure 1). The organisation of this framework allows the testing of these elements in relative isolation, in order to build a deeper understanding of underlying deficits to the surface presentation of SSD. As such, it might be possible to gain insight into what makes the surface presentation of one child with SSD more severe than another by comparing children's performance on multiple elements of the framework relative to surface presentation (i.e. speech production). For example, if the root of the observed severity of a SSD was imprecision of phonological representation, then severity of speech production would be correlated with scores achieved in an assessment of phonological representations. However, if the child's ability to remember phonological information was implicated in imprecise representations, then scores on tests of phonological memory and phonological representation would also be correlated.

The framework can be summarised as the assumption that information is received by the brain. From there, the information is remembered and stored in the lexicon of the brain as lexical representations. When needed, these representations can then be retrieved and produced, either as spoken or written words (Stackhouse & Wells, 1997). Hence, limitations in a child's ability to remember spoken information regarding an utterance would result in limitations in their ability to accurately store the information in the lexicon. This would result in representations of words that were incorrect or unclear. This in turn would affect the child's ability to verbally produce the word accurately, as the child would be relying on inaccurate information to formulate a motor program for production. This would then result in literacy difficulties, as the child's written production of a word would also be reliant on the child's internal, inaccurate, representation of the word.

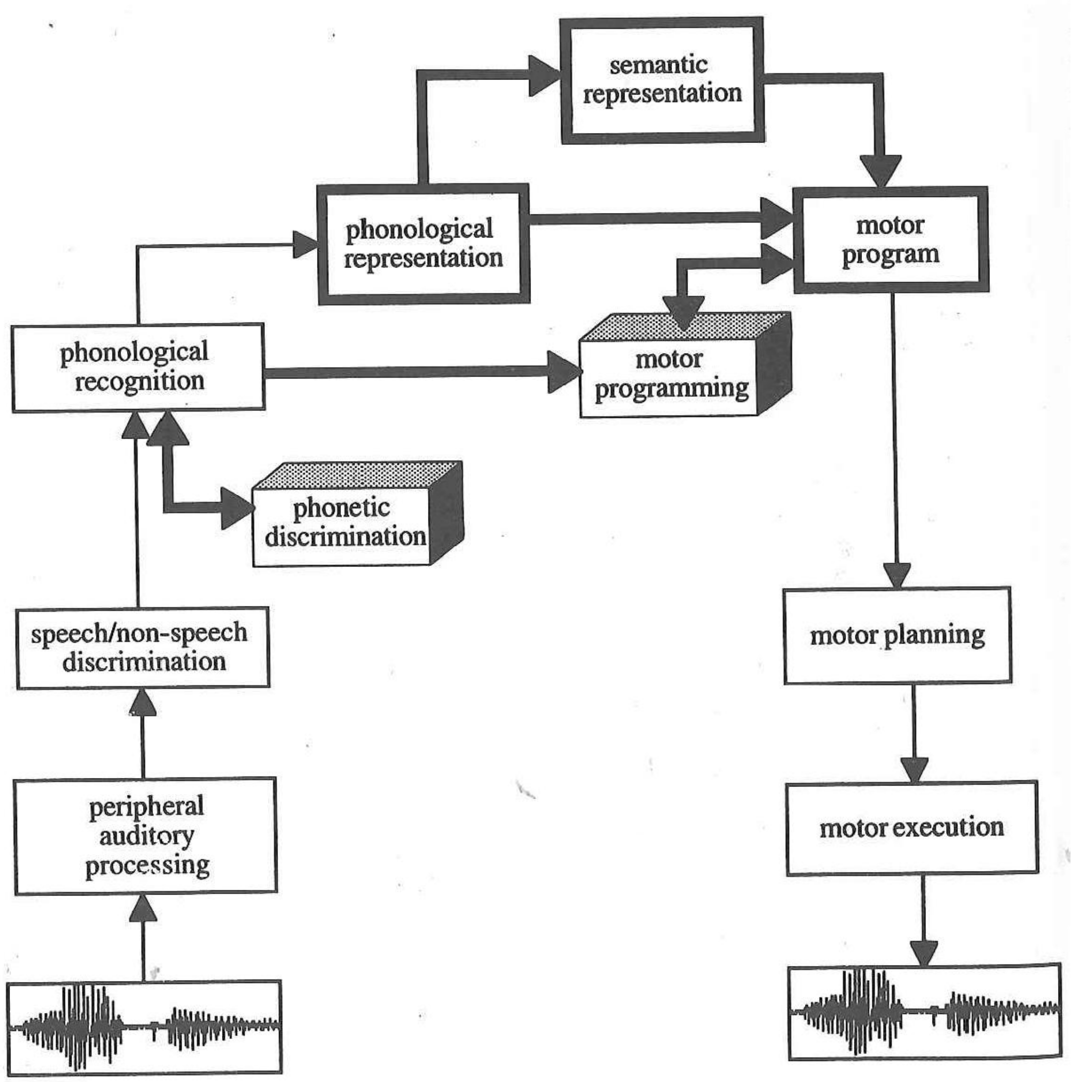

Figure 1: *Stackhouse and Wells (1997): Speech processing model (Appendix G)*

It has been suggested that a child's phonological memory, which refers to the child's ability to remember auditory information, should be explored as a separate factor that may be implicated across all levels of the framework (Stackhouse & Wells, 1997). As such, memory load could be manipulated in order to increase processing demands in testing situations. It was also argued that no element, memory included, should be tested in isolation, and that more accurate information regarding the child's phonological processing system could be gathered by comparing performance on tasks at multiple levels of the framework. However, phonological memory ability is only one element which might impact on severity SSD. A range of potential elements must therefore be discussed.

Candidate Psycholinguistic Factors that Relate to Severity of SSD

The psycholinguistic framework (Stackhouse & Wells, 1997) proposes a speech processing model containing several elements which could impact on severity of a SSD. These include: motor planning and programming, lexical access, auditory discrimination, phonological awareness, phonological short term memory and phonological representations.

Motor planning and programming. Potential support for a link between range of movement and motor coordinative pattern's stability has been found (van Lieshout, Bose, Square & Steele, 2001). This was done by measuring the movements of articulatory structures in a 30-year-old woman with apraxia of speech and Broca's aphasia, and then comparing the subject's fluent and dysfluent speech. However, various observations, such as a prevalence of substitution errors rather than distortions, call into question the viewing of SSD as purely motoric in origin (Leonard, 1995). In addition, the performance of 95 preschool-aged children with SSD on the Syllable Repetition Task (SRT) did not support a motor planning deficit as no notable differences in terms of ease of articulation was found between the experimental subgroups (Shriberg et al, 2009). This meant that sounds which were physically more difficult to produce did not result in notably poorer performance. However, the SRT was designed to eliminate the confound of using a speech production task with children with SSD by simplifying the stimuli. It is possible that the SRT might be so simplified that it simply does not challenge a child's articulatory system enough to be able to show such differences.

Lexical access. Access to the lexicon has been investigated in relation to the accuracy of speech production in 73 children between the ages of three and seven years by using a delayed naming task (Munson, et al, 2009). In this task, participants were required to name a picture upon the presentation of a response prompt. The delay interval between presentation of the picture and presentation of the prompt was varied. Concurrent presentation and prompt was assumed to involve both generation of a motor plan and lexical access. A delayed prompt would involve generation of the motor plan only, as the lexical access was presumed to have occurred during the delay. Following presentation and prompt, the latency between prompt and correct response was measured as a dependent variable. The lexical access abilities of children with SSD did not differ significantly from those of TD children, and severity of SSD predicted naming latencies equally well across all delay intervals. This suggested that the severity of the child's SSD was not related to lexical access abilities.

Auditory discrimination. The term auditory discrimination refers to the brain's ability to discriminate between two sounds prior to further processing them. Evidence of auditory discrimination difficulties has been put forward as a potential causative factor in SSD. A study of 24 seven- to nine-year-old children with language impairments found evidence of such a deficit. It was concluded that this deficit would then influence the onward processing of the speech signal and the quality of phonological representations laid down as a result (Čeponienė, Service, Kurjenluoma, Cheour & Näätänen, 1999). Poor quality phonological representations would then presumably lead to poor productions of the associated words. Children with SSD, however, were excluded from this study. Studies which did include children with SSD have found limited support for a deficit in this aspect of speech processing in children with SSD. For example, assessment of the speech discrimination of 14 five- and six-year-old children with SSD found that, while the children with SSD did perform more poorly than the control group, all were able to discriminate between phonemes that they were unable to produce to some degree (Bird & Bishop, 1992).

Phonological awareness. When compared to age-, socioeconomic status-, emergent literacy-, and receptive language-matched TD peers, a cohort of 13 four-year-old children with SSD were found to have significantly lower phonological awareness (PA) skills (Rvachew, Ohberg, Grawburg & Heyding, 2003). This suggested that PA might be related to SSD and prompted suggestions that children with SSD should be screened for PA difficulties while at preschool .These findings were refined in a study of 95 four- and five-year-old children with SSD (Rvachew & Grawburg, 2006). The study sought to elucidate the relationships between the variables believed to contribute to poor PA. However, it was found that perception of speech, rather than the production of it, appeared to be the significant contributor to PA skills. The production of speech itself was not related to PA skills. This suggested that children with SSD were not innately at risk for PA difficulties, but were only at risk if their speech perception skills were also low.

Further evidence countering PA as a causative factor of SSD came from a later study of the relationship between severity of SSD and PA (Mortimer & Rvachew, 2008). In that study, 14 female and 24 male four- and five-year-old children with SSD were assessed on measures of PA, language and speech. The study found that while some children with SSD did develop reading difficulties related to PA deficits, this relationship was due to co-morbid difficulties with finite verb morphology and inflectional suffixes, and not the SSD itself. Again, this suggested that PA deficits in children with SSD are not related directly to the SSD, but rather to other factors associated with it.

Phonological short-term memory. A link between memory and speech and language difficulties has been widely reported. One model of working memory has formed the theoretical basis for much of this research (Baddeley & Hitch, 1974). The model comprises the *central executive*, which is responsible for managing and manipulating the flow of information from its short-term memory storage spaces: the phonological loop which deals with auditory or phonological information, and the visuo-spatial sketchpad which deals with visual information. This model was expanded to include the episodic buffer, a temporary storage component of the system also under the control of the central executive, but able to integrate information from multiple sources (Baddeley, 2000). Two sub-components of the phonological loop have also been described, comprising: an articulatory rehearsal process, and a short-term phonological store. The latter is alternately referred to as phonological short-term memory (PSTM; Boudreau & Costanza-Smith, 2011) (Figure 2).

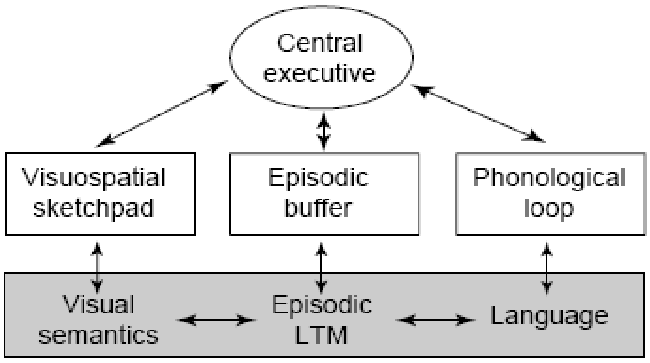

Figure 2: *Baddeley's (2000) model of the relationship between memory and language (Appendix G)*

PSTM has been noted to be influenced by age in a study of 51 TD children between the ages of two and five years (Kornisch, 2012). It was found that the performance of these children on tasks assessing PSTM improved with age. Additionally, it was noted that there was significantly more variability in PSTM abilities in the younger children within the sample, when compared to the older children within the sample. This provided evidence that not only does PSTM improve with age, but that variability in performance decreases with age.

PSTM has been widely implicated in speech and language deficits (e.g. Alloway, Rajendran & Archibald, 2009). While both language and motor difficulties are linked to working memory in children with various developmental disorders, language impairments are specifically associated with PSTM deficits (Alloway, et al, 2009). Additionally, SSD was linked with lower memory quotients in the Ross Information Processing Assessment Test – Primary in a study of 33 six- to ten-year-old children with SSD (Ozcebe & Belgin, 2005). Leonard (1995) described a possible explanation for these findings: if the PSTM's function is that of storing new phonological information long enough for the formation of a representation of the word, then an impairment in PSTM might result in degradation of the phonological information prior to the complete formation of this representation. This might then result in impaired new word learning, as the word would need to be heard additional times for it to be learned. It could also result in inaccurate representations of words being laid down.

PSTM is typically assessed using nonword repetition tasks (Boudreau & Costanza-Smith, 2011). These tasks require a child to listen to and then repeat nonwords, with only one exposure. The accuracy of the child's repetition of the word is used to measure their PSTM. However, a confound arises when attempting to investigate the PSTM of a child who experiences a SSD using a nonword repetition task. The child is scored on the accuracy of their imitation of a nonsense word, when accuracy of speech is already a difficulty for them. To address this, a tool named the Syllable Repetition Task (SRT) was developed (Shriberg, Lohmeier, Campbell, Dollaghan, Green & Moore, 2009) in a study on 95 children with SSD and 63 age-matched TD children, aged 36 to 60 months. It was argued that if a child is habitually unable to produce a sound which is assessed in a nonword repetition task, the consequent error would not be a reflection of their ability to perform the task, but would be related to their habitual speech difficulty. As a result, the SRT comprised stimuli which contained only four of the earliest-developing consonants, and one early-developing vowel. The study found that children with SSD significantly underperformed on this task in comparison to their TD peers, and gave some insight into PSTM constraints within a child's phonological processing system.

In the technical report relating to the SRT studies, it was noted that the severity of the SSD, as measured by several speech metrics, did not appear strongly associated with performance on the SRT (Shriberg & Lohmeier, 2008). However, within the same study, a significant correlation was found between severity of SSD and performance on the Nonword Repetition Test (NRT) designed by Dollaghan & Campbell (1998). A possible explanation for this discrepancy might be that, in simplifying the assessment to make it suitable for children with SSD, the SRT became oversimplified and was therefore unable to challenge the subjects enough to show a link between PSTM and severity of SSD. There is also a possibility that nonword repetition in isolation cannot accurately predict the severity of a SSD, but that in combination with another measure a stronger predictor may be identified. One candidate variable for such a combination could be accuracy of phonological representations.

Phonological representations. Phonological representations can be defined as the stored phonological codes representing words, which are stored in the long term memory of the brain (Claessen, Heath, Fletcher, Hogben and Leitão, 2009). The learning of these representations occurs after only a brief exposure, called fast mapping (Fisher, Hunt, Chambers, & Church, 2001). Fast mapping refers to the process wherein the child must first encode the sounds, and then generalise them enough to recognise them when spoken again, even when in a different context. Evidence for this process was found in a study of 24 two-year-olds (Fisher et al, 2001) who were able to encode and recognise new words with very few exposures.

Evidence has also been found for a constraint in the accuracy of the encoding of nonwords’ short-term representations (Shriberg, et al, 2009). This was done by contrasting within- vs. between-class substitution errors in 95 children with SSD and 63 TD children, aged 36 to 60 months. Within-class substitutions are when sounds with the same manner of articulation are substituted for each other (e.g. when a plosive is substituted for another plosive). Between-class substitutions are when the substituted sound does not have the same manner as the target (e.g. when a plosive is substituted for a fricative). It was theorised that within-class substitutions showed a partial ability to encode the sound. Between-class substitutions, on the other hand, would imply that there was not even this partial ability to encode the sound accurately. This would therefore imply an auditory-perceptual coding constraint. The study found that children with SSD consistently made more between-class errors than their TD peers in three- and four-syllable nonwords, supporting an auditory-perceptual encoding constraint.

There have also, however, been studies which did not support the hypothesis that children with SSD had deficits in their ability to encode words phonologically in order to create underlying representations during speech. For example, no significant differences were found in response latency between children with SSD and TD children (18 in each group) (Munson, et al, 2009). The children, between the ages of three and seven years, simultaneously attended to one aspect of a stimulus while disregarding another. That is, the participants were asked to name a picture while listening to a word which they were told to ignore. The response latency was then measured. The stimulus word either: (a) matched the picture, (b) did not match but was related to the picture in terms of phonological onset, (c) did not match but was related to the word in relation to phonological rime, or (d) did not match and was completely unrelated to the picture. The word would be played just before, just after, or simultaneously with the presentation of the picture. TD children were expected to have the shortest latencies for matching words, the longest latencies for unrelated words, and intermediate latencies for phonologically related words. In comparison to their TD peers, children with SSD were expected to have smaller differences between the types of latencies. However, these differences between the SSD and TD groups were not found. This indicated that the children with SSD had no more difficulty encoding phonological information than TD children.

Counter to this, a study of nine children with SSD aged three to five years found that children with SSD were less able than TD peers to correctly judge between correct and incorrect productions of familiar multisyllabic words (Sutherland & Gillon, 2005). This indicated limitations in the accuracy of the children’s underlying phonological representations. In addition, these children were also less able to learn nonwords compared to their TD peers, suggesting further difficulties in establishing new representations.

In a study designed to test the ability of 25 children with SSD to learn new phonological representations, novel words were presented in a passive listening task before requiring the child to repeat them (Munson, et al, 2009). It was found that children with SSD were less responsive to the effect of this priming than TD children. This suggested difficulties in implicitly learning new representations with minimal exposures. This effect was found not to be an artefact of the speech production accuracy between the groups, but the magnitude of it was found to be proportional to the severity of the SSD, as measured by percentile ranking on the Goldman-Fristoe Test of Articulation – 2 (Goldman & Fristoe, 2000). The study concluded that a deficit in learning new representations might be causally related to SSD, as such a deficit would in all probability result in targets for speech production which were imprecise and inadequately distinguished from one another. This provided support for the theory proposed by Stackhouse and Wells (1997) in their previously discussed psycholinguistic framework.

A way to assess the accuracy of a stored phonological representation is to ask the child to compare a spoken, familiar word to their own stored phonological representation of the word (Claessen et al, 2009). The child can then be expected to tell the examiner whether or not the spoken word matches their stored representation. However, the requirement of a spoken response creates a confound when assessing children with communication difficulties. Difficulties in generating this response may be related to the communication difficulty, rather than the task. In order to assess the quality of representations in children without the confound of requiring a spoken response from the child, the Quality of Phonological Representations (QPR) task was created (Claessen et al, 2009). In this task, the children were presented with a picture of a familiar item. The children then listened to a production of the word which the picture represented. The production of the word was either correct or incorrect, and the children were asked to judge this. The children responded by pointing to an image indicating whether they thought the spoken word was correct or incorrect. However, while that study investigated the correlation between performance on the task and PA, it did not correlate performance to severity of SSD. Additionally, the QPR was developed for Australian children, opening up the potential for cultural bias if used for children of other nationalities. A similar task, the Phonological Representation Judgement Task, was created in New Zealand (Sutherland, 2006). This task is further discussed in the methodology section of the current study.

Summary

The psycholinguistic framework (Stackhouse & Wells, 1997) provides a series of elements for consideration in the exploration of SSD. Of particular interest in the current study is the severity of SSD, and what elements of the speech processing model proposed in this psycholinguistic framework might predict it. There is limited or conflicting support for a relationship between severity of SSD and motor planning and programming, lexical access, auditory discrimination, or phonological awareness. However, there is significant support for a link between PSTM, phonological representations, and severity of SSD. These three factors, however, have not been directly associated in the research to date. If severity of SSD could be predicted by PSTM and the accuracy of representation in conjunction, the implications for intervention would be significant. It would imply that targeting phonological representations in isolation might be a more efficient and effective method of addressing SSD than more traditional methods. Such a finding could signify a wide-reaching change in the approach to the treatment of SSD.

Research questions.

1. Is there a significant relationship between children's PSTM abilities and the severity of SSD?

Hypothesis 1: Performance on a nonword repetition task is significantly correlated with severity of SSD.

2. Is there a significant relationship between the accuracy of children's phonological representations and the severity of SSD?

Hypothesis 2: Judgements on a phonological representation task are significantly correlated with severity of SSD.

3. If a relationship between both PSTM and phonological representations and the severity of SSD exists, how much independent and combined variance in speech severity scores is accounted for by performance on tests of PSTM and phonological representations?

Hypothesis 3: Accuracy of representations and performance on a nonword repetition task together will have a stronger relationship with severity of SSD than either measure on its own.

Chapter 2: Methodology

This study was approved by the University of Canterbury Human Ethics Committee on 9 November 2011 (approval number: HEC 2011/105) (Appendix H).

Participants

A total of 37 children were recruited to participate in the study. Of this total, two were excluded as they refused to complete the assessments, one was excluded due to bilingualism, and one was excluded as she was too old to be assessed using the Clinical Evaluation of Language Fundamentals Preschool – 2 Australian (Wiig, Secord & Semel, 2006). As a result, the final sample consisted of 33 children, aged between three and six years (Figure 3), with a mean age of 4.5 years. The group consisted of 25 males and eight females.

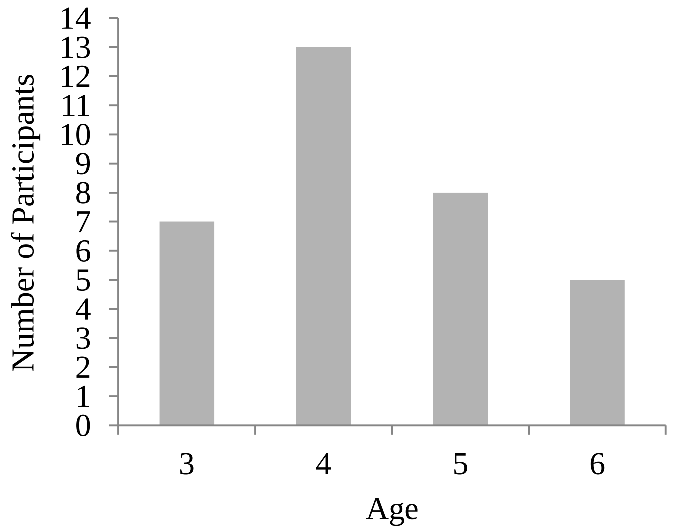

Figure 3: *Age of participants (years)*

The participants were drawn from children currently awaiting or receiving a service from the Ministry of Education, Special Education in Auckland, New Zealand, and from children currently receiving service at the Massey University Speech Therapy Clinic in Auckland, New Zealand. The study information sheet (Appendix A) was provided to parents by staff from the Ministry of Education, Special Education, or Massey University. Parents of participants then contacted the principal researcher to indicate their desire to discuss the study with the principal researcher. If, following this discussion, they chose to participate, signed parental consent (Appendix B) and verbal agreement from the participants was received. Parents were asked to complete a case history (Appendix C) detailing the child's social, medical, developmental and communicative history.

All children included in the study were monolingual New Zealand English speakers with isolated communication difficulties. Children were selected on the basis of having a SSD, and seven of the participants had co-morbid language delays as measured by the Clinical Evaluation of Language Fundamentals Preschool – 2 Australian (i.e. Core Language Scores below the 16^{th} percentile). One of the participants was previously diagnosed by a speech and language therapist and paediatrician as having Childhood Apraxia of Speech. None of the children had any other co-morbid diagnoses (e.g. hearing impairment, medical diagnoses, neurological diagnosis, psychological diagnosis) according to parent report.

Participants' socio-economic status was calculated by referring to the New Zealand government assigned decile rating of each child's school, or the child's local school if the child was not yet attending school. Decile ratings range from one to 10 (Ministry of Education, 2013). A decile rating of one indicates schools that have the highest proportion of students drawn from low socio-economic backgrounds. A decile rating of ten indicates a school which has the lowest proportion of students drawn from low socio-economic backgrounds. Participants were recruited from all decile ratings (one to ten), and the mean decile rating of the group was 6.6 (Figure 4).

In total, 28 of the participants were reported by parents to be of solely European or New Zealand European descent. Two participants were identified as being of mixed

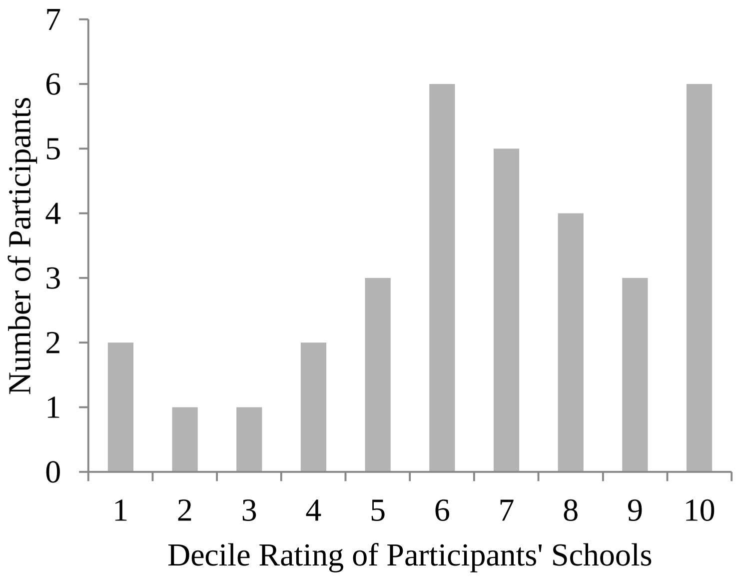

Figure 4: *Number of participants per decile rating of local school*

New Zealand European and Māori descent, and one was identified as mixed New Zealand European and Chinese descent. One was identified as being of Māori and Cook Island Māori descent, and the last participant was identified as being of Pilipino descent.

Materials

In order to answer the research questions, four areas of speech and language performance and processing were measured. These were: general language ability, speech accuracy, PSTM, and accuracy of phonological representations. The following materials were used.

Clinical Evaluation of Language Fundamentals Preschool – 2 Australian. Three subtests of the Clinical Evaluation of Language Fundamentals Preschool – 2 Australian (CELF Pre – 2 Australian) (Wiig, Secord & Semel, 2006) were administered: Sentence Structure (comprehension of various sentence structures), Word Structure (expression of various syntactic forms) and Expressive Vocabulary (naming of vocabulary items). This was to establish the Core Language Score, which allowed the evaluation of each subject's general language skill. It also enabled the diagnosis of the presence or absence of a language disorder, thereby allowing the identification of subjects with co-morbid language difficulties.

The Diagnostic Evaluation of Articulation and Phonology. The Phonological Picture Naming task is part of the Phonological Assessment. This is a section of the Diagnostic Evaluation of Articulation and Phonology (DEAP) (Dodd, Hua, Crosbie, Holm & Ozanne, 2002). The Picture Naming task was administered to establish the subjects' PCC. This task measures children's phonological ability, defined by the test as the child's skills in using phonemes within the context of real words. It allows calculation of PCC based on the speech sample gathered. In this assessment, the child is required to name 50 pictures, and their productions are recorded and transcribed. Errors are recorded as a difference between the child's production of the word and an expected adult model, as identified using the international phonetic alphabet (IPA) transcriptions provided by the assessment. Test-retest reliability and inter-rater reliability of PCC as assessed by the DEAP was reported to be robust. The test samples a wide variety of English phonemes, including all consonants (in both syllable initial and word final positions), all but one vowel, and a range of consonant clusters. In addition, the test samples a range of syllable lengths, contexts and shapes, giving it strong content validity. In the development of the test, the PCC scores of the DEAP were compared to those of the Edinburgh Articulation Test (Anthony, Bogle, Ingram & McIsaac, 1971), and these scores were reported to be significantly correlated ($r=0.95$, $p<0.001$), indicating concurrent validity.

The Nonword Repetition Task. The Nonword Repetition Task (NRT) (Dollaghan & Campbell, 1998) was administered to test the participants' PSTM. This test is comprised of audio recordings of 16 nonwords, produced by an adult speaker according to the IPA transcriptions described by Dollaghan and Campbell (1998). The child is expected to repeat the nonwords following a single exposure. The intended purpose of this test was to use it as a screening tool for language impairments, and it was found to predict these very accurately ($p<0.01$). Inter-rater reliability of this test was reported to range between 90%-100%.

The Phonological Representation Judgement Task. The Phonological Representation Judgement Task (PRJT) (Sutherland, 2006) was administered to test the accuracy of participants' phonological representations of familiar words. This test measures children's ability to judge the correctness of the vowel productions within 30 familiar multi-syllabic words, without requiring a verbal response. Instead, the child is required to point to a picture indicating their response. The words are produced according to the IPA transcriptions reported by Sutherland (2006), divided into the following five categories: (a) all vowel sounds produced correctly; (b) all vowel sounds produced incorrectly; (c) the vowel in an unstressed syllable produced incorrectly; (d) the vowel in a stressed syllable produced incorrectly; or (e) an unstressed syllable deleted from the word altogether. Internal consistency was reported to be high ($\alpha=0.8$), and inter-rater reliability was reported as 100%.

Procedures

In total, 31 of the participants were assessed in their own home with a caregiver present. Two participants were seen at their school instead at parental request, and of these, one was seen without the parent present at parental request. Participants were seated at a child-sized chair and table or on the floor of their home, as per the child's stated preference. Environmental noise was kept to a minimum during testing (e.g. turning off televisions, removing siblings from the room).

The principal researcher, a qualified speech language therapist, interviewed the caregivers to gather the case history information (Appendix B) and administered the tests to all of the participants. The assessment lasted approximately 30 to 45 minutes, and all four assessments were typically administered in the same session. The participants were able to request breaks and were also monitored by the principal researcher and their caregivers for signs of fatigue. Two participants required the assessments to be broken over two sessions in the same environment, the first of which were four days apart, and the second five days apart.

CELF Pre – 2 Australian. The first three subtests (Sentence Structure, Word Structure and Expressive Vocabulary) of the CELF Pre – 2 Australian were administered according to the published procedures of the test.

DEAP. The phonology stimulus items of the DEAP were administered according to the published procedures. The participants' responses were recorded using a Sony ICD-BX700 digital voice recorder and transcribed by the principal researcher.

NRT. The published stimulus items of the NRT (Table 1) were spoken by the primary researcher, a native NZ English speaker, according to the published IPA transcriptions (Dollaghan & Campbell, 1998). Only one change was made to the final stimulus item (number 16), where the last vowel was changed from /aɪ/ to /eɪ/, which was due to an error on the primary researcher's part.

These productions were recorded digitally using a Sony ICD-BX700 digital voice recorder. The item recordings were then entered into a digital audio editing program (Audacity® 1.3.14-beta (Unicode)) and the item length of each item adjusted to match the published mean item lengths (Dollaghan and Campbell, 1998), using the Change Speed function of the programme. The adjusted item lengths were then averaged to ensure that they matched the published averages (Table 2).

Table 1

IPA transcriptions of NRT stimulus items

Item	Transcription
1	/n aɪ b/
2	/v oʊ p/
3	/t aʊ dʒ/
4	/d ɔɪ f/
5	/t eɪ v a k/
6	/tʃ oʊ v æ g/
7	/v æ tʃ aɪ p/
8	/n ɔɪ t aʊ f/
9	/tʃ i n ɔɪ t aʊ b/
10	/n aɪ tʃ oʊ v eɪ b/
11	/d ɔɪ t aʊ v æ b/
12	/t eɪ v ɔɪ tʃ aɪ g/
13	/v eɪ t a tʃ aɪ d ɔɪ p/
14	/d æ v oʊ n ɔɪ tʃ i g/
15	/n aɪ t ɔɪ t aʊ v u b/
16	/t æ v a tʃ i n eɪ g/

Note: the vowel in the last syllable in # 16 was produced as /eɪ/ due to user error.

Following adjustment of the stimulus item lengths, the pitch of the recorded voice for each stimulus item was adjusted to within the primary researcher's typical

Table 2

Digitally adjusted length of stimulus items (milliseconds)

Number of syllables	Item	Length adjustment (from - to)	Average	Dolloghan & Campbell average
1	1	0.66 - 0.62	0.62	0.62
	2	0.60 - 0.62		
	3	0.78 - 0.63		
	4	0.56 - 0.62		
2	5	0.82 - 0.91	0.92	0.92
	6	0.83 - 0.91		
	7	0.83 - 0.92		
	8	0.97 - 0.92		
3	9	1.56 - 1.26	1.25	1.25
	10	1.21 - 1.26		
	11	1.15 - 1.24		
	12	1.34 - 1.25		
4	13	1.40 - 1.50	1.51	1.50
	14	1.75 - 1.50		
	15	2.63 - 1.51		
	16	1.59 - 1.51		

vocal range (±2000Hz – ±4000 Hz). This was done using the Change Pitch function of the programme, and subjectively judged to sound perceptually normal by the principal researcher. Background noise was then digitally removed from all stimulus items using the Noise Removal function of the programme.

Once adjustments were completed, the clarity of the items was tested by having three qualified speech language therapists phonetically transcribe them. The transcripts were 100% accurate.

The items were then embedded into a Microsoft Powerpoint® presentation and were alternated with cartoon pictures of dinosaurs, aliens and monsters gathered from Google Images®. The Powerpoint® presentation was administered to participants by playing it on an HP EliteBook® 8440p laptop running Windows® 7 Pro OA (Appendix D).

All items were administered to all of the participants. The two trial items were introduced to the participants as follows: *"We're going to play a game about some monsters that have funny names. See, like this one (researcher pointed to one picture). The monsters only come out when children call their names. So, I'll tell you the name, and then you call the monster. Ready? Our first monster's name is /mæb/. [child repeated word]* The researcher then provided feedback on the child's performance, and continued with: *Let's do another one:/tɒb/"*. If necessary, the child was prompted to call the monsters by saying *"you call him"* immediately after the stimulus item. If the child required re-focusing to the task, the prompt: *"Listening …"* was used.

Following the training items, the child was asked to wear Sony MDR-XB300 headphones to hear the test stimuli play through the Powerpoint® presentation. Three participants refused to wear the headphones, and the stimuli were played through the built-in speakers of the laptop instead. The volume was set at a comfortable listening level. After each item, the child was praised with *"Good calling!"* and the researcher would click the mouse to make a picture of a monster come up on the screen. Following this, the next item was introduced by saying *"Let's do another one."*

Six participants required repetitions. Four of these were due to no response from the child, and two were due to the child not understanding the task despite completing the trial items accurately. These repetitions were not scored (i.e. the item was scored "0"), as they were performed to keep the child on task and motivated. The participants' responses were recorded using a Sony ICD-BX700 digital voice recorder and were transcribed by the principal researcher.

Four out of 33 participants' recordings (12% of the total sample) of the NRT were randomly selected and the fidelity of the examiner's administration of the test checked by a qualified speech language therapist. The test was administered with 93% accuracy.

PRJT. The stimulus items of the PRJT were produced by the primary researcher, a native NZ English speaker, as per the phonetic transcriptions used in a former study (Sutherland, 2006). These productions were recorded digitally using a Sony ICD-BX700 digital voice recorder. The item recordings were then entered into a digital audio editing program (Audacity® 1.3.14-beta (Unicode)) and background noise was digitally removed using the Noise Removal function of the programme. The stimulus items were manipulated in one of four ways (Sutherland, 2006): typical production of the word (Norm), all vowels altered (Max), deletion of an unstressed syllable (DelUS), and change of an unstressed syllable (ChgUS) (Table 3). Once adjustments were completed, the judgement task was administered to three adults who experienced no communication or hearing difficulties. This was done in order to ensure that the stimuli were clear and the correct responses were achievable. The three adults were able to correctly judge the accuracy of all of the items.

Table 3

IPA transcriptions of PRJT stimulus items

Item	Stimulus	Change	Transcription
1	Telephone	Norm	/teləfoʊn/
2	Dinosaur	Norm	/daɪnəsɔ/
3	Motorbike	Max	/mɜtaɪboʊk/
4	Hippopotamus	DelUS	/hɪpɒtəmɪs/
5	Caterpillar	Norm	/kætəpɪlə/
6	Elephant	DelUS	/elfɪnt/
7	Kangaroo	Norm	/kæŋgəru/
8	Helicopter	ChgUS	/helaɪkɒptə/
9	Telephone	DelUS	/telfoʊn/
10	Butterfly	Norm	/bʌtəflaɪ/
11	Caterpillar	ChgSS	/kautəpɪlə/
12	Motorbike	ChgSS	/meatəbaɪk/
13	Helicopter	Norm	/helɪkɒptə/
14	Dinosaur	DelUS	/daɪnsɔ/
15	Caterpillar	ChgUS	/kætupɪlə/
16	Elephant	Norm	/eləfɪnt/
17	Kangaroo	ChgUS	/kæŋgauru/
18	Butterfly	ChgSS	/bɒtəflaɪ/
19	Elephant	ChgUS	/eloufɪnt/
20	Motorbike	ChgUS	/moutibaɪk/

Item	Stimulus	Change	Transcription
21	Telephone	ChgSS	/touləfoʊn/
22	Kangaroo	DelUS	/kæŋru/
23	Hippopotamus	Norm	/hɪpəpɒtəmɪs/
24	Dinosaur	ChgSS	/dʌnəsɔ/
25	Hippopotamus	DelUS	/hɪpɒtəmɪs/
26	Caterpillar	DelUS	/kætpɪlə/
27	Butterfly	ChgUS	/bʌtuflaɪ/
28	Motorbike	Norm	/moutəbaɪk/
29	Elephant	ChgSS	/ɜləfɪnt/
30	Motorbike	DelUS	/moutbaɪk/

Note. Norm = no change to production of word, ChgSS = vowel of stressed syllable changed, DelUS = deletion of unstressed syllable, ChgUS = vowel of unstressed syllable changed, Max = all vowels changed

The recorded items were then embedded into a Microsoft Powerpoint® presentation and were paired with the same cartoon pictures used in a previous study (Sutherland, 2006). The Powerpoint® presentation was administered to participants by playing it on an HP EliteBook® 8440p laptop running Windows® 7 Pro OA (Appendix D). All items were administered to all of the participants. The task was introduced to the participants as follows: *"We're going to play a game of picture naming. I'm going to name some pictures, and you have to listen carefully, because sometimes I'll say them a good way, and sometimes I'll say them a funny way. Let's look at some pictures"*.

The researcher then asked the child to point to each of the stimulus pictures on a familiarisation page to ensure that the child had a semantic and a phonological representation for each stimulus item. Only one participant required training for one stimulus item (hippopotamus), which was provided by saying: *"it's a hippopotamus. A hippopotamus."* The child was then asked to point to the other four familiarisation pictures on the page before being asked again *"show me the hippopotamus"*, which he was then able to do.

Following the familiarisation task, the trial items were introduced by saying: *"You'll hear me say 'this is a watermelon'. I want you to listen to how I say watermelon. If I say it a good way, then point to the smiley face [researcher pointed to picture of the smiley face], but if I say it a funny way, then point to the cross [researcher pointed to picture of the cross]. Even if you think it's nearly the right way, point to the cross."*

The child was asked to wear Sony MDR-XB300 headphones to hear the 10 trial and 30 test stimuli play through the Powerpoint® presentation. Three participants refused to wear the headphones, and all of the stimuli (trial and test) were played through the built-in speakers of the HP EliteBook® 8440p laptop instead. The volume was set at a comfortable listening level. The child was shown a picture of the stimulus item, while the recording played simultaneously, saying *"this is a [stimulus]"*. If necessary, the researcher then prompted the participant's response by saying *"was that a good way [researcher pointed to the picture of the smiley face] or a funny way [researcher pointed to the picture of the cross]?"* This prompt was dropped within the 10 trial items, as soon as the child began to respond without it. Most children pointed to the pictures, but unsolicited verbal responses were also accepted by the principal researcher. Each response was praised by the principal researcher by saying *"good* *pointing, you pointed to the smiley face / cross"*. If the child required re-focussing to the task, the prompt: *"Listening …"* followed by: "*was that a good way or a funny way?"* was used. The stimuli were repeated on request by the child.

Four out of 33 participants' recordings (12% of the total sample) of the PRJT were randomly selected and the fidelity of the examiner's administration of the test was checked by a qualified speech language therapist. In this sample, the examiner administered 96% of the test correctly.

Data Analysis

The analysis of the CELF Pre – 2 Australian, the DEAP, the NRT and the PRJT are detailed as follows. In addition, the age of participants was also analysed.

CELF. The first three subtests (Sentence Structure, Word Structure and Expressive Vocabulary) of the CELF Pre – 2 Australian were scored, and the Core Language Score and percentile rank calculated. This was done according to the published procedures of the test, in order to identify subjects with co-morbid language difficulties. Additionally, the participants' raw scores for these three subtests were totalled (CELF (Raw)) and entered into subsequent correlation analyses where age was controlled as a confound.

DEAP. The subjects' PCC was calculated according to the published procedures. A phonological process analysis was completed according to the published procedures, and habitual errors noted.

NRT. Each phoneme used in the test was listed at the top of the participant's score form (Appendix E), and the researcher noted the participant's habitual production of each of these phonemes (as noted in the DEAP) in initial, medial and final word positions. The participants' production of each phoneme in each stimulus item was then scored as correct or incorrect. However, habitual substitution and distortion errors, as assessed by the DEAP and noted at the top of the score form, were marked as correct if repeated in the NRT. For example, if a participant habitually produced /k/ as /t/ in the DEAP, a production of /teivat/ for the stimulus item /teivak/ was marked as correct for all five phonemes. This principle was also applied to habitual deletions. For example, if a participant habitually deleted final consonants, then a deleted final consonant within the stimulus set was not marked as an error. This generated a final raw score (NRT Raw) out of a total maximum achievable score of 96.

An example of the NRT scoring is that of Subject 24. The subject habitually (as assessed by the DEAP) produced /tʃ/ as /ts/, /dʒ/ as /dz/, and /v/ as either /b/ or /f/. As a result, any of these substitutions was marked as correct if repeated in the NRT. For example, the target word /naɪtʃoʊveɪb/, when realised as /naɪtsoʊfeɪb/, was scored as being seven correct phonemes. Each of the phonemes was then scored either correct (70 phonemes produced correctly or with a habitual error, scored as 1) or incorrect (26 non-habitual errors, scored as 0). These scores were then added up to a total raw score of 70 (number of phonemes correct).

Addition errors, such as the production of /teibvak/ for the stimulus item /teivak/, were not counted in the scoring. When items were repeated, these were scored as a null response. That is, the participant was awarded a score of zero and marked as having deleted all of the phonemes.

PRJT. The participants' responses were marked as correct (one) or incorrect (zero) on the score form (Appendix F). The sum of these generated the test raw score (PRJT Raw) out of a total possible score of 30.

Age. Age was calculated in months (Age), and months were not rounded up. For example, a child born on 30 January 2008 and tested on 29 January 2012 would be considered as being 3.11years old at age of testing. This age would then be converted to months, coming to 47 months of age, for use in the analyses.

Scoring Agreement

Four out of 33 participants' recordings (12% of the total sample) of the DEAP, NRT and PRJT were randomly selected and re-scored by a qualified speech language therapist. The speech therapist was provided with scoring instructions and the recordings, but was not provided with the primary researcher's scoring. Inter-judge scoring agreement was calculated to be: 91% for the PCC of the DEAP; 96% for the raw score of the NRT; and 100% for the raw score of the PRJT.

Chapter 3: Results

The aim of the current study was to examine the relationship between the severity of SSD in young children and elements of the speech processing model described in the psycholinguistic framework (Stackhouse & Wells, 1997). Specifically, the relationship between severity of SSD and phonological representations, as well as between severity of SSD and PSTM were of interest. Other factors such as age and language ability were taken into consideration.

Descriptive Statistics

Table 4 shows the mean and standard deviation of the speech and language performance and processing tests for the entire group of 33 children. In addition, descriptive statistics for age were included.

Table 4

Means and standard deviations for all subjects and all variables

Variable	Mean	Standard deviation
PCC	67.09	16.09
PRJT (Raw)	17.70	5.54
NRT (Raw)	62.67	15.93
CELF (Raw)	27.79	7.16
Age	57.36	10.76

Note: n = 33; PCC = PCC from the DEAP; PRJT (Raw) = raw score of the PRJT; NRT (Raw) = raw score of the NRT; CELF (Raw) = the sum of the raw scores for the first three subtests of the CELF Pre – 2 Australian

The primary variables for analysis in the study were PCC, NRT (Raw) and

PRJT (Raw). The relationship for all 33 subjects between the PCC and the NRT (Raw) is shown in Figure 5, and between PCC and PRJT (Raw) in Figure 6.

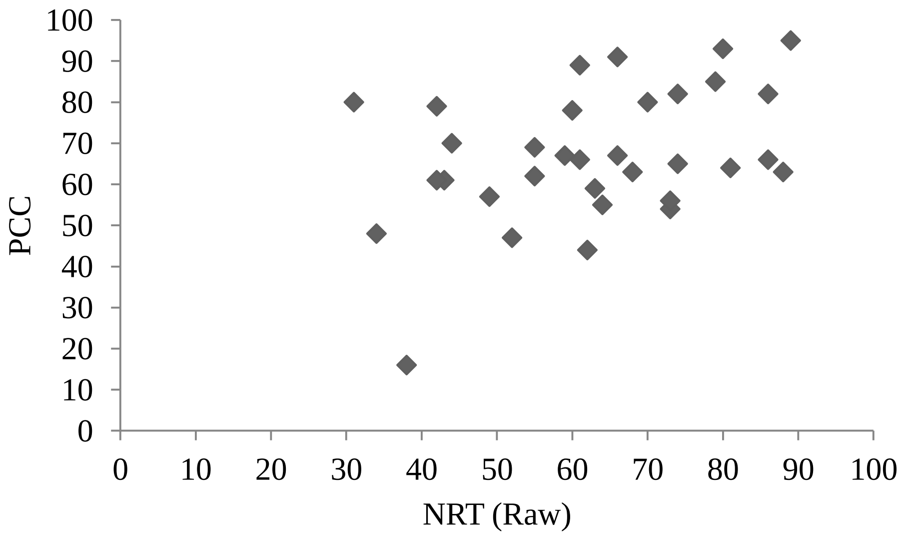

Figure 5: *PCC vs. NRT (Raw)*

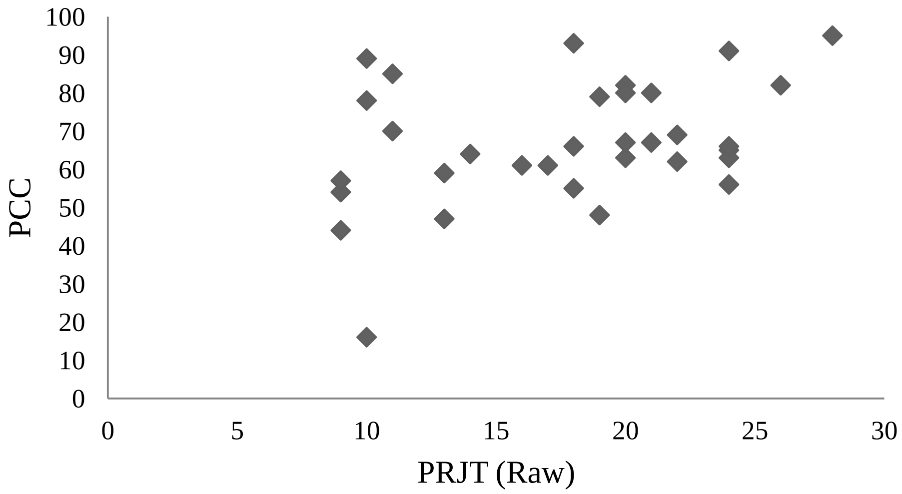

Figure 6: *PCC vs. PRJT (Raw)*

In order to determine the level of speech severity, participant's PCC scores were compared to the expected scores based on their age (Campbell, et al, 2007). In addition, z scores, which indicate the number of SD from the mean as reported by Campbell, et al (2007), were calculated. This was done in order to establish which participants experienced a SSD, and exclude those that did not. Children with a z-score of two or more (i.e. ≥-2SD below the mean) were judged as experiencing a SSD, and were included for analysis (n = 27).

Correlation Statistics

In order to examine the relationships between severity of SSD and elements of the speech processing model (Stackhouse & Wells, 1997), a series of bivariate correlations was carried out on the children who presented with a SSD (n = 27).

Bivariate correlations. The first set of correlations was conducted to examine whether relationships existed between PCC, PRJT (Raw), and NRT (Raw) for children with a SSD. Table 5 shows that there was no significant correlation between PCC and the NRT (Raw). A significant correlation did exist between PCC and PJRT (Raw) (r(27) = .46, p = .02).

Table 5

Bivariate correlation (2-tailed) for subjects with SSD (PCC≥-2SD)

	Age	CELF (Raw)	PCC	PRJT (Raw)	NRT (Raw)
Age	1	.54**	.28	.31	.38*
CELF (Raw)		1	.41*	.46*	.60**
PCC			1	.46*	.33
PRJT (Raw)				1	.31

Note: n=27; * p<0.05; ** p<0.01; PCC = PCC from the DEAP; PRJT (Raw) = raw score of the PRJT; NRT (Raw) = raw score of the NRT; CELF (Raw) = the sum of the raw scores for the first three subtests of the CELF Pre – 2 Australian

Language ability, as measured by the CELF, was correlated with all three primary variables. Age was also correlated with language performance and with one of the phonological processing measures, the NRT (Raw). Partial correlations were therefore conducted to examine whether or not severity of SSD was related to the other two primary variables, once the effects of age and language ability were removed.

Partial correlations controlled for Age. Partial correlations among all variables were performed on participants with SSD (Table 6) by controlling for the age of subjects.

Table 6

Partial correlation (controlled for age) for subjects with SSD (PCC≥-2SD)

Control Variable		CELF (Raw)	PCC	PRJT (Raw)	NRT (Raw)
Age	CELF (Raw)	1	.31	.37	.51**
	PCC		1	.41*	.25
	PRJT (Raw)			1	.21

Note: n = 24; * = p<0.05; ** = p<0.01; PCC = PCC from the DEAP; PRJT (Raw) = raw score of the PRJT; NRT (Raw) = raw score of the NRT; CELF (Raw) = the sum of the raw scores for the first three subtests of the CELF Pre – 2 Australian

The correlation between NRT (Raw) and PCC remained insignificant when controlled for age. The previously noted bivariate correlation between PCC and the PRJT (Raw) remained significant (*r*(24) = .41, p = 0.04).

Partial correlations controlled for CELF (Raw). Partial correlations among all variables were performed on participants with SSD (Table 7) by controlling for the CELF (Raw) of subjects.

The correlations between the NRT (Raw) and the PCC were again not significant when controlled for CELF (Raw). The previously noted bivariate and partial (Age) correlation between PCC and the PRJT (Raw) was no longer significant (r(24) = .34, p = .09).

Table 7

Partial correlation (controlled for CELF (Raw)) for subjects with SSD (PCC≥-2SD)

Control Variable		Age	PCC	PRJT (Raw)	NRT (Raw)
CELF (Raw)	Age	1	.08	.09	.09
	PCC		1	.34	.11
	PRJT (Raw)			1	.04

Note: n = 24; * = p<0.05; ** = p<0.01; PCC = PCC from the DEAP; PRJT (Raw) = raw score of the PRJT; NRT (Raw) = raw score of the NRT; CELF (Raw) = the sum of the raw scores for the first three subtests of the CELF Pre – 2 Australian

Partial correlations controlled for Age and CELF (Raw). Partial correlations among all variables were performed on participants with SSD (Table 8) by controlling for both the Age and CELF (Raw) of subjects. This was done to examine the

Table 8

Partial correlation (controlled for Age and CELF (Raw)) for subjects with SSD (PCC≥-2SD)

Control Variables		PCC	PRJT (Raw)	NRT (Raw)
CELF (Raw) & Age	PCC	1	.33	.11
	PRJT (Raw)		1	.03

Note: n = 23; * = p<0.05; ** = p<0.01; PCC = PCC from the DEAP; PRJT (Raw) = raw score of the PRJT; NRT (Raw) = raw score of the NRT; CELF (Raw) = the sum of the raw scores for the first three subtests of the CELF Pre – 2 Australian combined influence of language ability and age on the primary variables.

The correlation between the NRT (Raw) and PCC was not significant for participants with a SSD when controlled for Age and CELF (Raw), and neither was the correlation between PCC and the PRJT (Raw).

Chapter 4: Discussion

Findings

Phonological Short-Term Memory. In order for verbal information to be processed, it must be stored in an accessible location for the duration of the processing. This storage is called PSTM, also referred to as the phonological loop (Baddely, 2000). Once stored in PSTM, the information is accessible to and can be manipulated by the central executive, alongside information stored in the visiospatial sketchpad and the episodic buffer (Figure 2). As such, PSTM is a temporary storage space for information that is accessed by the working memory, where the information is processed. When the processing of the information has been completed, it can then be laid down into long-term memory.

PSTM is typically assessed using nonword repetition tasks. The theory underpinning this is that these assessments require the brain to perceive a novel phonological string, and then hold this information in storage, while using it to generate and execute a motor program replicating the perceived information. Of note is that, by using nonwords, lexical access is denied. The brain is unable to attach a known lexical item, along with the previously stored motor program for the lexical item, to the nonword. Additionally, because the nonword has no meaning of its own, the brain is not required to add it to the lexicon, which would require the building of a phonological representation of the word. In a nonword repetition task, the brain is required to simply hold the information without processing it any further, and build a new motor plan while it does so. Once this task is complete, the phonological information can be discarded.

PSTM has been found to be associated with language impairments (Alloway, Rajendran & Archibald, 2009) and SSD (Ozcebe & Belgin, 2005). A theory explaining this association is that the accuracy of PSTM would predict the accuracy of any phonological representation. That is, that if the PSTM was unable to hold the information accurately, the resulting long-term memory would also be inaccurate. If the representation was inaccurate, the subsequent realisation of the word would be incorrect as well (Leonard, 1995). The theory that limited PSTM would, via the inaccuracy of the resultant phonological representations, lead to impaired speech production was supported in the development of the SRT. This is a nonword repetition task which allows testing of PSTM while controlling for the confound of a child's SSD (Shriberg, et al, 2009). However, it was found that performance on the SRT did not significantly correlate to severity (Shriberg & Lohmeier, 2008). Conversely, in the same study) the NRT, a nonword repetition task which included more complex phonemes, did correlate to severity. This raised the question of whether the SRT was too simple to show this relationship, or whether a secondary indicator was required.

This lead to the first hypothesis of the current study being that PSTM performance would significantly correlate with SSD. Therefore, the first research question addressed in this study sought to clarify whether there was a significant relationship between children's PSTM abilities and the severity of SSD. It was expected that a relationship would exist between PSTM and severity of SSD. This relationship was expected to be reflected in a significant correlation between the raw score of the NRT and PCC. However, the current study found no significant correlation between the raw score of the NRT and PCC. Therefore, this study did not support the hypothesised relationship between PSTM and severity of SSD.

It is possible that the discrepancy between the current study and the study by Shriberg, et al (2009) could be accounted for by different methodology in terms of scoring of the NRT. In the Shriberg, et al. study, the subjects' habitual errors were not reported to be accounted for within the methodology, as they were in the current study. This meant that even if a child habitually produced /k/ as /t/, this production would be marked as incorrect in the scoring of the NRT within Shriberg, et al.'s study. The opposite was true for the current study.

Another possible reason for the lack of significant correlation between the severity of SSD and performance on the NRT may be the age of the subjects. It has been reported that variability in PSTM ability is linked to maturation (e.g. Kornisch, 2012). The mean age in the current study was 4.5 years. This raises the question as to whether the previously reported variability in the PSTM abilities of young children could account for the lack of correlation between scores on the NRT and severity of SSD. This age-related variability could also explain the discrepancy in findings between the current study and Ozcebe & Belgin's study (2005). In that study, the subjects ranged in age from six to ten years, rather than from three to six years as in the current study. As such, the subjects of Ozcebe & Belgin's study may have experienced less variability in PSTM ability, resulting in a stronger correlation between variables.

Another possible explanation for the difference in findings between the current study and Ozcebe & Belgin's study (2005) may be the fact that the SSD experienced by the subjects in Ozcebe & Belgin's study had persisted into later childhood. That is, that the speech difficulties had not yet resolved in children up to the age of 10 years. This raises the possibility that the memory difficulties reported by Ozcebe & Belgin (2005) might predict persistence of SSD into later childhood, rather than predicting severity.

A fourth possible reason for the lack of relationship was that a secondary indicator might be required for the relationship between PSTM and severity of SSD to become clear. If a secondary indicator was required, phonological representations were identified as a possibility. These two variables were linked in this study because PSTM abilities can theoretically be implicated in a child's ability to create an accurate phonological representation.

Phonological Representations. When the brain is exposed to a word, or string of phonological information, for the first time, there is no matching lexical item already stored in long-term memory. As such, the word can be considered a nonword until a lexical item for it is created. In this case, instead of being discarded, as in a nonword repetition task, the phonological information is processed further and stored as a phonological representation. This representation is then linked with a semantic representation, giving it meaning, and a stored motor program, enabling it to be produced in future. As a result, the word changes from being a nonword to being a known word.

A way to test a child's ability to correctly create phonological representations would be to test the accuracy of existing representations stored in the child's lexicon (Sutherland & Gillon, 2005). One way to do this is to ask the child to judge whether a perceived word is accurate or not. This task requires the child to perceive a familiar word, discriminate it from a non-speech sound, recognise the phonemic string, and then compare it with the matching phonological representation held in the lexicon. Based on this comparison, the child must then make a judgement on whether the perceived production was correct. That is, did the perceived production match the stored representation or not. If accuracy of phonological representations was impaired it would imply a constraint the ability to judge this accuracy.

Inaccurate representations being stored in the lexicon would theoretically result in the stored motor programs based on those representations also being inaccurate.

This would, in turn, presumably result in inaccurate realisations of those motor programs (Stackhouse & Wells, 1997). This theory has found significant support in the literature, such as the finding that the learning of phonological representations is proportional to severity of SSD (Munson, et al, 2009), that children with SSD appear to have a constraint in auditory-perceptual encoding (Shriberg et al, 2009), and that children with SSD experience more difficulty than TD peers in learning nonwords, or correctly judging the accuracy of heard productions of words (Sutherland & Gillon, 2005). This element of phonological processing has, however, never been directly compared to severity of SSD. As such, the question was raised as to whether this might be a secondary factor that, in combination with PSTM, might predict severity of SSD.

This lead to the second hypothesis, that a child's ability to accurately judge the accuracy of the phonological representation of a familiar multisyllabic word would be correlated to severity of SSD. This hypothesis was tested by the second research question, which aimed to address whether a significant relationship existed between the strength of children's phonological representations and the severity of speech sound disorder. The question was tested by correlating the raw score of the PRTJ with PCC. A significant correlation was initially found, but when language ability was controlled for, the correlation became insignificant. This indicated that the relationship between the PRJT and PCC was mediated by language.

Combined phonological short-term memory and phonological representations. In the current study, it was hypothesised that, should relationships between PSTM, phonological representations and severity of SSD be found, that PSTM and phonological representations together might predict this severity more strongly than either measure in isolation. This lead to the third research question:

"how much independent and combined variance in speech severity scores is accounted for by performance on tests of PSTM and phonological representations?" However, this hypothesis was contingent on the previous two hypotheses being found to be accurate. That is, if a relationship between both PSTM and phonological representations and the severity of SSD existed, the accuracy of representations and PSTM together would have a stronger relationship with severity of SSD than either measure on its own. As the first two hypotheses were not found to be true, the third hypothesis was abandoned.

Summary of findings. Children who scored at or below 2SD below the mean for PCC were described as experiencing SSD. For these children, there was not a significant relationship between the severity of the SSD and PSTM. A significant relationship between the severity of the SSD and a test of the accuracy of phonological representations was found. However, when language ability was controlled, this relationship was no longer significant. The relationship between severity of SSD and phonological representation accuracy was mediated by language ability.

Limitations of the Current Study

A possible reason for the lack of association between the severity of SSD and PSTM might have been the sample size. With 33 subjects, and only 27 of those participants defined as experiencing SSD, the sample size was very small in comparison to some prior studies. For example, Shriberg, et al (2009) had 95 three- to five-year-old children with SSD when they developed the SRT and found that children with SSD significantly underperformed on the NRT in comparison to their TD peers. Therefore, the discrepancy in findings between that study and the current one could be attributable to sample size.

The lack of a significant correlation between the severity of SSD and the subjects’ performance on the PRJT might also be explained by the small sample size. The constraints in auditory-perceptual processing that had been found by comparing types of substitution errors (Shriberg, et al, 2009) was again seen in a far larger sample size of 95 children with SSD between the ages of three and five years. It is therefore possible that the limited sample size prevented similar findings in the current study.

Co-morbidity of language disorders may be another explanation for the lack of correlations between any of the primary variables. Due to the small sample size, the seven participants who were found to have co-morbid language disorders were not excluded from the sample. Nor were the two sub-samples (SSD only and SSD with language disorder) independently assessed. As a result, it is not possible to rule out language ability as a contributing factor to these findings.

Implications for the Understanding of SSD within a Psycholinguistic Framework

This study investigated an element of SSD (i.e. severity) within a psycholinguistic framework (Stackhouse & Wells, 1997). This framework details the pathway of information from auditory input through to motor production of speech. It theorises that when a word is perceived by the ear and moves on to processing within the brain, an initial discrimination between speech and non-speech sound is made. From there, the word is recognised on a phonological level and the phonemes of it are discriminated. The recognition of a phonological representation, the abstract representation of the word stored in the lexicon, takes place thereafter. This representation can then be linked to the stored semantic representation of the word, and also the stored motor program. After this program has been accessed, the brain assembles the motor plan required to produce the word. This in turn leads to the motor production of the word by the muscles of speech. In summary, this framework is a model of how speech is processed within the brain.

Within the current study, the two assessment tools used tested several elements of the speech processing model proposed by the psycholinguistic framework of speech processing (Stackhouse & Wells, 1997). These tools were used in order to provide measures of the primary variables. The first tool, the NRT, was used to measure PSTM. However, in so doing, it required the use of multiple elements of the speech processing model. In particular, the NRT required processing through the following elements of the model: peripheral auditory processing, speech/non-speech discrimination, phonological recognition, generation of a novel motor program, generation of a novel motor plan, and novel motor execution. Of note is that lexical access was denied in this task. Therefore, stored phonological representations, stored semantic representations and stored motor programs were not involved in the task.

In the current study there was no significant correlation between severity of SSD and performance on the NRT. If the NRT assesses all of the above-listed elements of the model, the implication of this is that none of these elements are related to severity of SSD. This, in turn, implies that severity must be related to one of the elements of the model not assessed by the NRT. That is, the elements relating to lexical access.

The second tool used in the current study was the PRJT. This was used to assess the accuracy of a child’s stored phonological representations. In doing so, the PRJT also required processing through several elements of the speech processing model described in the psycholinguistic framework (Stackhouse & Wells, 1997). It required processing through all of the same input elements of the framework as the NRT. However, in addition, it also required processing of the stored phonological and semantic representations. That is, it required some lexical access. The PRJT did not, however, require processing of the stored motor program.

In this study there was no significant correlation between the PRJT and severity of SSD. If the PRJT requires processing through all of the input elements of the speech processing model, including the lexical elements, this implies that none of these elements are related to severity of SSD. This, in turn, implies that severity must be related to one of the output elements of the framework. However, when this implication is combined with the implications arising from the findings of the NRT, only one element remains: the stored motor program.

Therefore, by a process of elimination, it can be concluded that severity of SSD may be related to a breakdown between the accuracy of a child’s phonological representations and their ability to generate a motor program. It is therefore possible that the root of variability of severity of SSD may be related to: (a) a child’s ability to create their stored motor programs, (b) the accuracy of these stored motor programs, or (c) the translation of these stored motor programs into motor plans.

Implications for Future Research

The current study provides evidence that PSTM ability and accuracy of phonological representations are not implicated in severity of SSD in three- to six-year-old children. However, the limited sample size may have impacted on the findings of this study. As such, it cannot be held as conclusive evidence, and repetition of this study would be required before the findings can be accepted as conclusive evidence.

Another potential avenue for future research might be to further investigate the relationships between the primary variables and age. A study with a similar number of subjects found a correlation between memory and SSD in older (aged six to ten years) children than in the current study (Ozcebe & Belgin, 2005). Additionally, different assessments were used by this study and the current one, begging the question as to whether these methodological differences were the reason for the discrepancy, or whether it was related to the age of participants. That is, could memory be related to the fact that the SSD persisted into later childhood, rather than the severity of the SSD in terms of accuracy of speech production? Or is the discrepancy due to the use of different assessments?

The current study does appear to support PSTM involvement in language disorders, as relationships between PSTM and the measures of phonological processing were mediated by language, as well as age, and performance on the NRT was correlated with those of the CELF Pre – 2 Australian, even when controlled for age. While outside of the scope of the current study, this may provide some evidence for further research into the relationship between language and PSTM in children with co-morbid language and speech disorders. Opportunities for data collection were severely limited in this study by constraints on the availability of children for inclusion. It was not possible to exclude children with co-morbidity of language impairment. Clearly follow-up studies need to recruit children with isolated SSDs, if possible.

Conclusions

The current study sought to elucidate relationships between the severity of SSD and elements of the speech processing model proposed by Stackhouse and Wells (1997). It was hypothesised that the existence of such relationships would have far-reaching implications for intervention for children with SSD. In particular, it was hypothesised that the accuracy of phonological representations, the abstract representations of words laid down into long term memory, would be correlated to severity of SSD, as would PSTM. It was further hypothesised that accuracy of phonological representations and PSTM in conjunction would be a stronger predictor of the severity of SSD than either one alone.

The study sought to test these hypotheses by comparing the subjects' PCC, calculated from the DEAP (Dodd, et al, 2002), their raw score from the NRT (Dollaghan & Campbell, 1998), and their raw score from the PRJT (Sutherland, 2006). These comparisons were made while simultaneously controlling for the SSD of the child. This was done by accounting for the SSD in the subjects' responses to the NRT by counting habitual speech errors as correct if repeated in the NRT. This confound was also avoided in the use of PRJT, as this task did not require a verbal response from the child.

The current study has found no significant relationships between these three primary variables, when age and language were controlled for. The absence of these relationships might be accounted for by the small size of the sample in the study, the age of participants, or co-morbid language delays. However, the findings of this study do imply that severity of SSD may be related to the stored motor programming element of the speech processing model (Stackhouse & Wells, 1997). The current study found a link between language ability and PSTM, but further follow-up on this finding fell outside of the scope of the study.

Further avenues for research might be: (a) repetition of the study with a larger sample in order to achieve greater rigour and exclude children with co-morbid language delays, (b) investigation of these factors over a wider age range, (c) investigation of a suspected relationship between stored motor programming and the severity of SSD, or (d) further investigation into the reported relationship between language ability and PSTM.

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Appendices

Appendix A: Information Sheet

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UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

INFORMATION SHEET

We would like to ask your child to be part of a research project called: Processing Predictors of Severity of Speech Sound Disorders.

The point of this project is to find out if there is a link between a child's memory and word skills and how clear their speech is.

Your part of this project will be to give some background information about your child, and to be there while your child is being tested. Your child's part of the project will be to do four book tests using pictures and words. This will take about an hour.

You can stop your child being a part of the project at any time. If take your child out of the project, the information about them won't be used.

During the tests, your child might become upset because it is too hard. If this happens, the testing will stop straight away, and their information won't be used for the project.

We will publish the results of the project, but your child's information will stay confidential. This means that nothing that can be used to identify your child (like their name, address or date of birth) will be printed. We will give your child a number for the project to make sure of this, and anything that is published will only have that number and the decile ranking of their school. Also, all of the information will be safely locked away in a filing cabinet at the researcher's home.

If you want, when the tests for the project have been done, the researcher can pass on the information to the Ministry of Education, Special Education.

The project is being done because it is a part of the Masters of Science programme with the University of Canterbury Department of Communication Disorders. Natalie Pera is the person doing the project, and you can call her on 021 299 0080, or email her at natalie.pera@pg.canterbury.ac.nz. Prof. Stephanie Stokes is supervising Natalie, and you can call her on 03 – 364 2987 #7084, or email her at stephanie.stokes@canterbury.ac.nz if you have any concerns. Stephanie and Natalie will be happy to talk about any worries you might have.

If you would like your child to be a part of this research project, please call or text Natalie on 021 299 0080 and she will discuss it with you.

The University of Canterbury Human Ethics Committee has reviewed **and approved** this project.

Appendix B: Informed Consent Form

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

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CONSENT FORM

Processing Predictors of Severity of Speech Sound Disorders

I have read and understood the information sheet for this project. I agree for my child to join the project, and I agree to publication of the results of the project with the understanding that each child will be given a project number, and no names will be used.

I understand that I can leave the project, at any time, and that testing can stop if my child does not want to continue.

I **do / do not** *(circle one)* want the researcher to pass on any relevant assessment findings to the Ministry of Education, Special Education.

I note that the project has been reviewed ***and approved*** by the University of Canterbury Human Ethics Committee.

____
Child's Name (please print)

____
Parent/Guardian Name (please print)

____
Parent/Guardian Signature

____
Date

Appendix C: Case History Form

SPEECH LANGUAGE THERAPY

CASE HISTORY

Name: ____

Male / Female *(circle one)* Date: ____________ Date of Birth: ___________ Age: ________

Address: ____

____

Contacts: Home: ____________________________ Work: _________________________

Mobile: ____________________________ Email: _________________________

Primary Caregiver: ____

Relationship to Child: ____

Ethnicity: ___________________________ Home Language: _______________________

School: _________________________________ Teacher: _________________________

Concerns:

Are you concerned about your child's speech and language, and if so, what are your specific concerns? (eg. stammering/stuttering; unusual voice quality; difficulty following directions; can't be understood by family members or others; doesn't have many words; social skills not well developed)

How do you think your child feels about your concerns?

Background Information:

Please describe the child's home environment (eg. who lives with the child, how many people are in the home?)

Is there anyone else in the child's family who has experienced speech-language difficulties, and if so, what?

Birth and Early Infancy:
What was the pregnancy like (i.e. was it a normal pregnancy or were there problems, and if so what)?

Was the pregnancy full term, or was your child premature (and if so, by how much)?

Was the birth normal or were there difficulties?

Did your child have any trouble eating as an infant (eg. severe colic, trouble moving the child on to solid foods, dislike of certain food groups, textures or tastes), and if so, what?

Speech and Language Development
When, more or less, did you first notice your child's difficulty?

What did you notice, and if it has changed, how did it do so?

When, more or less, did your child say their first word?

When, more or less, did your child start putting two words together?

When, more or less, did your child start putting three words together?

When playing, does your child demonstrate 'pretend play' (eg. pretending that a stick is a wand or that a doll is a real baby)?

Motor Development

At what age, more or less, did your child start:

Sitting?

Crawling?

Standing?

Walking?

Using a toilet or potty?

Other?

Health

Does your child have any ongoing health problems, and if so what are they?

Is your child on any medications, and if so, what?

Has your child had any major illnesses in the past?

Has your child had any major accidents requiring hospitalisation?

Has your child ever had glue-ear or ear infections, and if so, how many and when?

If your child has had ear infections, were grommets put in?

Has your child's hearing been tested, and if so, what were the results?

Has your child's vision been tested, and if so, what were the results?

Relationships
How does your child get along with:

- Adults he/she knows?

- Adults that he/she doesn't know

- Brothers and sisters?

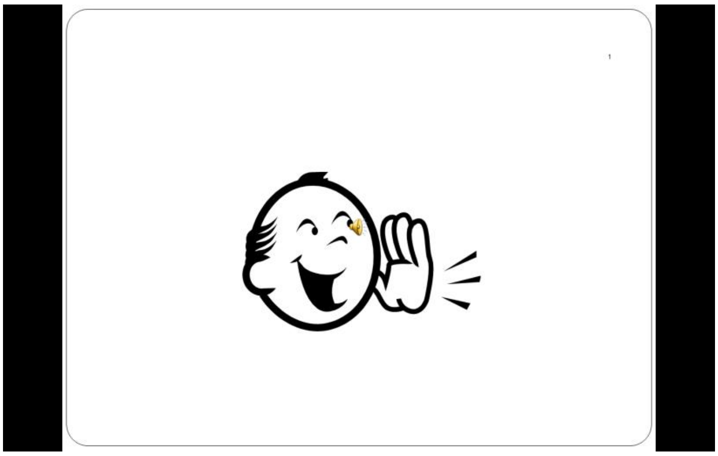
- Other children that he/she interacts with?

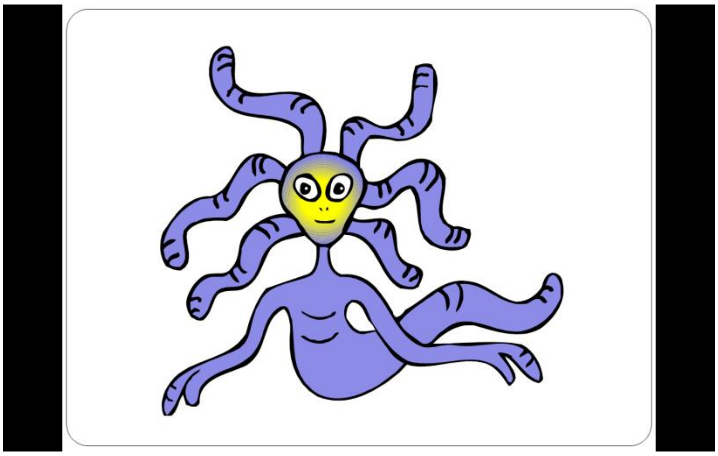
Other
Are there, or have there ever been, any other professionals involved with your child (eg. GP, paediatrician, other services, private professionals), and if so, who?

Is there anything else that you think we should know?

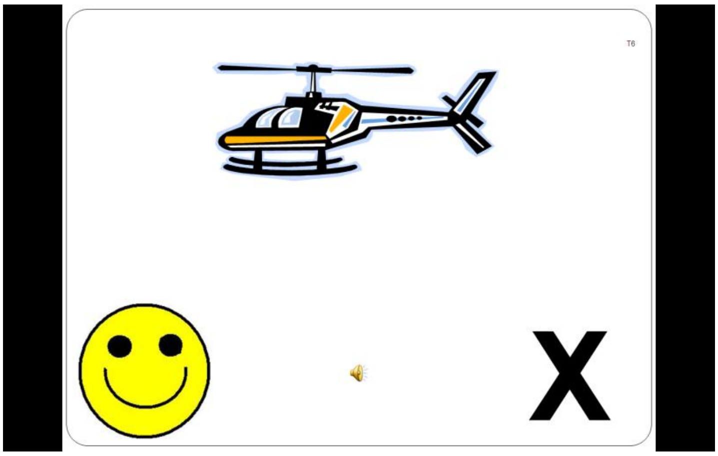
Appendix D: Screenshots of the Powerpoint® Presentations used to Present the NRT and PRJT

NRT Screenshots:





PRJT Screenshot:



Appendix E: NRT Score Form

NONWORD REPETITION TASK

SCORE FORM

Participant Number: ______________ Examiner: ______________________________

Education Facility: ____________________________________ Noise Level: _____

Date of Examination: ______________ Date of Birth: ______________ Age: _____

Habitual Sound Substitutions (see DEAP):

Initial	Medial	Final	Initial	Medial	Final	Initial	Medial	Final	Initial	Medial	Final
	n			b			p			v	
	f			d			t			dʒ	
	tʃ			g			k				
aʊ	ɔɪ	oʊ	æ	aɪ	i	eɪ	a	u			

Response Record

#	Stimulus Picture	Target	Transcription	Score
Demo		/m æ b/		
Trial		/t ɒ b/		
1		/n aɪ b/		/3
2		/v oʊ p/		/3
3		/t aʊ dʒ/		/3
4		/d ɔɪ f/		/3
5		/t eɪ v a k/		/5
6		/tʃ oʊ v æ g/		/5
7		/v æ tʃ aɪ p/		/5
8		/n ɔɪ t aʊ f/		/5
9		/tʃ i n ɔɪ t aʊ b/		/7
10		/n aɪ tʃ oʊ v eɪ b/		/7
11		/d ɔɪ t aʊ v æ b/		/7
12		/t eɪ v ɔɪ tʃ aɪ g/		/7
13		/v eɪ t a tʃ aɪ d ɔɪ p/		/9
14		/d æ v oʊ n ɔɪ tʃ i g/		/9
15		/n aɪ t ɔɪ t aʊ v u b/		/9
16		/t æ v a tʃ i n eɪ g/		/9
			Total:	/96

Appendix F: PRJT Score Form

PHONOLOGICAL REPRESENTATION JUDGEMENT TASK

SCORE FORM

Participant Number: ____________ Examiner: ______________________________

Education Facility: ______________________________________ Noise Level: _____

Date of Examination: _______________ Date of Birth: _______________ Age: _____

Response Record

#	Stimulus	Level	Expected	Response	Repetitions	Score
T1	Watermelon	Norm	☺			
T2	Watermelon	Max	X			
T3	Watermelon	Norm	☺			
T4	Watermelon	DelUS	X			
T5	Watermelon	ChgUS	X			
T6	Helicopter	Max	X			
T7	Hippopotamus	Max	X			
T8	Hippopotamus	Norm	☺			
T9	Hippopotamus	ChgSS	X			
T10	Butterfly	DelUS	X			
1	Telephone	Norm	☺	☺ X		
2	Dinosaur	Norm	☺	☺ X		
3	Motorbike	Max	X	☺ X		
4	Hippopotamus	DelUS	X	☺ X		
5	Caterpillar	Norm	☺	☺ X		
6	Elephant	DelUS	X	☺ X		
7	Kangaroo	Norm	☺	☺ X		
8	Helicopter	ChgUS	X	☺ X		
9	Telephone	DelUS	X	☺ X		
10	Butterfly	Norm	☺	☺ X		
11	Caterpillar	ChgSS	X	☺ X		
12	Motorbike	ChgSS	X	☺ X		
13	Helicopter	Norm	☺	☺ X		
14	Dinosaur	DelUS	X	☺ X		
15	Caterpillar	ChgUS	X	☺ X		
16	Elephant	Norm	☺	☺ X		
17	Kangaroo	ChgUS	X	☺ X		
18	Butterfly	ChgSS	X	☺ X		
19	Elephant	ChgUS	X	☺ X		
20	Motorbike	ChgUS	X	☺ X		
21	Telephone	ChgSS	X	☺ X		
22	Kangaroo	DelUS	X	☺ X		
23	Hippopotamus	Norm	☺	☺ X		
24	Dinosaur	ChgSS	X	☺ X		
25	Hippopotamus	ChgSS	X	☺ X		
26	Caterpillar	DelUS	X	☺ X		
27	Butterfly	ChgUS	X	☺ X		
28	Motorbike	Norm	☺	☺ X		
29	Elephant	ChgSS	X	☺ X		
30	Motorbike	DelUS	X	☺ X		
					Total:	

Comments: ____

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Appendix H: Human Ethics Committee Approval

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HUMAN ETHICS COMMITTEE

Secretary, Lynda Griffioen
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2011/105

9 November 2011

Natalie Pera
Department of Communication Disorders
UNIVERSITY OF CANTERBURY

Dear Natalie

The Human Ethics Committee advises that your research proposal "Processing predictors of severity of speech and sound disorders" has been considered and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your email of 31 October 2011.

Best wishes for your project.

Yours sincerely

Michael Grimshaw
Chair
University of Canterbury Human Ethics Committee

University of Canterbury Private Bag 4800, Christchurch 8140, New Zealand. www.canterbury.ac.nz

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UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

HUMAN ETHICS COMMITTEE

Secretary, Lynda Griffioen
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2011/105

4 April 2012

Natalie Pera
Department of Communication Disorders
UNIVERSITY OF CANTERBURY

Dear Natalie

Thank you for your request for an amendment to your research proposal "Processing predictors of severity of speech and sound disorders".

I am pleased to advise that this request has been considered and approved by the Human Ethics Committee.

Yours sincerely

Michael Grimshaw
Chair
University of Canterbury Human Ethics Committee