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Orthographic Knowledge and Phonological Awareness in Children with Speech Sound Disorder

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Dedication

My dissertation is dedicated to my husband and best friend, Josh, who has been a constant source of support and encouragement during the challenges of graduate school and life as new parents. Lots was thrown at us unexpectedly throughout this journey -- two baby girls and a pandemic. There were many obstacles to navigate, and you always did your best to lighten the pressure of balancing family and academic responsibilities. Throughout this journey, you were always patient and understanding with my many early mornings and late nights. Because of you, I am reaching my dream of becoming a children’s speech, language, and literacy researcher. Words cannot express how thankful I am to have you as my partner for life.

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Abstract

Speech sound disorder (SSD) puts children at risk for word reading difficulties but does not guarantee them. Research on early literacy skills in children with SSD has primarily focused on phonological awareness due to speech sound deficits associated with SSD. Researchers have begun to examine multiple factors beyond phonological awareness that may impact word reading and spelling development. Orthographic knowledge is another essential factor understudied in children with SSD. Previous research has shown that orthographic properties of words influence phonological awareness performance in skilled readers and children with reading difficulties. No known previous studies have examined whether orthography influences phonological awareness performance in children with SSD as compared to their peers with typical speech development (TSD). Additionally, oral language ability is known to impact reading outcomes, and these difficulties can co-occur with SSD increasing the risk of word reading and spelling difficulties. The current study examined orthographic knowledge, phonological awareness, and the interaction of these components in children with SSD and children with TSD while considering oral language ability.

Sixty children (TSD = 30; SSD = 30) between ages 6-8 years old completed speech, language, and literacy assessments through a virtual platform (Zoom), including a mixture of norm-referenced and experimental measures. Two experimental tasks were designed to measure orthographic knowledge: one measured children's knowledge of phoneme-grapheme correspondence and the other measured children's knowledge of orthographic patterns. An experimental phonological awareness task was used to determine whether the orthographic properties of words influenced children's phonological awareness performance.

Results showed that children with SSD demonstrate less phonological awareness and orthographic knowledge compared to their peers with TSD and that oral language ability is a prominent factor in predicting these outcomes. Additionally, children with SSD had less orthographic properties of words influence their phonological awareness performance compared to children with TSD. Oral language ability was shown to only significantly impact the experimental phonological awareness performance in children with SSD, not children with TSD. These results suggest that oral language ability may be a pivotal protective factor for word reading and spelling in children with SSD. Gained phoneme-grapheme correspondence knowledge may also serve as a protective factor during word reading and spelling development for children with SSD, and possibly other disordered groups of children with oral language deficits who also have poor phonological awareness. Strengthening the co-development and interaction between the phonological and orthographic factors in these children could improve phonological awareness and word reading and spelling skills.

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List of Symbols

$\bar{x}$	Sample mean.
n	Sample size.
$\geq$	Greater than or equal to.
$\leq$	Less than or equal to.
X^2	Chi-Square test statistic determines if a difference between observed data and expected data is due to chance.
p	P-value is the probability of obtaining test results at least as extreme as the result actually observed, under the assumption that the null hypothesis is correct.
SD	Standard deviation measures the amount of variation or dispersion of a set of values.
t	A t-statistic is the ratio of the parameter estimated value from its hypothesized value to its standard error.
CI	A confidence interval is a range of estimates for an unknown parameter.
g	Hedge's g measures effect size indicating how much one group differs from another that is not biased on the sample size.
F	A F-statistical value in regression is a ratio parameter estimated value from its explained variance (i.e., mean of squares for model) to its unexplained variance (mean of squares for error).
R^2	R-squared represents the proportion of the variance for an outcome variable that's explained by the predictor variable(s) (e.g., goodness-of-fit).
α	Alpha is the probability of rejecting the null hypothesis when it is true.

List of Abbreviations

CC	Congruent-Consistent
CELF-5	*Clinical Evaluation of Language Fundamentals, Fifth Edition*
CI	Congruent-Inconsistent
CTOPP-2	*Clinical Test of Phonological Processing, Second Edition*
CTOPP-2 PA	*Clinical Test of Phonological Processing, Second Edition* Phonological Awareness composite
DLD	Developmental Language Disorder
GFTA-3	*Goldman-Fristoe Test of Articulation 3*
HI	High Probability versus Illegal
HL	High Probability versus Low Probability
IN	Incongruent-Inconsistent
LI	Low Probability versus Illegal
OG	Orton-Gillingham
PCC	Percent Consonants Correct
PIW	Percentage of Intelligible Words
PPVT-5	*Peabody Picture Vocabulary Test, Fifth Edition*
SALT	Systematic Analysis of Language Transcripts
SSD	Speech Sound Disorder
TD	Typical Development

TSD	Typical Speech Development
WRMT-III	*Woodcock Reading Mastery Test, Third Edition*

Chapter 1

Introduction

Speech sound disorder (SSD) is one of the most common reasons children ages 3- to 10-years receive speech-language services (Black et al., 2015). Children with SSD present with speech sound production difficulties affecting their intelligibility during communication (Peterson et al., 2009; Shriberg et al., 2010; Sutherland & Gillon, 2007). Importantly, research suggests that having SSD also puts children at risk for a word reading and spelling disorder (Burgoyne et al., 2019; Wren et al., 2021). An estimated 25-30% of children with disordered word reading have a history of SSD in preschool, suggesting that SSD is a risk factor for future reading and spelling difficulties (Lewis et al., 2000; Pennington & Lefly, 2001; Raitano et al., 2004). Although these results indicate that SSD increases a child’s risk for word reading difficulties, not all children with SSD have reading and spelling problems (Cabbage et al., 2018; Tambyraja et al., 2020). The current study examined foundational early literacy skills in children with SSD.

1.1 Word Reading Theory

The Triangle Model emphasizes the importance of phonological awareness, orthographic knowledge, and semantics in skilled word readers (Seidenberg, 2005). Phonological awareness is the awareness that words are comprised of speech sounds and is the ability to reflect on and manipulate these sounds (Rayner et al., 2012).

Orthographic knowledge is the knowledge of how oral language is represented in written form (Apel, 2011). This knowledge involves knowing how letters represent sounds in spoken language (e.g., the letter ‘m’ spells the sound /m/) and which letters frequently appear together in specific positions of syllables (e.g., ‘ge’ or ‘dge’ frequently occur together to form the sound /ʤ/ at the final position within a syllable, whereas ‘j’ form the sound /ʤ/ in initial syllable position). In addition, orthographic knowledge involves knowing how specific words are spelled (e.g., you spell the word ‘hope’ as ‘h-o-p-e’ not ‘h-o-a-p’). Semantics is the meaning of words and the combination of words in oral or written language (Gleason & Ratner, 2009). Once a skilled word reader, the model suggests that these factors are coactivated to read a word. The Triangle Model identifies skills that support word reading but doesn’t explain their co-development.

The self-teaching hypothesis tries to explain the development and interaction of these foundational factors. The Self-Teaching hypothesis suggests that skilled word reading occurs through an item-by-item based learning mechanism where each word is self-taught (Share, 1995; 1999; 2004). When a student encounters an unfamiliar word, they can decode it by attending to the sounds that are represented by the letters. For example, within the sentence “The night was quiet with a full moon”, the word “moon” is decoded “m” - /m/, “oo” - /u/, “n” - /n/ and the letter(s)-sound connections are combined to read the whole word. The meaning (i.e., semantics) is being determined for “moon” based on the context within the sentence and oral vocabulary knowledge. If successful in decoding the unfamiliar word, an initial word-specific orthographic representation (i.e., written word) is formed that can be further solidified through additional reading exposures. Through multiple exposures, the unfamiliar word becomes a familiar word and there is no longer a need to phonologically decode the written word because it is now recognized by sight (i.e., coactivation of each factor occurs). The Self-Teaching hypothesis highlights the relationship between orthographic and phonological factors as identified in the Triangle model. Additionally, this hypothesis suggests that oral language knowledge is important and supports word reading development. These speech sound deficits in children with SSD may lead to difficulties gaining orthographic knowledge to decode an unfamiliar word and decrease known written word forms. Examination of these speech sound and orthographic factors may explain the varying word reading and spelling abilities in developing readers with SSD. Next, we consider how phonological awareness and orthographic knowledge have been studied with regard to word reading development in children with SSD.

1.2 Speech Sound Disorder and Risk for a Word Reading Disorder

Children with SSD are at risk for reading difficulties due to their speech sound production deficit (Burgoyne et al., 2019; Wren et al., 2021). While speech sound production is one of the main characteristics of SSD, a recent systematic review showed that children with SSD have speech perception deficits that significantly impact the accurate acquisition and production of speech sounds (Cabbage & Hitchcock, 2022). These deficits were shown when children with SSD were compared to their peers with typical development (Brosseau-Lapré et al., 2020; Benway et al., 2021; Mari et al., 2022; Roepke & Brosseau-Lapré, 2021; Rvachew et al., 2003) and peers who have word reading difficulties with no history of SSD (Miller & Lewis, 2022). Multiple studies have shown that, even after remediation of speech sound production, children with SSD have persistent deficits in using their speech representations to understand how speech sounds are represented meaningfully in their oral and written language (Raitano et al., 2004; Rvachew et al., 2003; Sutherland & Gillon, 2007). In other words, children with SSD have difficulty understanding that the speech sounds, /n/- /aɪ/ - /t/, blend together to make the word /naɪt/ (i.e., phonological awareness), and that these speech sounds map onto the letters to make the word forms “night” and “knight” (orthographic knowledge). Therefore, the speech sound deficits in children with SSD increase risk for word reading difficulties, and relatedly spelling difficulties.

A primary deficit related to speech sounds can lead to phonological awareness difficulties, which has been shown to mediate word reading development (Burgoyne et al., 2019). These difficulties may explain why only some children with SSD later develop word reading difficulties (Cabbage et al., 2018; Pennington, 2006; Pennington et al., 2012; Tambyraja et al., 2020). Research examining SSD literacy outcomes has begun to consider a multi-deficit cognitive model (e.g., Miller & Lewis, 2022). Recently, Miller and Lewis (2022) examined multiple factors related to speech sound production and perception, phonological processing, and oral language ability in children with word reading difficulties with and without SSD. Results suggested that children with reading difficulties and SSD had significantly lower phonological awareness, phonological memory, speech sound production and perception, and oral language ability than peers with word reading difficulties and no SSD history. A limitation of this study identified by authors was no measurement of orthographic knowledge besides the word reading accuracy and fluency outcomes. This suggests that the presence of SSD provides additional risk factors for word reading and spelling difficulties. Therefore, early literacy research in SSD needs to examine these various speech and oral language abilities in addition to orthographic knowledge to better understand risk for word reading and spelling difficulties in SSD.

Phonological Awareness

Literacy research with children with SSD has focused mostly on their phonological deficits through the measurement of phonological awareness (Ehrhorn & Adlof, 2021). Studies have measured a wide range of phonological awareness skills in children with SSD that involve the ability to identify, blend, segment, and manipulate sounds or units of sounds within words through various norm-referenced measures (Apel & Lawrence, 2011; Brosseau-Lapré & Roepke, 2019; Lewis et al., 2011) and experimental tasks (Preston & Edwards, 2007; 2010). Many studies showed that children with typical development (TD) have a higher performance on phonological awareness tasks than children with SSD (Apel & Lawrence, 2011; Brosseau-Lapré & Roepke, 2019) especially if the children with SSD had co-occurring language difficulties (Skebo et al., 2013). A recent study by Miller and Lewis (2022) showed that children with word reading difficulties and SSD had lower phonological awareness performance as compared to peers with word reading difficulties who did not have SSD. These findings are in contrast with several studies that did not find a significant difference between children with TD and children with SSD in all phonological awareness tasks (Cabbage et al., 2016; Hesketh et al., 2000; Lewis et al., 2018; Markikainen et al., 2021; Nathan et al., 2004).

The performance differences may be due to the type of phonological awareness task used, but this is unlikely as many of the tasks required similar manipulation of speech sounds such as blending and segmenting speech sounds (Ehrhorn & Adlof, 2021). Another possibility is that there may be issues related to the phonological awareness task scoring procedures and interpretation as many studies relied on accurate speech sound production. An example norm-referenced assessment used most often in studies (Ehrhorn & Adlof, 2021) is *the Clinical Test of Phonological Processing, Second Edition* (CTOPP-2; Wagner et al., 2003) where many researchers adjust scoring for speech sound production errors by scoring items as correct when produced incorrectly (Brosseau-Lapré, & Roepke, 2019; Cabbage et al., 2016; Lewis et al., 2011). Similar methods are often used with other norm-referenced and experimental assessments as well (Apel & Lawrence, 2011; Carson et al., 2015; Peterson et al., 2009). Adjusting for speech sound production errors during phonological awareness assessment may result in an overestimation of these abilities in SSD. For example, if a child produces /s/ clusters in error, a phonological awareness task that requires the manipulation and blending of speech sounds may ask the child to delete the second speech sound from /stɪnk/ to make a new word (answer: sink). This response may be scored accurately if adjusted for the errored sound (e.g., responses possibly scored accurately /tɪnk/, /fɪnk/, /ɪnk/, ect.). If not adjusted for the speech sound in error, the item would be given an incorrect score. This first scoring method may overestimate by giving credit to errors, but the second may underestimate by indicating an error for something to do with production. Scoring procedures for tasks that require speech sound production have the potential to interfere with an accurate interpretation of phonological awareness abilities in SSD. The use of a receptive task rather than an expressive task to measure phonological awareness in children with SSD may be helpful for addressing these limitations.

Even though literacy research in SSD has mainly focused on phonological awareness, phonological awareness deficits alone have not been sufficient for explaining word reading and spelling difficulties. Some word reading studies have shown that phonological awareness deficits do not guarantee word reading difficulties (Catts et al., 2017; Pennington et al., 2012; Van Bergen et al., 2011). In addition, children with SSD may have difficulties in the development of their word reading even when phonological awareness abilities are similar to their peers with TD (Nathan et al., 2004). Studies show that orthographic knowledge accounts for unique variance in word reading and spelling, above and beyond phonological awareness in children with TD (Cunningham & Stanovich, 1990; 1991; Wang et al., 2014). Based on the self-teaching hypothesis, children with SSD may have difficulty gaining orthographic knowledge to allow for word reading and spelling development. Therefore, orthographic knowledge is a factor that may assist in explaining why some children with SSD become skilled word readers and spellers while others demonstrate word reading and spelling difficulties.

Orthographic Knowledge

Orthographic knowledge has been minimally examined within literacy research, especially in children with SSD (Ehrhorn & Adlof, 2021). When included, the main types of orthographic knowledge measured are letter identification (i.e., alphabetic knowledge) and letter-sound correspondence (i.e., phoneme-grapheme correspondences; Anthony et al., 2011; Apel & Lawrence, 2011; Bird et al., 1995; Carroll & Snowling, 2004; Carson et al., 2015; Raitano et al., 2004; Treiman et al., 2008). Most of these studies suggest that children with SSD have difficulties identifying letters and their corresponding speech sounds as compared to their peers with TD. While these are the earliest developed and most common types of orthographic knowledge measured, these skills do not capture the depth of orthographic knowledge required to read words.

Wang and colleagues (2014) showed that knowledge of orthographic patterns rather than phoneme-grapheme and alphabetic knowledge is more strongly related to word reading ability. Apel (2011) defines knowledge of orthographic patterns as the rules that govern how speech sounds are represented in print. Although knowledge of orthographic patterns has been investigated in children who are developing typically and those with word reading difficulties, only two studies have measured these constructs in children with SSD. McNeill and colleagues (2017) examined orthographic pattern knowledge in children with SSD as compared to two groups of their peers with TD (age-matched and reading matched). A nonword reading ability task developed by Apel and colleagues (2012) was designed to tap into and measure their orthographic pattern knowledge when a nonword was spoken. The children circled one of three written spellings that looked “most like” a nonword spoken by the examiner (e.g., heard /spʌz/ and selected either “spuzz, spuze, or spuz”). All selection options were related to the speech sounds, but only one was probably based on orthographic pattern rules. Results showed that age-matched children with TD outperformed children with SSD, but the reading-matched children with TD performed similarly to children with SSD. These results suggest that children with SSD have poorer orthographic pattern knowledge than their same-aged peers with TD, but a similar level of knowledge as their younger reading-matched peers with TD. Further examination of orthographic knowledge in SSD focused on phoneme-grapheme correspondences and orthographic patterns may provide insight into another essential factor that explains word reading and spelling outcomes.

1.3 Influence of Orthography on Phonological Awareness Performance

Research in skilled adult readers suggests that orthography influences phonological awareness performance. Orthographic knowledge has been shown to be accessed without conscious effort when processing speech sounds once reading instruction occurs and in skilled readers (Frith, 1998; Port, 2010; Seidenberg & Tanenhaus, 1979; Ziegler & Ferrand 1998). This phenomenon occurs across languages no matter the depth of orthographic systems (Jevtović et al., 2022). The study by Seidenberg and Tanenhaus (1979) was the first to examine orthographic influences on two phonological awareness tasks focused on rhyming detection. These researchers showed that the rhyming words that had similar orthography (e.g., boy and soy) had a quicker response time as compared to dissimilar orthographic rhyming words (e.g., buy and tie). These results were extended by Ziegler and Ferrand (1998) examining orthographic influence in French skilled adult readers using an oral lexical decision task. Results showed that spoken words containing consistent rime spellings (e.g., st<u>age</u>) were selected with higher accuracy and quicker response time as compared to words with less consistent phoneme-grapheme forms (e.g., y<u>acht</u>). Supporting the Triangle model, these studies showed that orthographic information is connected to and coactivates phonological information in skilled adult readers.

Only two studies have examined orthographic knowledge influences on phonological awareness performance in children (Castles et al., 2003; Castles et al., 2011). Castles et al. (2003) examined the orthographic influences on phonological awareness performance in skilled adult readers and school-aged children with typical development within multiple experiments. One experiment used a phoneme deletion task where the stimuli were selected to either have transparent letter-sound correspondence (e.g., take the /s/ from “slant”) or opaque letter-sound correspondence (e.g., take the /s/ from “scene”). Results showed that skilled readers, adults and children, performed better on the phonological awareness tasks when the stimuli had transparent phoneme-grapheme correspondences. The same results were shown when using a phoneme reversal task as well (transparent: “pot” becomes “top”; opaque: “knife” becomes “fine”. Another study by Castles et al. (2011) examined orthographic influences on phonological awareness performance in preschool-aged children by measuring phonological awareness abilities throughout training on specific phoneme-grapheme correspondences. They showed that children improved their phonological awareness performance on items that corresponded with their orthographic knowledge training. Both studies’ results corroborate earlier findings that orthographic knowledge influences phonological awareness performance not only in skilled adult readers but also in developing readers. This influence is interesting to consider when thinking about how it could impact the development of word reading, especially in children with SSD. Specifically, if provided with explicit phoneme-grapheme correspondence instruction, children with SSD may be influenced by their orthographic knowledge to improve phonological awareness. This would suggest that orthographic knowledge could be a protective factor of word reading and spelling difficulties.

No known studies have examined whether orthography influences phonological awareness performance in SSD, although some studies have investigated this in children with dyslexia (Baron et al., 2021; Landerl et al., 1996). Dyslexia is a reading disorder characterized by difficulties with accurate or fluent word reading and spelling (American Psychiatric Association, 2019; Lyon et al., 2003), and deficits in the phonological component of oral language are considered a core feature of the dyslexia profile (Snowling et al., 2020). Studies examining whether orthography influences phonological awareness performance in children with dyslexia could provide insight in SSD as both disorders are thought to share a phonological awareness deficit. Landerl and colleagues (1996) examined orthographic influences on various phonological awareness tasks in children with typical development and children with dyslexia. Results showed that both groups of children were influenced by orthography during phonological awareness tasks, but this effect was not to the same extent in the children with dyslexia as compared to their peers with TD. Based on these findings, we could hypothesize that the phonological deficit in children with SSD leads to weaker orthographic knowledge development (i.e., phoneme-grapheme correspondence knowledge). Thus, children with SSD could be influenced by orthography similarly to their peers with typical development but not to the same extent.

There is some evidence that children with dyslexia may have a relative strength in their orthographic pattern knowledge and that this knowledge may compensate for weak phonological awareness performance (van der Leij & van Daal, 1999). The study by van der Leij and van Daal (1999) examined accuracy and speed of reading real and nonwords in children with dyslexia as compared to children with typical development. Within the stimuli, the real and nonwords were designed to contain more or less common parts of words. While children with dyslexia have poorer real and nonword reading performance than their peers with typical development, results showed that children with dyslexia increased word reading accuracy and speed relative to themselves when the word contained more common parts of a word. This study suggests that children with dyslexia use their orthographic knowledge of patterns to improve their word reading performance. It is possible that children with dyslexia have relative orthographic strengths that are used to overcome phonological awareness deficits. If children with SSD have a relative orthographic pattern knowledge strength similar to peers with dyslexia, it may be hypothesized that children with SSD could also use orthographic knowledge to support their phonological awareness performance. The current study was the first known study to examine whether orthographic knowledge influences phonological awareness performance in children with SSD using a receptive-experimental task.

1.4 Impact of Oral Language Ability on Word Reading and Spelling Development

Early literacy research has identified oral language ability to be a prominent factor leading to skilled word reading Speech sound and language development are separate but overlapping oral communication abilities that develop simultaneously throughout childhood. Oral language ability includes a variety of knowledge and skills that build upon one another (i.e., phonology, morphonology, semantics, syntax, pragmatics, and discourse). As vocabulary increases in preliterate children, greater precision in the phonological system is needed in order to differentiate phonologically similar words (Ainsworth et al., 2016). This suggests that speech sound and oral language development are connected and partially dependent on one another.

Oral language deficits frequently co-occur with SSD (Eadie et al., 2015; Schuele, 2004). Schuele (2004) showed that SSD co-occurs with oral language deficits at a rate of 56% in clinically referred samples. Yet, studies of literacy in children with SSD have varied in their approach to considering oral language. A recent scoping review examined the extent that the last two decades of early literacy studies in SSD measured oral language abilities and controlled for oral language deficits (Ehrhorn & Adlof, 2021). Results suggested that most studies in SSD measured oral language abilities, but the approach to consider oral language deficits and capture the depth of oral language ability assessed varied. These studies most often reported oral language descriptively and measured receptive vocabulary. It is well established that vocabulary measurement is not sensitive or specific enough to determine the presence of oral language deficits, such as developmental language disorder (DLD; Gray et al., 1999). Only 66% of studies that did measure oral language included broader language measures beyond vocabulary. A third of these studies controlled oral language ability as a continuous variable or through subgrouping children based on speech and oral language scores. These studies that controlled broader oral language ability generally showed that poorer oral language abilities were associated with poorer word reading ability in children with SSD. This suggests that more comprehensive measurement and consideration of oral language abilities in children with SSD needs to occur while interpreting risk for word reading and spelling difficulties associated with SSD.

The early literacy research that has controlled for oral language ability in SSD suggests that oral language deficits are known to increase the likelihood of word reading and spelling difficulties in children with SSD (Jin et al., 2020; Lewis et al., 2018; Miller & Lewis, 2022; see review Pennington & Bishop, 2009). Pennington and Bishop (2009) reviewed previous literature examining the overlap between SSD, DLD, and word reading disorders. The review indicated that risk for word reading deficits was “almost entirely restricted” to the co-occurrence of SSD and DLD (Risk Ratio =4.6–8.9) and not the sole presence of SSD (Risk Ratio = 0.9 – 1.6). Multiple early literacy studies following have shown that DLD is an explanatory factor for word reading and spelling deficits in children with SSD (Hayiou-Thomas et al., 2017; Jin et al., 2020; Lewis et al., 2018; Miller & Lewis, 2022; Peterson et al., 2009; Skebo et al., 2013).

Using a population-based sample and continuous variables, Jin and colleagues (2020) recently examined the association between preschool speech intelligibility and literacy performance at 8 years of age, and associated risk factors (e.g., oral language ability). Results showed that persistent speech sound difficulties at age 5 years predict later literacy, but that oral language ability mediated this association. This suggests that oral language ability is a crucial mediating factor between speech sound production and later literacy. These findings were supported by an exploratory analysis that most recently examined whether word reading, speech sound production and perception, and phonological processing differed between children with SSD-only and children with SSD and DLD (Miller & Lewis, 2022). Results showed that children with SSD-only had low-average word reading ($\bar{x}$ = 90.4) and read words significantly better than peers with co-occurring SSD and DLD ($\bar{x}$ = 68.0). This suggests that word reading deficits are highly likely when children have the co-occurrence of oral language deficits as compared to SSD alone. Collectively, the last decade of early literacy research in SSD suggests that oral language has an additive role in predicting word reading and spelling difficulties in children with SSD.

Research examining children with DLD longitudinally has shown that oral language deficits increase risk for word reading difficulties but do not guarantee these difficulties (Catts et al, 2005; Schuele, 2004). For example, Catts and colleagues (2005) examined early literacy phonological awareness and phonological memory factors in children with oral language deficits DLD starting in kindergarten, and examined these factors at second, fourth and eighth grades while applying classification criteria for the presence or absence of word reading deficits. The children with DLD and no word reading deficits showed only mild phonological awareness difficulties ($\bar{x}$ = 90) in kindergarten as compared to children with TD ($\bar{x}$ = 105). This single deficit group showed improved phonological awareness by second grade ($\bar{x}$ = 100) when children were no longer significantly different from the TD group ($\bar{x}$ = 107). The other group of children with DLD and word reading deficits had more severe phonological awareness deficits in kindergarten. These children were shown to have more persistent phonological awareness deficits through eighth grade. Catts and colleagues (2005) interpreted these findings together as that reading instruction helped improve phonological awareness in children with mildly lower phonological awareness scores in kindergarten than peers with TD, but not in children with more severe phonological awareness deficits in kindergarten.

In a new sample of children, Catts et al. (2017) examined the association between a deficit with phonological awareness, alone and in combination with oral language and rapid automatic naming deficits, in kindergarten and word reading deficits in second grade. Results showed that phonological awareness deficits are core to explaining word reading deficits and that oral language deficits and/or rapid naming deficits increase risk for word reading deficits. These studies support that difficulties with phonological awareness and oral language ability in kindergarten increase risk for word reading deficits, but that rapid autonomic naming and/or acquired foundational orthographic knowledge serve as protective factors for word reading difficulties (Catts et al., 2005; 2017). Therefore, consideration of multiple factors leads to better prediction of word reading difficulties.

These findings align with early literacy research in SSD suggesting that other factors in addition to phonological awareness and oral language ability predict word reading and spelling difficulties (Burgoyne et al., 2019; Cabbage et al., 2018; Miller & Lewis, 2022; Wren et al., 2021). For example, multiple studies have suggested that phonological processing deficits and/or rapid automatic naming deficits in children with SSD are also predictive of word reading and spelling development (Jin et al., 2020; Miller & Lewis; Tambyraja et al., 2020). Foundational orthographic knowledge is another factor that could influence word reading and spelling development in SSD, but few studies have examined foundational orthographic knowledge, especially after accounting for oral language ability (Ehrhorn & Adlof, 2021). Only 39% accounted for oral language ability within analyses when examining an aspect or aspects of foundational orthographic knowledge in children with SSD. The current study measured and accounted for oral language ability using a comprehensive assessment while examining phonological awareness, orthographic knowledge, and the interplay between these two word reading and spelling factors in children with SSD.

1.5 Literature Review Summary

In summary, early literacy research suggests that children with SSD are at risk for word reading difficulties due to their phonological deficits. Most of the research evidence suggests that children with SSD have phonological awareness deficits, but this does not guarantee word reading difficulties. Some possibilities that could explain why some children with SSD have word reading difficulties relate to how phonological awareness was measured and additional deficits in other factors, orthographic knowledge and oral language ability. The limited studies that measure orthographic knowledge suggest that children with SSD potentially have difficulty acquiring phoneme-grapheme correspondence knowledge and knowledge of orthographic patterns. No known studies have examined the relationship between orthographic knowledge and phonological awareness in children with SSD. Additionally, oral language ability has been identified as a necessary factor that influences children’s word reading and spelling development. Previous early literacy research suggests that children with SSD have lower oral language ability due to the co-development and partial dependence of speech sounds and oral language, but the approach to consider oral language abilities has varied. The current study addressed gaps and provides further understanding of risk factors and protective factors for children with SSD during word reading and spelling development.

1.6 Current Study

The primary aim of the current study was to examine the influence of orthography on phonological awareness performance in children with SSD and children with typical speech development (TSD).

Specifically, the research questions were the following:

1) Do children with SSD differ from peers with TSD in their phonological awareness and foundational orthographic knowledge?
2) Does orthography influence phonological awareness performance in children with SSD before and after controlling for oral language ability?
3) Does the relationship of orthographic influence on phonological awareness performance in children with SSD differ from peers with TSD?
4) Do any significant group differences remain after controlling oral language ability?

HYPOTHESES. Children with SSD were predicted to have poorer phonological awareness performance as compared to their peers with TSD. These predictions were based on research on children with SSD (Apel & Lawrence, 2011; Brosseau-Lapré & Roepke, 2019; Burgoyne et al., 2019; Jin et al., 2020; Masso et al., 2017; Miller & Lewis, 2022). The difference between groups was predicted to be greater in the receptive-based experimental phonological awareness task as compared to the norm-referenced composite phonological awareness due to accounting for the speech sound error productions while scoring. Additionally, these group differences in phonological awareness performance were hypothesized to remain after accounting for oral language ability (fourth question).

Based on minimal SSD research, I predicted less phoneme-grapheme correspondence knowledge and orthographic pattern knowledge in children with SSD as compared to their peers with TSD. This hypothesis was informed by previous literature showing that children with SSD have less phoneme-grapheme correspondence knowledge as compared to peers with TSD (Anthony et al., 2011; Apel & Lawrence, 2011; Bird et al., 1995; Carroll & Snowling, 2004; Carson et al., 2015; Raitano et al., 2004; Treiman et al., 2007). The predicted decreased orthographic pattern knowledge in SSD as compared to their peers with TSD was informed by McNeil and colleagues (2017) results. These hypothesized phoneme-grapheme correspondence knowledge and orthographic pattern knowledge in SSD were predicted to no longer be significantly different from peers with TSD after accounting for language ability. This was predicted based on previous findings that oral language ability is closely related to orthographic knowledge deficits as compared to speech production skills (Anthony et al., 2011; Burgoyne et al., 2019). Examining phonological awareness and foundational orthographic knowledge in SSD may explain why the risk of word reading and spelling is variable in children with SSD. These results build upon theoretical and deficit models to inform clinical practice.

Regarding the second and third research questions, I predicted children with TSD would be influenced by the orthographic properties of words during a phonological awareness task, and children with SSD would be influenced minimally. Based on Landerl and colleagues (1996), I predicted that children with TSD would perform with higher accuracy on the phonological awareness task when the stimuli have congruent phoneme-grapheme correspondences throughout the task and that this influence would remain the same after controlling oral language ability. For children with SSD though, I predicted that these children would have low accuracy that is similar, no matter the phoneme-grapheme correspondence congruency. This minimal influence in SSD would remain the same after controlling oral language ability.

Regarding the third research question, I had two predictions when examining between-group differences based on the dyslexia literature. If orthographic properties of words influenced phonological awareness performance differently between groups as showed by Landerl and colleagues (1996), I expected that children with TSD would outperform children with SSD on their accuracy and that children with SSD would have similar accuracy across the phoneme-grapheme correspondence congruency. If orthographic properties of words influence phonological awareness performance in children with SSD similarly to TSD children (e.g., aligns with van der Leij and van Daal (1999) results), this would further suggest that orthographic knowledge may be leveraged to improve phonological deficits in children with SSD and potentially serve as a protective factor during word reading and spelling development.

Study Contribution

This study added to the existing literature on children with SSD and addressed gaps in previous studies in four ways. First, this study examined whether orthographic properties of words influenced phonological awareness performance in children with SSD and whether this differed from their peers with TSD. This is the most novel aspect of the study and has not been studied in children with SSD to the current authors' knowledge. Second, the current study accounts for the range of possible oral language abilities within the planned statistical analyses, as this factor has been identified to increase risk of word reading difficulties in SSD (Burgoyne et al., 2019; Miller & Lewis, 2022; Tambyraja et al., 2020). Therefore, this study provides the opportunity to better be able to identify and associate deficits or strengths with SSD. Third, the current study more comprehensively measures foundational orthographic knowledge (i.e., phoneme-grapheme correspondence knowledge and orthographic pattern knowledge) through two experimentally designed tasks. Lastly, the current study used receptive- and production-based tasks of phonological awareness skills in children with SSD. Measuring phonological awareness through a receptive-based task provides the opportunity to measure phonological awareness separately from speech sound production.

Chapter 2

Method

Approval by the University of South Carolina Institutional Review Board was obtained prior to recruitment and data collection.

2.1 Study Structure

The study involved three 90-minute or four 60-minute data collection sessions depending on participant and caregiver preference. Table 2.1 provides an outline of the assessment administration order with administration times for each assessment. All tasks were delivered virtually through a Zoom platform, and study assessment administration was audio- and video-recorded for scoring and reliability assessment. To ensure the quality of communication, all tasks were administered using headphones with a microphone. The Decibel X: dB Sound Level Meter app (https://skypaw.com/decibelx.html) was used to ensure participants' environmental noise level at the beginning of the session was < 40 dB. Caregivers were asked to provide access to headphones for the participant. Participants were given the option to wear headphones with a microphone if the environmental noise was <40 dB. Published assessments were administered over Zoom with the publishers' permission. Experimental tasks were programmed for web-based assessment through Gorilla Experiment Builder (www.gorilla.sc; Anwyl-Irvine et al., 2019).

2.2 Participants

Sixty monolingual English-speaking children (TSD *n* = 30; SSD *n* = 30) between ages 6-8 years old (SSD $\bar{x}$ = 6.77 yrs.; TSD $\bar{x}$ = 6.80 yrs.) were recruited through two sources. The initial recruitment source was an invitation to previous research participants within a larger study recently conducted in the South Carolina Research on Oral Language and Literacy laboratory. Potential participants were only contacted if they indicated an interest in future research and met some of the classification criteria of the current study. The second source of recruitment was through additional community and nationwide social media advertisements targeting caregivers, educators, and speech-language pathologists who treat children with current SSD. Caregivers indicated an interest in study participation via email or interest survey before they were sent current study information. Consent, assent, and an intake questionnaire were obtained for all participants who completed the study. The researcher confirmed no other known diagnoses that impact development (e.g., Autism, genetic disorders, recent TBI, hearing impairment, and uncorrected vision impairment) for all participants according to the caregiver report within the intake questionnaire. One child in the SSD group also presented with a co-occurrence of stuttering which is not uncommon (Unicomb et al., 2020). Table 2.2 provides age and demographic information of the children by group.

2.3 Participant Classification

Table 2.3 presents the various speech sound production and oral language assessments used for classification and further description of these abilities. Children with TSD had no reported history of speech sound production difficulties. Typical speech sound production was confirmed through a norm-referenced speech sound production assessment, *Goldman-Fristoe Test of Articulation 3* (GFTA-3; Goldman & Fristoe, 2015), with a standard score of ≥ 90 on the Sounds-in-Words subtest. If some consistent speech sound production errors were noted with no reported history of SSD, the child was required to produce ≥ 99 percent consonants correct (PCC; Shriberg & Kwiatkowski, 1982) calculation on a 50-word speech sample using the Systematic Analysis of Language Transcripts (SALT; Miller & Iglesias, 2012) Story Retell protocol. PCC is the total number of correctly produced consonants divided by the total number of consonant targets. PCC was selected for the consonant accuracy measurement as it is correlated with overall speech intelligibility in conversation and is a good index of SSD severity (Shriberg et al., 1997). No children within the TSD group were shown to have consistent speech sound errors to require their speech sample to be analyzed for PCC requirement.

Children with SSD had a history and current parental concerns related to their speech sound production and measured below the typical development standards for one of two measurements of speech sound production. These measurements are a standard score of ≤ 85 on the GFTA-3 Sounds-in-Words subtest, and ≤ 95 PCC during a 50-word speech sample. All participants met the GFTA-3 Sounds-in-Words requirement except for three children with a history and current speech sound errors. Through their speech sample, the three children exhibited speech sound errors meeting the PCC requirements to be included in the SSD group. Oral language abilities were assessed for all participants with the Core Language subtests of the *Clinical Evaluation of Language Fundamentals, Fifth Edition* (CELF-5; Wiig et al., 2013) and the *Peabody Picture Vocabulary Test, Fifth Edition* (PPVT-5; Dunn, 2019).

The norm-referenced speech sound production assessments do not include all consonants and vowels in all positions of words. Therefore, a Brosseau-Lapré multisyllable word assessment (Brosseau-Lapré et al., 2019) was administered to all participants. This assessment was used to further describe speech sound production differences between the TSD and SSD groups. All children completed the 50-word speech sample using the SALT Story Retell protocol. The percentage of intelligible words (PIW) from the 50-word conversational speech sample was calculated for all participants. PIW is a subjective measure that provides a measure of “real life” overall intelligibility of connected speech quantitatively, which calculates the number of words understood by the listener divided by the total number of produced words in the transcript (Gordon-Brannan & Hodson, 2000; Shriberg & Kwiatkowski, 1985). Recordings were transcribed with Microsoft Office (https://www.microsoft.com/en-us/microsoft-365) and edited by a research assistant to ensure the accuracy of the transcription for 50-words (filler, repeated words, and words not understood due to audio recording issues were not counted in the total). The research assistant coded an unintelligible word as “XXX” within the transcript if they could not understand the word attempted.

To calculate PIW, the scorer counted the number of words understood out of 50-words (the total number of words in the speech sample). The PIW was completed at least one week after the participant completed the study, and the scorer did not use any audiovisual information. PIW is a descriptive measure of their overall intelligibility of words produced providing a more holistic picture of speech sound production abilities in the TSD and SSD groups. Table 2.4 presents the descriptive information for all speech sound production and oral language assessments, and statistical tests to indicate significant group differences. The oral language assessment score distributions were similar and overlapping but children with SSD generally had a wider spread and lower peak of scores as compared to peers with TSD.

2.4 Assessments of Foundational Skills in Word Reading and Spelling

Table 2.5 presents the various assessments and tasks used to measure phonological awareness, orthographic knowledge, orthographic influence on phonological awareness, phonological processing, and word reading and spelling.

Phonological Awareness

Phonological awareness was primarily measured through an experimental, receptive-based task (Baron et al., 2021; Fisher, 2019). In each trial of this task, children see four pictures that are named at the bottom of the computer screen (i.e., response choices) followed by a picture appearing and named on the top of the screen (i.e., stimulus). Children are asked to click on the picture that ends with the same last sound as [stimulus]. Performance differences between groups (SSD versus TSD) were determined using the overall proportion of accurate responses (dependent variable). Children with stronger phonological awareness skills were predicted to have higher accuracy on the task, whereas the opposite would be predicted for children with poorer phonological awareness skills. This task was designed to also investigate the influence of orthographic knowledge on phonological awareness performance by control of the stimuli and conditions within the task. Further details of the task design are explained in the section accordingly below.

In addition, three subtests of the *Clinical Test of Phonological Processing, Second Edition* (CTOPP-2; Wagner et al., 2003) were administered to derive the Phonological Awareness (PA) composite score: Elision, Blending Words, and Sound Matching (ages 4-6 years)/Phoneme Isolation (ages 7-21 years). Elision measures the ability to remove phonological segments from spoken words to form other words (e.g., hotdog without hot is dog). Blending words measures the ability to synthesize sounds to form words (e.g., hot – dog, together forms hotdog). Sound matching measures the ability to segment phonemes from a stimulus word presented and identify the targeted word from three presented options that contain the same phoneme in the same position. Phoneme isolation measures the ability to isolate individual sounds within words (e.g., the last sound in the word hotdog is /g/). This is a widely utilized norm-referenced assessment that measures phonological awareness based on children’s productions. Scoring was adjusted based on the speech sound errors identified in the word-level speech sound assessments as done by previous studies (Brosseau-Lapré, & Roepke, 2019; Cabbage et al., 2016; Lewis et al., 2011). For example, if they produce /s/ in error, the items that require the production of /s/ will be given credit if their response is consistent with their speech sound production error. For children who presented with inconsistent speech sound production errors (*n* = 2), subtests were administered and scored by a certified clinical speech-language pathologist who has extensive knowledge and clinical expertise working with this subtype of SSD. The scorer allowed for more time and self-corrections for each item before the child indicated their final answer. The standardized CTOPP-2 PA index score was used to examine phonological awareness differences between groups (SSD versus TSD).

Orthographic Influences on Phonological Awareness

The previously mentioned experimental phonological awareness task was specifically designed to examine whether orthography influences phonological awareness performance. Congruency and consistency of the phoneme-grapheme pairs (i.e., orthographic properties of words) were manipulated in three conditions (see Figure 2.1). In a congruent trial, the spelling of final phonemes in the stimulus and target were the same (see figures 2.1A (mug-tag) and 2.1B (bricks-clocks)). In an incongruent trial, the spelling of the final phonemes in the stimulus and target were different (see Figure 2.1C (blocks-fox). Spelling consistency of the phoneme-grapheme pairs was also manipulated across all trials in the task. Consistent phoneme-grapheme pairs were those in which the final phonemes were spelled the same way across all other trials within the task (see figure 2.1A [mug-tag] as well as table A.1 showing consistent spellings of phonemes within the task). Inconsistent phoneme-grapheme pairs were those in which the final phonemes were spelled differently in other trials within the task (see figures 2.1B [bricks-clocks] and 2.1C [blocks-fox] as well as table A.1 to review inconsistent spellings of the phonemes). The task included three conditions each having 12 trials for a total of 36 trials: 1) Congruent-Consistent [CC; e.g., mug-tag], 2) Congruent-Inconsistent [CI; e.g., bricks-clocks], and 3) Incongruent-Inconsistent [IN; e.g., blocks-fox]. This was an important aspect to consider when examining the effects of orthographic properties of words because a) there is not always a one-to-one mapping of phoneme-graphemes in the spelling of words (e.g., bricks-clocks), and b) not all phonemes were consistently spelled the same over all words (see Figure 2.1C [blocks-fox]). Table A.1 contains the stimulus, target, and three foils for 12 trials in each condition.

The target position was randomly set for each trial within the experiment. Additionally, the order of trials was randomized for each child through Gorilla programming. Child word databases were used to ensure that all stimulus words would be familiar to young children (e.g., Moe et al., 1982; Zeno et al., 1995). Additionally, we ensured that the targets and foils did not differ in phonotactic probability and neighborhood density (Vaden et al., 2009). Table A.2 presents the average phonotactic probability and neighborhood density levels for each type of stimuli (stimulus, target, and three foils) by condition (CC, CI, IN). The dependent variable is proportion accurate by condition. If orthograph properties of words influence phonological awareness performance, then children should be more accurate on items that are congruent items than on incongruent items, and more accurate on items that are consistent than on inconsistent items.

Other Phonological Processing

Other phonological processing components are included within the study because recent studies suggest that children with SSD have a phonological memory deficit and rapid symbolic naming deficit that increase risk of word reading and spelling difficulties (Farquharson et al., 2021; McWeeny et al., 2022). The CTOPP-2 was also used to measure phonological processing by deriving the 1) Phonological Memory composite score through Memory for Digits and Nonword Repetition subtests, and 2) Rapid Symbolic Naming composite score through Rapid Digit Naming and Rapid Letter Naming subtests. Memory for Digits measures the ability to recall a string of digits that is presented through an audio recording. Nonword Repetition measures the ability to repeat a nonword presented through an audio recording. The difficulty level increases as one progresses in the task for both subtests. Rapid Digit Naming measures the ability to accurately name as many numbers presented as quickly as possible. Rapid Letter Naming measures the ability to accurately name as many letters presented visually as quickly as possible. Each subtest was scored using binary methods for accuracy (i.e., correct versus incorrect). For the timed subtests, the number of errors not self-corrected was counted and the total time was measured.

Orthographic Knowledge

Orthographic knowledge was measured through three experimental tasks: an alphabet knowledge task, a phoneme-grapheme correspondence task, and an orthographic pattern knowledge task. The alphabet knowledge task was designed to assess children’s ability to name all the letters (i.e., graphemes) in English orthography.

The children saw a grapheme presented on the screen using Tahoma font and were instructed to “Tell me the name of the letter you see on the Screen.” The task included both upper and lowercase graphemes resulting in a total of 52 trials. The trials were in a randomized set order that differs from the traditional alphabet order. The dependent variable is the proportion of accurately named letters. The alphabet knowledge task was purely included as a descriptive measure to better understand their performance on the main two orthographic knowledge tasks.

The phoneme-grapheme correspondence task was designed to measure children’s knowledge of speech sounds and their correlated spelling(s). The children were asked, “Does [visually presented grapheme] make [audiovisually presented phoneme].” The children were required to answer Yes or No. The task consisted of 48 trials (24 True, 24 False). To design a task that includes items across a range of difficulty, phoneme-grapheme pairs were selected from three Orton-Gillingham (OG) instructional levels (I, II, III). A total of 8 Yes options and 8 No options were constructed for each OG level (16 trials in each OG level). Within level I, 12 out of 16 items measured single grapheme-phoneme correspondences (e.g., /t/ and ‘t’). Across all levels, 36 items measured more complex phoneme-grapheme pairs (e.g., /f/ and ‘ff’ or ‘ph’). Table A.3 contains the phoneme-grapheme correspondence task stimuli. D-prime scores on the phoneme-grapheme correspondence task were the dependent variable to examine group differences. A signal detection theory measurement (i.e., d-prime) was used in analyses to account for response bias in the forced-choice designed task that has “true options” and “false options.” Specifically, d-prime measured the distance between the “true option” and the “false option” means in standard deviation units resulting in a response measurement that accounts for bias. See Stanislaw & Todorov (1999) for further rationale.

The orthographic pattern task was designed to measure children’s knowledge of orthographic constraints and sensitivity to orthographic regularities. In the task, children were presented with two strings containing four letters and asked, “Which one looks MOST like a word you would see in a book?” This forced-choice task had three sets of items. To measure knowledge of orthographic constraints, two sets of items presented an orthographically legal letter string against an illegal string [i.e., high versus illegal items (HI); the low versus illegal items (LI)]. High orthographic strings were letter strings that have *high* orthotactic probability, meaning it has pairs of letters that frequently occur together (i.e., rean). Low orthographic strings were letter strings that have *low* orthotactic probability, meaning that it has legal pairs of letters that go together but are less frequent than the high probability strings (i.e, aper). Illegal orthographic letter strings do not follow the rules of the English written language by containing a *digraph that is illegal in that word position* and/or *no vowel present* (i.e, ecdx, vpyf). The MCWord database was used to automatically generate nonword 4-letter strings that are allowable and 4-letter stings that were illegal in English orthography (Medler & Binder, 2005). The selection of stimuli was guided by orthographic neighborhood (Coltheart's N) and orthographic frequency of the letter in various positions within a word. To further determine the level of sensitivity to orthographic regularities, a third set of items was incorporated that presented both orthographically probable letter strings against one another [i.e., high versus low items (HL)].

The orthographic pattern knowledge task included 90 total trials, with the intention to include 30 trials for each set of items. However, some trials were excluded from the analyses when it was discovered that some strings were similar to the spellings of word abbreviations or proper names, and some trials contained two illegal strings in the trial. This resulted in differing numbers of trials for each set of items (HI items = 30 trials; LI items = 26 trials; HL items = 25 trials) for a total of 81 trials. Table A.4 contains the orthographic pattern knowledge task stimuli for each set of items in the analyses. Table A.5 contains the average and standard deviations for the orthographic neighborhood (Coltheart's N) and orthographic frequency of the letter in various positions within a word included in the analyses. Trial order and the location of each letter string were randomized through Gorilla programming. The dependent variable was proportion accurate by set of items. Children with stronger and more sensitive orthographic pattern knowledge were predicted to have high proportions accurate for each condition. Even if children were able to distinguish an orthographically legal letter string versus an illegal orthographic letter string, they still may demonstrate weaker sensitivity to orthographic probability by having lower proportions accurate in the high versus low items.

Word Reading and Spelling Ability

Additional orthographic measures were incorporated to examine two orthographic outcomes. Word reading was measured through the Word Identification (real word reading) and Word Attack (reading pseudowords) subtests on the *Woodcock Reading Mastery Tests, Third Edition* (WMRT-III; Woodcock, 2011) to derive the Basic Skills composite scores. For each word reading subtest, the children were presented with a list of words and asked to read each word. These WRMT-III subtest scores and WRMT-III composite scores were used to describe the children's current abilities.

Spelling was measured through a spelling task consisting of 10 real words used in previous studies (Masterson & Apel, 2010; Wolter & Apel, 2010). The stimuli were taken from a kindergarten and first grade spelling inventory (Bear et al., 2000) and were the following: fan, pet, dig, mop, rope, wait, chunk, sled, stick, slide. The examiner read each word aloud, and the children were instructed to write the spelling on the piece of paper. If they were unsure or took more than one minute to begin writing, the examiner encouraged them to make their best guess or to indicate their need to skip it, and then moved on to the next item. The proportion spelled accurately was used to describe the children's current spelling abilities.

2.5 Planned Analyses

Descriptive statistics were calculated for all assessments (experimental and norm-referenced) by group. For the main questions, simple and multiple linear regression models were used to determine significant group, condition, and/or oral language ability differences.

Examination of the data occurred for each task to first identify outliers systematically. Outlier detection is an important step in data analysis as it removes erroneous or inaccurate values observed which might skew interpretations. For each task, scores were flagged if higher or lower than 1.5 standard deviations away from the data mean or mode. Then, the evaluation of two possible errors occurred to determine if the flagged score could be inaccurate. The child's other assessment scores were reviewed to determine if there was a possible behavioral response error (e.g., not willing to participate, other distractions occurred, etc.). This was followed by an examination of data scoring/entering errors through review of data videos, scoring, and entering. No data scoring or entering errors occurred. If the score was determined to be a possible behavioral response error, the observed score was deleted. If identified outliers were not explained by the previous two possible errors, further determination of whether the child's score was inaccurate occurred through the regression analyses. The regression residuals were reviewed using Cook's D plot and Residual-Leverage Plot. The Cook's D plot identified any scores that could be highly influential outliers. Then, the Residual-Leverage plot was reviewed to determine if any identified scores were outside of Cook's D line of approximation (values 0.5 and 1.0). These observed values were considered erroneous outliers and deleted from the reported descriptives and regression analyses. The decision to delete the value(s) was made instead of winsorizing to eliminate the weight of these extreme values (minimal occurrence within tasks).

Two scores were suspected to be inaccurate within the study, once in the phoneme-grapheme correspondence task and once in the experimental phonological awareness task. One child in the TSD group exhibited scores determined to be erroneous on the phoneme-grapheme correspondence task; this child's data was excluded from analyses and this child is not reflected in the phoneme-grapheme correspondence boxplot (Figure 3.2) or descriptive statistics reported (Tables 3.3 and 3.11). Within the experimental phonological awareness task, two children from the total TSD sample were not included in this analysis due to 1) one child not completing the task after an attempt (missing data), and 2) one child's results were not included as the value was determined to be an erroneous outlier. These children are not reflected in the experimental phonological awareness boxplot (Figure 3.4) or descriptive statistics reported (Tables 3.7 and 3.9). Due to time constraints and child fatigue, some children did not complete the CTOPP-2 or other descriptive assessments. This is reflected in Tables 2.4, 3.1, and 3.2.

Additionally, an examination of the data occurred for each model to determine if assumptions were met (i.e., linearity, normality, homoscedasticity, and independence). All models met the assumptions. Refer to Appendix B figures for residual plots and detailed descriptions for each model. Effect sizes for all descriptives were calculated using Hedge's *g* to determine the magnitude of group differences. This measure of effect size was used to decrease the amount of bias due to varying group sizes and a relatively smaller sample size.

Main Analyses

To answer the first research question which aims to determine whether children with SSD differ from their peers with TSD in their phonological awareness and foundational orthographic knowledge, linear regression models were conducted for each task targeting a word reading construct (i.e., phonological awareness and orthographic knowledge). For the phonological awareness construct, the performance of children with SSD and children with TSD was analyzed using a norm-referenced assessment (CTOPP-2; expressive-based) and an experimental task (receptive-based). The CTOPP-2 PA composite score was used as the dependent variable. The experimental phonological awareness task used proportion accuracy by condition as the dependent variable (refer to the group analysis within question three).

For the orthographic knowledge construct, the performance of children with SSD and children with TSD was analyzed using linear regression models. A simple linear regression model was used to examine group differences using the d-prime scores on phoneme-grapheme correspondence. A planned multiple linear regression model examined group differences on the orthographic pattern knowledge task using proportion accurate by condition (i.e., HI, LI, and HL).

To answer the second research question which aimed to determine whether orthographic properties of words influence phonological awareness performance in children with SSD, a simple linear regression was completed using the proportion accurate of each task condition (CC, CI, IN) before controlling for oral language ability. An additional multiple linear regression model was completed using the same variables but including the CELF-5 Core Language Score (CELF-5 CLS) as another predictor.

The third research question examined whether orthographic properties of words influence phonological awareness performance differently between children with SSD and their peers with TSD. Two linear regression models were conducted to examine whether children with TSD were influenced by orthographic properties of words according to their proportion accurate on the experimental phonological awareness task by condition (CC, CI, IN). One model examined these without controlling oral language ability while the other did. After determining whether children with TSD experience orthographic influence, a multiple linear regression model was conducted for proportion accurate by condition (CC, CI, IN) on the experimental phonological awareness task with an additional predictor, group classification (SSD and TSD).

The last research question examined whether any significant group differences in the above regression models remained after controlling for oral language ability. This was determined by re-running these models with an additional predictor added to control for oral language ability, CELF-5 Core Language Index Score. If language ability is significant in addition to group, this would indicate that both the presence of SSD and oral language need to be considered to predict risk for difficulty in the measured foundational component of word reading and spelling word reading and spelling. If oral language ability is significant and group is no longer significant, this would indicate that oral language ability can better predict difficulty in the measured foundational component for word reading and spelling than the presence of SSD.

The regression models were all reported within the text regardless of significance. Only significant interaction models and any significant main effects are reported in the regression tables.

Sample Size Justification

The current study examined phonological awareness, orthographic knowledge, and the relationship between these foundational knowledge areas of word reading and spelling in children with SSD as compared to peers with TSD. An a priori power analysis using G*Power version 3.19.7 (Faul et al., 2007) indicated that a sample size of at least 30 per group would provide adequate power (.80) for detecting a small effect using linear regression analyses, at the significance criterion of α = .05. Additionally, a total sample of 60 children was thought to be feasible in the timeline of this dissertation study.

Table 2.1 *Administration Order and Times for all Assessments*

Order of Administration	Administration Time
SESSION 1: Classification Speech Sound Production and Oral Language tasks	Total = 60 minutes
Sounds-in-Words subtest on GFTA-3	~ 5 minutes
50-word conversational speech sample using SALT Story Retell protocol	~ 10 minutes
Core Language subtests on the CELF-5	~ 45 minutes
SESSION 2: Phonological Awareness and Orthographic Knowledge tasks for Main Analyses	Total = 60 minutes
Experimental Phonological Awareness Task	~ 20 minutes
Experimental Alphabet Knowledge Task	~ 5 minutes

Experimental Phoneme-Grapheme Correspondence Task	~ 15 minutes
Experimental Orthographic Pattern Knowledge Task	~ 20 minutes
SESSIONS 3-4: Measures for exploratory analyses and descriptive measures	Total = 90 minutes
Brosseau-Lapré multisyllable word assessment	~ 15 minutes
Word Identification and Word Attack subtests on the WMRT-III	~ 5 minutes
Spelling Task of Real Words	~ 10 minutes
Phonological awareness subtests on the CTOPP-2 (total of 3 subtests)	~ 25 minutes
Phonological processing subtests on the CTOPP-2 (total of 4 subtests)	~ 15 minutes
PPVT-5	~ 20 minutes

Note. Further details of the listed assessments are the following: *Goldman-Fristoe Test of Articulation 3* (GFTA-3; Goldman & Fristoe, 2015), *Systematic Analysis of Language Transcripts* (SALT; Miller & Iglesias, 2012), *Clinical Evaluation of Language Fundamentals, Fifth Edition* (CELF-5; Wiig et al., 2013), *Peabody Picture Vocabulary Test, Fifth Edition* (PPVT-5; Dunn, 2019), Brosseau-Lapré multisyllable word assessment (Brosseau-Lapré, et al., 2019), *Clinical Test of Phonological Processing, Second Edition* (CTOPP-2;

Wagner et al., 2003), *Woodcock Reading Mastery Tests, Third Edition* (WMRT-III; Woodcock, 2011), and a Spelling Task of Real Words (Masterson & Apel, 2010; Wolter & Apel, 2010).

Table 2.2 *Demographic Descriptives and Test Statistics by Group*

Demographic		*n*	Proportion	*n*	Proportion	X^2 Test	*p*
		SSD		TSD			
Age	6 years	13	0.22	12	0.20	0.08	.959
	7 years	11	0.18	12	0.20		
	8 years	6	0.10	6	0.10		
Grade	Kindergarten	5	0.08	5	0.08	6.91	.075
	1st	12	0.20	15	0.25		
	2nd	13	0.22	6	0.10		
	3rd	0	0.00	4	0.07		
Sex	Male	16	0.27	13	0.22	0.60	.438
	Female	14	0.23	17	0.28		
Ethnicity	Hispanic/Latino	4	0.20	3	0.10	0.00	.999
	Not Hispanic/Latino	26	0.80	27	0.90		

Demographic		*n*	Proportion	*n*	Proportion	X^2 Test	*p*
		SSD		TSD			
Race	American Indian/Alaska Native	1	0.03	0	0.00	10.11	.431
	Asian	2	0.07	1	0.03		
	Black/African American	1	0.03	2	0.07		
	White	22	0.73	25	0.83		
	Other	2	0.07	0	0.00		
	More than one	2	0.07	2	0.07		
*Maternal Highest Attained Level of Education	High School Diploma/GED	0	0.00	0	0.00	1.47	.999
	Associate's Degree/Technical School Certificate	2	0.07	2	0.07		
	Some College Completed	1	0.03	3	0.10		
	Bachelor's Degree	8	0.27	4	0.14		
	Master's Degree or Higher	19	0.63	20	0.69		

Note. The chi-squared statistical analyses reference was the children with typical speech development (TSD) as compared to children with speech sound disorder (SSD). Change in TSD sample size indicated by (*). Over-representation occurred for many demographics within the sample. The study captured the abilities of children who were identified as not Hispanic/Latino, white children from highly educated mothers. This indicates that generalizability of the study findings to children outside of this demographic should not be done.

Table 2.3 *Assessment Purpose and Classification Criteria for each listed Speech Sound Production and Oral Language Assessment*

Assessment	Assessment Purpose	TSD Criteria	SSD Criteria
Intake Form: History and Report of Speech Sound Disorder	Classification	None	Current
Sounds-in-Words subtest standard score on the GFTA-3	Classification	≥ 90	≤ 85
50-word conversational speech sample using SALT's Story Retell protocol			
Percent Consonants Correct (PCC)	Classification	≥ 99	< 95
Percentage of Intelligible Words (PWI)	Descriptive	N/A	N/A
Brosseau-Lapré multisyllable word assessment	Descriptive	N/A	N/A
Core Language Score on the CELF-5	Main Analyses	N/A	N/A
PPVT-5	Descriptive	N/A	N/A

Note. Further details of the listed assessments are the following: *Goldman-Fristoe Test of Articulation 3* (GFTA-3; Goldman & Fristoe, 2015), S*ystematic Analysis of Language Transcripts* (SALT; Miller & Iglesias, 2012), *Clinical Evaluation of Language Fundamentals, Fifth Edition* (CELF-5; Wiig et al., 2013), *Peabody Picture Vocabulary Test, Fifth Edition* (PPVT-5; Dunn, 2019), and the Brosseau-Lapré multisyllable word assessment (Brosseau-Lapré, et al., 2019).

Table 2.4 *Speech Sound Production and Oral Language Assessments Descriptives by Group and Test Statistic Comparing Groups*

Assessment	*Group*	*n*	*Mean*	*SD*	*Median*	*Min*	*Max*	*t-statistic*	*p*	*95% CI*	*g*
Speech Sound Production											
*GFTA-3 Sounds-In-Words Subtest Standard Score	SSD	30	68.70	14.80	72.00	40.00	89.00	13.06	**<.001**	33.3 - 45.4	3.37
	TSD	30	108.10	7.20	110.00	93.00	122.00				
SALT 50-word Speech Sample Percent Consonants Correct	SSD	3	91.67	0.50	92.00	90.00	93.00	---	---	---	---
	TSD	---	---	---	---	---	---				
SALT 50-word Speech Sample Proportion Intelligible	SSD	29	0.96	0.08	0.98	0.56	1.00	1.88	.066	0.00 - 0.06	0.50
	TSD	29	0.99	0.03	1.00	0.84	1.00				
	SSD	29	0.63	0.23	0.65	0.12	0.97	7.55	**<.001**	0.24 - 0.41	1.86

Assessment	*Group*	*n*	*Mean*	*SD*	*Median*	*Min*	*Max*	*t-statistic*	*p*	*95% CI*	*g*
*Brosseau-Lapré Multisyllable Word Proportion Accurate	TSD	28	0.96	0.04	0.97	0.85	1.00				
Oral Language Ability											
CELF-5 Core Language Index Score	SSD	30	101.53	15.05	100.50	78.00	133.00	1.11	.272	-3.13 - 10.93	0.28
	TSD	30	105.40	12.00	105.00	82.00	136.00				
CELF-5 Sentence Comprehension subtest Scaled Score	SSD	30	10.70	2.09	10.50	7.00	14.00	1.59	.117	-0.26 - 2.26	0.41
	TSD	30	11.70	2.73	12.00	6.00	16.00				
	SSD	30	9.50	2.94	9.00	4.00	17.00	0.52	.605	-0.95 - 1.62	0.13

Assessment	Group	n	Mean	SD	Median	Min	Max	t-statistic	p	95% CI	g
CELF-5 Word Structure subtest Scaled Score	TSD	30	9.83	1.91	9.00	7.00	14.00				
CELF-5 Formulated Sentences subtest Scaled Score	SSD	30	10.00	3.16	11.00	3.00	16.00	1.52	.133	-0.37 - 2.70	0.39
	TSD	30	11.17	2.76	11.00	4.00	18.00				
CELF-5 Recalling Sentences subtest Scaled Score	SSD	30	10.57	3.28	10.50	6.00	17.00	0.22	.827	-1.35 - 3.28	0.05
	TSD	30	10.73	2.56	11.00	5.00	16.00				
PPVT-5 Standard Score	SSD	28	103.79	21.09	105.00	49.00	140.00	1.79	.079	-1.14 - 19.97	1.47
	TSD	30	133.20	19.05	108.50	86.00	160.00				

Note. The *t* statistical test group comparisons reference was the children with typical speech development (TSD) as compared to children with speech sound disorder (SSD). The assessments found to have significant group differences are marked with (*) and the p-values are **bolded**. Further details of the listed assessments are the following: *Goldman-Fristoe Test of Articulation 3* (GFTA-3;

Goldman & Fristoe, 2015), S*ystematic Analysis of Language Transcripts* (SALT; Miller & Iglesias, 2012), *Clinical Evaluation of Language Fundamentals, Fifth Edition* (CELF-5; Wiig et al., 2013), *Peabody Picture Vocabulary Test, Fifth Edition* (PPVT-5; Dunn, 2019), and the Brosseau-Lapré multisyllable word assessment (Brosseau-Lapré, et al., 2019). The oral language assessment score distributions were similar and overlapping but children with SSD generally had a wider spread and lower peak of scores as compared to peers with TSD. This means that the most common score occurred less frequently in children with SSD as compared to peers with TSD.

Table 2.5 *Skills Assessed and Assessment Purpose for each listed Foundational Word Reading Assessment*

Assessment	Skills Assessed	Assessment Purpose
Experimental Phonological Awareness Task	Phonological Awareness: Receptive ability to identify and match the final speech sound within an orally presented task. Orthographic influence on phonological awareness.	Main Analyses
CTOPP-2	Phonological Awareness: Elision, Blending sounds, and Matching sounds/Phoneme isolation. Phonological Memory: Memory for Digits and Nonword Repetition. Rapid Symbolic Naming: Rapid Digit Naming and Rapid Letter Naming.	Main Analyses Descriptive

Assessment	Skills Assessed	Assessment Purpose
Experimental Alphabet Knowledge Task	Orthographic knowledge: Ability to name the single letters of the English written system in lowercase and uppercase forms.	Descriptive
Experimental Phoneme-Grapheme Correspondence Task	Orthographic knowledge: Ability to identify the sets of graphemes that represent a produced speech sound (similar to letter-sound knowledge but more comprehensive as speech sound can be represented in multiple sets of graphemes).	Main Analyses
Experimental Orthographic Pattern Knowledge Task	Orthographic knowledge: Sensitivity and knowledge of the regularities of orthographic patterns within the written English language.	Main Analyses
WMRT-III	Word reading: Real word reading and Pseudoword reading	Descriptive

Assessment	Skills Assessed	Assessment Purpose
Spelling Task of Real Words	Spelling of ten real words	Descriptive

Note. Further details of the listed assessments are the following: *Clinical Test of Phonological Processing, Second Edition* (CTOPP-2; Wagner et al., 2003), and *Woodcock Reading Mastery Tests, Third Edition* (WMRT-III; Woodcock, 2011), and Spelling Task of Real Words (Masterson & Apel, 2010; Wolter & Apel, 2010).

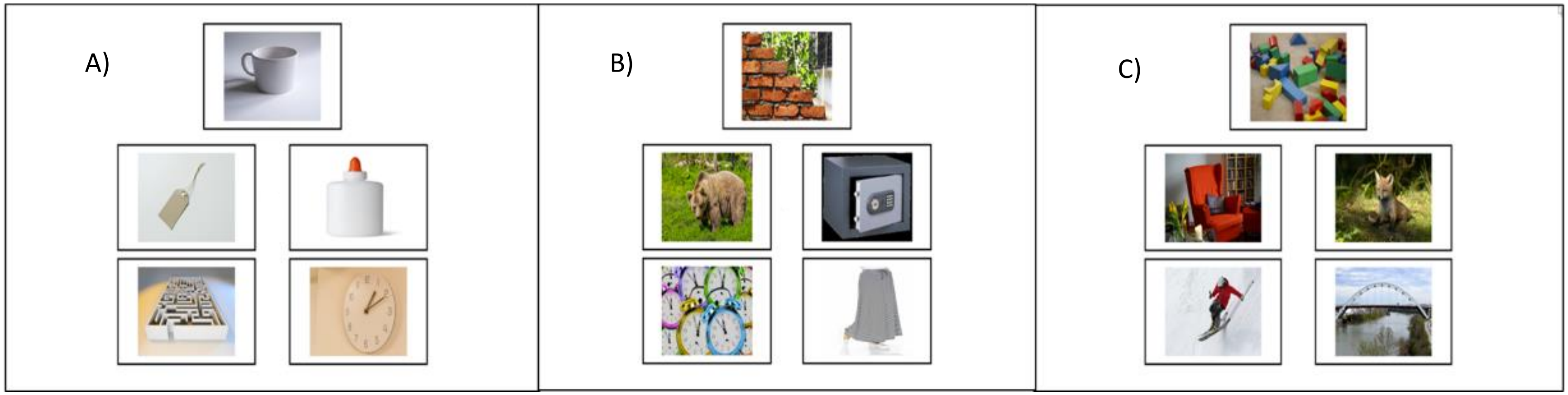

Figure 2.1 *Experimental task to examine Orthographic Influences on Phonological Awareness Performance*

Note. The three phonological awareness task conditions are A) Congruent-Consistent (e.g., mug-tag), B) Congruent-Inconsistent (e.g., bricks-clocks), and C) Incongruent-Inconsistent (e.g., blocks-fox).

Chapter 3

Results

Table 3.1 presents descriptives (mean, median, range, standard deviation) and group significance test statistic results of each groups' current word reading and spelling abilities, and other related knowledge areas that have been shown to be correlated or predictors of word reading/or spelling. Results indicate that children with SSD had lower word reading and spelling performance than children with TSD. Children with TSD were shown to have better word reading as measured by the WRMT-III Basic Skills composite [$t(57) = 3.09$, $p < .01$, $g = 0.80$], as well as subtest scores testing real words [$t(57) = 3.17$, $p < .01$, $g = 0.82$] and decoding of pseudowords [$t(57) = 2.62$, $p = .011$, $g = 0.68$]. While children with SSD had lower word reading, this did not necessarily indicate a deficit as some had average or higher than average performance on the WRMT-III. This is evident in the descriptive statistics and review of score distributions. Both groups had a bell-shaped distribution, but the peak was lower indicating a wider spread of scores in children with SSD as compared to children with TSD. This means that the most common value occurred less in children with SSD as compared to peers with TSD.

Children with TSD also demonstrated higher accurate spelling of words than peers with SSD [$t(58) = 2.34$, $p = .023$, $g = 0.90$]. Both groups distributions were bimodal but the SSD group had a wider spread in lower proportions of words spelled accurately. This means that two common values occurred in both groups but that these values occurred less in children with SSD than peers with TSD. No group differences in alphabet knowledge were shown as children with TSD named letters of the alphabet (upper and lowercase) with similar accuracy as children with SSD [*t*(58) = 1.69, *p* = .097, *g* = 0.37]. The SSD group distribution of proportion letters named accurately was negatively skewed whereas the TSD group's distribution was narrower and more indicated a ceiling effect, evidenced by the most common value at 0.98 proportion accurate.

Results from the CTOPP-2 assessment measuring current phonological processing showed that children with SSD have lower phonological processing abilities as compared to peers with TSD. Children with TSD had better phonological awareness on the CTOPP-2 Blending Words subtest [*t*(58) = 2.76, *p* < .01, *g* = 0.72] but not in the two other subtests that combine into the CTOPP-2 PA composite score, Elision subtest [t(57) = 1.46, *p* = .150, *g* = 0.38] and Sound Matching subtest [t(22) = 0.70, *p* = .490, *g* = 0.29] /Phoneme Isolation subtest[t(33) = 1.61, *p* = .117, *g* = 0.47]. The distributions of scores in the CTOPP-2 subtests Elision, Sound Matching, and Phoneme Isolation have similar and overlapping shapes between groups, but distributions differed between groups for the Blending Words subtest. The TSD group's distribution was bell-shaped whereas the SSD group's distribution was positively skewed. This means that the scores in the SSD group were near the lower end of the range, and higher scores were infrequent. Section 3.1 below presents the results examining group differences using the CTOPP-2 PA composite score.

Children with TSD had better phonological memory performance on the CTOPP-2 Nonword Repetition subtest [*t*(57) = 2.21, *p* = .031, *g* = 0.57] as compared to peers with SSD. The distribution of CTOPP-2 Nonword Repetition scores differed between groups as children with SSD had a wider distribution with a lower peak as compared to children with TSD. This means that the most common score occurred less frequently in children with SSD than peers with TSD. These group differences were non-significant on the CTOPP-2 Memory for Digits subtest [t(57) = 0.36, *p* = .718, *g* = 0.10] or the overall CTOPP-2 Phonological Memory composite scores [t(57) = 1.57, *p* = .121, *g* = 0.41]. Both groups had similar and overlapping distributions of scores on the CTOPP-2 Memory for Digits subtest and the Phonological Memory composite scores. This means that both groups had similar common scores and that these scores occurred with similar frequency between groups. There were non-significant group differences on the CTOPP-2 rapid symbolic naming composite scores [t(56) = 1.73, *p* = .010, *g* = 0.46] and subtests, Rapid Digit Naming subtest [t(57) = 1.68, *p* = .098, *g* = 0.44] and Rapid Letter Naming subtest [t(55) = 1.68, *p* = .098, *g* = 0.45]. Both groups had similar and overlapping distributions of scores for the Rapid Symbolic Naming subtests and the composite scores, but the children with SSD did demonstrate wider distributions with a lower peak as compared to peers with TSD. This means that the most common scores for these subtests and composite occurred less frequently in children with SSD than peers with TSD.

3.1 Examination of Phonological Awareness and Foundational Orthographic Knowledge Between Groups

A simple linear regression examined the CTOPP-2 PA composite scores between groups. The overall F test indicated that the model significantly predicts CTOPP-2 PA composite score [*F*(1, 57) = 5.22, *p* = .026, R^2 = 0.08]. On average, the TSD group outperformed the SSD group by 9.63 points on the CTOPP-2 PA composite score, 95% CI [1.19, 18.07]. This suggests that children with SSD have lower CTOPP-2 PA performance than peers with TSD. Figure 3.1 presents a boxplot of CTOPP-2 PA composite scores by group. Refer to Table 3.2 for a summary of descriptives and the regression model. Bell-shaped distribution of scores occurred in both groups, but the distribution was wider and started lower in the SSD group than the TSD group. A summary of descriptives and the significant interaction and main effect of the regression model is presented in Table 3.2. All regression model assumptions were met through examination of the residuals but interpretation of extremely high or low scores should occur cautiously when extrapolating beyond the range of the sample data. Refer to Figure B.1 for residual plots and a detailed description of model residuals.

A simple linear regression examined the phoneme-grapheme correspondence knowledge between groups. The overall F test indicated that the model significantly predicts phoneme-grapheme correspondence knowledge [$F(1, 57) = 5.45$, $p = .023$, $R^2 = 0.09$]. On average, the TSD group outperformed the SSD group by 0.39 points in determining whether the phoneme(s)-grapheme(s) presented were corresponding, 95% CI [0.06, 0.72]. This suggests that children with SSD have less phoneme-grapheme correspondence knowledge as compared to peers with TSD. Figure 3.2 presents a boxplot of phoneme-grapheme correspondence d-prime scores by group. The distribution of d-prime points was bell-shaped for the TSD group, whereas the distribution was bimodal for the SSD group. to Table 3.3 for a summary of descriptives and the significant interaction and main effect of the regression model. All regression model assumptions were met through examination of the residuals but interpretation of extremely high or low scores should occur cautiously when extrapolating beyond the range of the sample data. Refer to Figure B.2 for residual plots and a detailed description of model residuals.

Multiple linear regressions examined the orthographic pattern knowledge between groups and conditions. The orthographic pattern knowledge task was designed to capture their knowledge of orthographic patterns and how sensitive they were to the rules through three sets of items (HI, LI, HL). Two models were examined to compare groups, the three sets of items, and interactions: 1) one model examined condition differences with the HI items as reference, and 2) one model examined condition differences with the LI condition as reference. The overall F test indicated that the models significantly predict the proportion of accurately identified orthographic strings [$F(5, 174) = 7.47$, $p < .001$, $R^2 = 0.18$]. On average, the TSD group was about 9% better in identifying the accurate orthographic string than the SSD group for the overall model, 95% CI [0%, 17%]. This suggests that children with SSD have less knowledge of orthographic constraints than peers with TSD.

Additionally, the legal and highly probable orthographic strings were identified 15% more in the HI items as compared to the HL items, 95% CI [6%, 23%]. Children found it easier to discriminate between high probability strings and illegal strings (i.e., HI items) than high probability strings and low probability strings (i.e., HL items). The two other sets of item comparisons did not significantly differ. The accurate orthographic strings in the HL items were identified 7% less with marginal significance than in the LI items, 95% CI [-16%, 1%]. The accurate orthographic strings in the HI items were non-significantly identified 2% more than in the LI items, 95% CI [-11%, 6%]. No significant interaction between group and sets of items was shown. This difference between groups may not be predicted by their knowledge of orthographic regularities solely as a small amount was explained by the models and no significant interaction between group and items occurred. Figure 3.3 presents a boxplot of proportion accurate for orthographic pattern knowledge by group and sets of items. The distributions of proportion accurate by condition were negatively skewed for both groups, but the SSD group had a wider distribution than the TSD group. Refer to Table 3.4 for a summary of descriptives and the combined significant interaction and main effects of the regression models. All regression model assumptions were met through examination of the residuals but interpretation of extremely high or low proportions accurate should occur cautiously when extrapolating beyond the range of the sample data. Refer to Figure B.3 for residual plots and a detailed description of model residuals.

3.2 Whether Orthography Influences Phonological Awareness Performance in SSD

Simple linear regressions examined whether orthographic properties of words influence phonological awareness performance in children with SSD (*n* = 30) before accounting for oral language ability. Two models were examined to compare the three conditions and interactions in SSD: 1) one model examined condition differences with the CC condition as reference, and 2) one model examined condition differences with the CI condition as reference. The overall F tests indicated that the models did not significantly predict the proportion accurate on the experimental phonological awareness task [$F(2, 87) = 0.93$, $p = .398$, $R^2 = 0.02$]. Even though not significant, children with SSD performed 4% better on the CC condition than the CI condition (95% CI = [-9%, 18 %]) and 9% better than the IN condition (95% CI = [-4%, 23%]), and 5% better on the CI condition than the IN condition (95% CI = [-9%, 18%]). This indicates that phonological awareness performance for children with SSD was not significantly influenced by orthographic properties of words but demonstrated an expected general trend of accuracy (CC > CI > IN). Refer to Figure 3.4 for a boxplot of the SSD group's proportion accurate on the experimental phonological awareness by condition. Bell-shaped distributions of proportion accurate occurred across all conditions for children with SSD. Table 3.5 presents the descriptive statistics for proportion accurate by condition for children with SSD. All regression model assumptions were met through examination of the residuals but interpretation of extremely high or low scores should occur cautiously when extrapolating beyond the range sample data. Refer to Figure B.4 for residual plots and a detailed description of model residuals.

Multiple linear regressions were used to examine whether orthographic properties of words explain phonological awareness performance in children with SSD after accounting for oral language ability. Two models were examined to compare the three conditions, oral language ability, and interactions in SSD: 1) one model examined condition differences with the CC condition as reference, and 2) one model examined condition differences with the CI condition as reference. The overall F tests indicated that the models significantly predict the proportion accurate on the experimental phonological awareness task [$F(3, 86) = 13.21$, $p < .001$, $R^2 = 0.32$]. On average, experimental phonological awareness performance was 1% higher in children with SSD who had better oral language ability, 95% CI [1%, 1%]. Children with SSD were not significantly influenced by their orthographic knowledge when completing a phonological awareness task. Similar to the initial SSD model without oral language ability, the same non-significant accuracy trend by condition was observed (CC > CI > IN). This suggests that orthographic properties of words did not influence phonological awareness performance in children with SSD but that oral language ability did. Refer to Table 3.6 for the combined significant interaction and main effect of the regression models. All regression model assumptions were met through examination of the residuals but interpretation of extremely high or low scores should occur cautiously when extrapolating beyond the range of the sample data. Refer to Figure B.5 for residual plots and a detailed description of model residuals.

3.3 Examination of Whether Orthography Influences Phonological Awareness Performance Similarly Between Groups

Prior to direct group comparison, two sets of regression models were conducted to determine if children with TSD experienced orthographic influence in their phonological awareness performance with and without considering oral language ability. These analyses were conducted as this sample is younger than relevant previous studies (Castles et al., 2003; 2011). Simple linear regressions examined whether orthographic properties of words influence phonological awareness performance in children with TSD (*n* = 28) before accounting for language ability. Two models were examined to compare the three conditions and interactions in TSD: 1) one model examined condition differences with the CC condition as reference, and 2) one model examined condition differences with the CI condition as reference.

The overall F tests indicated that models significantly predict the proportion accurate on the experimental phonological awareness task [*F*(2, 81) = 3.14, *p* = .049, R^2 = 0.07]. Direct condition comparisons showed that orthographic properties of words did significantly influence children with TSD as they performed 11% better on the CC condition than the IN condition, 95% CI [2%, 20%]. Additionally, children with TSD performed 4% non-significantly better on the CC condition than the CI condition (95% CI [-5%, 12%]), but 7% better with marginal significance on the CI condition than the IN condition (95% CI [-1%, 16%]). This suggests that children with TSD were significantly influenced by orthographic properties of words on their experimental phonological awareness performance. Refer to Figure 3.4 for a boxplot of the TSD group's proportion accurate on the experimental phonological awareness by condition. The distribution of proportion accurate between phonological awareness conditions (CC, CI, IN) differed in children with TSD. The CC condition distribution was uniform. The CI condition was normally distributed with a slight negative skew. The IN condition distribution was bimodal with a slight negative skew. Refer to Table 3.7 for the combined significant interaction and main effect regression models. Refer to Figure B.6 for residual plots and a detailed description of model limitations.

Multiple linear regressions examined whether orthographic properties of words influence phonological awareness performance in children with TSD after accounting for oral language ability. Two models were examined to compare the three conditions, oral language ability, and interactions in TSD: 1) one model examined condition differences with the CC condition as reference, and 2) one model examined condition differences with the CI condition as reference. The F tests indicated that the models did not significantly predict the proportion accurate on the experimental phonological awareness task [$F(3, 80) = 2.13$, $p = .103$, $R^2 = 0.07$]. This suggests that oral language does not explain more variance or improve the model fit to predict phonological awareness performance in children with TSD.

Even though the overall model fit was non-significant, the children with TSD significantly performed 11% better on the CC condition than in the IN condition, 95% CI [2%, 20%], and 7% better with marginal significance on the CI condition as compared to the IN condition, 95% CI [-2%, 16%]. Similar to the previous models, the same nonsignificant pattern of phonological awareness was shown based on condition (CC > CI > IN). Oral language ability was not a significant predictor of phonological awareness performance in children with TSD. This suggests that phonological awareness performance in children with TSD is influenced by the orthographic properties of words to some extent and that their performance is not driven by their oral language ability. Table 3.8 presents the combined significant multiple linear regression main effect models even though the interaction is non-significant. This was because the model is important to compare with other findings to answer one of the main research questions. All regression model assumptions were met through examination of the residuals but interpretation of extremely high or low scores should occur cautiously when extrapolating beyond the range of the sample data. Refer to Figure B.7 for residual plots and a detailed description of model residuals.

Multiple linear regressions examined the proportion accurate on the experimental phonological awareness task between groups (SSD n = 30, TSD n = 28) and conditions (CC, CI, IN). Two models were examined to compare groups, the three conditions, and interactions: 1) one model examined condition differences with the CC condition as reference, and 2) one model examined condition differences with the CI condition as reference. The overall F tests indicated that the models significantly predict proportion accurate on the experimental phonological awareness task [$F(5, 168) = 8.67$, $p < .001$, $R^2 = 0.21$]. On average, the TSD group was 22% higher in their phonological awareness performance than the SSD group, 95% CI [10%, 33%]. This suggests that children with SSD have lower phonological awareness performance as compared to peers with TSD.

No significant difference in phonological awareness performance between conditions across both groups was shown. The interactions between group and condition were nonsignificant as well. Figure 3.4 presents a boxplot of proportion accurate for experimental phonological awareness by group and condition. The distribution of proportion accurate by condition differed between groups. Similar bell-shaped distributions across all conditions occurred for children with SSD whereas various distributions occurred for each condition for children with TSD. Table 3.9 presents the significant interaction and main effect of the combined regression models. All regression model assumptions were met through examination of the residuals but interpretation of extremely high or low scores should occur cautiously when extrapolating beyond the range of the sample data. Refer to Figure B.8 for residual plots and a detailed description of model residuals.

3.4 Examination of Whether Any Significant Group Differences Remain After Controlling Language Ability

All four models comparing groups showed that children with SSD had lower performance than peers with TSD. These models examined the following: 1) the CTOPP-2 PA composite scores, 2) the phoneme-grapheme correspondence d-prime scores, 3) the orthographic pattern knowledge proportion accurate, and 4) the experimental phonological awareness proportion accurate. These models were re-modeled to include oral language ability as a predictor before comparing group differences.

A multiple linear regression examined the CTOPP-2 phonological awareness composite scores between groups while controlling oral language ability. The overall F test indicates that the model predicts CTOPP-2 PA performance [$F(2, 56) = 7.17$, $p = .002$, $R^2 = 0.20$]. Oral language ability was the only significant predictor of CTOPP-2 PA performance. On average, CTOPP-2 PA performance was 0.44 points higher in children who had better oral language ability, 95% CI [0.14, 0.74]. Group was no longer a significant predictor, but the TSD group non-significantly performed 7.61 points better than the SSD group on the CTOPP-2 PA composite score, 95% CI [-0.46, 15.67]. Two possible reasons for group to no longer significantly predict CTOPP-2 PA are that 1) the scoring method may have over-estimated CTOPP-2 PA performance in children with SSD, or that oral language ability significantly and primarily drives phonological awareness performance on the CTOPP-2 PA rather than the presence of SSD. Refer to Table 3.10 for a summary of the significant interaction and main effect regression model. All regression model assumptions were met through examination of the residuals but interpretation of extremely high or low scores should occur cautiously when extrapolating beyond the range of the sample data. Refer to Figure B.2 for residual plots and a detailed description of model residuals.

A multiple linear regression examined the phoneme-grapheme correspondence knowledge between groups while controlling oral language ability. The overall F test indicated that the model significantly predicts phoneme-grapheme correspondence knowledge [$F(2, 56) = 6.71$, $p = .002$, $R^2 = 0.19$]. On average, phoneme-grapheme correspondences were accurately identified 0.33 d-prime points higher in children with TSD as compared to peers with SSD, 95% CI [0.01, 0.65]. On average, phoneme-grapheme correspondence knowledge was 0.02 d-prime points higher in children with better oral language ability, 95% CI [0.00, 0.03]. This suggests that children with SSD who have lower oral language ability have less phoneme-grapheme correspondence knowledge as compared to peers with SSD and stronger oral language ability and peers with TSD. Refer to Table 3.11 for a summary of the significant interaction and main effects regression model. All regression model assumptions were met through examination of the residuals but interpretation of extremely high or low scores should occur cautiously when extrapolating beyond the range of the sample data. Refer to Figure B.10 for residual plots and a detailed description of model residuals.

Multiple linear regressions examined the orthographic pattern knowledge between groups and sets of items after controlling oral language ability. Two models were examined to compare groups, the three sets of items, oral language ability, and interactions: 1) one model examined sets of item differences with the HI items as reference, and 2) one model examined sets of item differences with the LI items as reference. The F tests indicated that the models significantly predict proportion of accurately identified orthographic strings [*F* (6, 173) = 6.99, *p* <.001, R^2 = 0.20]. Group no longer significantly predicted knowledge of orthographic regularities. Children with TSD performed 8% better with marginal significance than children with SSD [95% CI (-0%, 16%), *p* = .064].

The same sets of item differences remained significant and marginally significant. The accurate orthographic strings were identified 10% more in the HI items (95% CI [2%, 19%], *p* = .018) and 7% more in the LI items (95% CI [-1%, 15%], *p* = .098) as compared to the HL items. Oral language was shown to significantly predict knowledge of orthographic regularities. On average, orthographic pattern knowledge was 0.18% higher in children with better oral language ability, 95% [0.00%, 0.36%].

Additionally, no significant interactions between group and sets of items were shown to predict orthographic pattern knowledge. In combination, knowledge of orthographic regularities significantly predicted oral language ability rather than the presence of SSD, and that children found it easier to discriminate between high probability strings and illegal strings (i.e., HI items) than high probability strings and low probability strings (i.e., HL items). This suggests that children with SSD and adequate oral language abilities have similar knowledge of orthographic regularities as peers with TSD and adequate oral language abilities, especially when items compare a probable orthographic string to an illegal orthographic string. Refer to Table 3.12 for a summary of the combined significant interaction and main effects regression models. All regression model assumptions were met through examination of the residuals but interpretation of extremely high or low scores should occur cautiously when extrapolating beyond the range of the sample data. Refer to Figure B.11 for residual plots and a detailed description of model residuals.

Multiple linear regressions were used to determine if the significant group differences on the experimental phonological awareness task remained after controlling oral language ability. Two models were examined to compare groups, the three conditions, oral language ability, and interactions: 1) one model examined condition differences with the CC condition as reference, and 2) one model examined condition differences with the CI condition as reference. The F tests indicated that the models significantly predict proportion accurate on the experimental phonological awareness task [$F(6, 167) = 12.48$, $p < .001$, $R^2 = 0.31$]. Group differences remained significant where the TSD group was about 18% higher in accuracy on the experimental phonological awareness task as compared to the SSD group, 95% CI [7%, 28%].

Oral language ability was also found significant as children who had stronger language ability had 1% higher experimental phonological awareness performance, 95% CI [0%, 1%]. No significant differences occurred in conditions across groups or between groups. This suggests that children with SSD who have oral language ability difficulties had lower experimental phonological awareness performance as compared to peers with SSD who have stronger oral language and peers with TSD. Refer to Table 3.13 for a summary of the combined significant interaction and main effects regression models. All regression model assumptions were met through examination of the residuals but interpretation of extremely high or low scores should occur cautiously when extrapolating beyond the range of the sample data. Refer to Figure B.12 for residual plots and a detailed description of model residuals.

Table 3.1 *Descriptives of Related Abilities Measured by Group and Test Statistic Comparing Groups*

Assessment	*Group*	*n*	*Mean*	*SD*	*Median*	*Min*	*Max*	*t-statistic*	*p*	*95% CI*	*g*
WRMT-III											
*WRMT-III Basic Skills Composite Score	SSD	29	97.76	19.20	99.00	59.00	143.00	3.09	**.003**	4.81 – 22.61	0.80
	TSD	30	111.50	14.71	111.50	83.00	145.00				
*WRMT-III Word Identification Standard Score	SSD	29	98.10	20.17	96.00	56.00	145.00	3.16	**.003**	5.34 – 23.86	0.82
	TSD	30	112.70	15.06	116.50	79.00	143.00				
*WRMT-III Word Attack Standard Score	SSD	29	97.76	18.14	96.00	64.00	139.00	2.62	**.011**	2.58 – 19.24	0.68
	TSD	30	108.70	13.56	108.50	79.00	142.00				
**Spelling Task* Proportion Accurate	SSD	30	0.52	0.32	0.55	0.00	1.00	2.34	**.023**	0.02 – 0.31	0.90
	TSD	30	0.69	0.22	0.70	0.30	1.00				
Alphabet Knowledge Proportion Accurate	SSD	30	0.94	0.15	0.98	0.21	1.00	1.69	.097	-0.10 – 0.01	0.37
	TSD	30	0.98	0.02	0.98	0.94	1.00				

Assessment	*Group*	*n*	*Mean*	*SD*	*Median*	*Min*	*Max*	*t-statistic*	*p*	*95% CI*	*g*
CTOPP-2 Phonological Processing											
Phonological Awareness Composite Score *(See in Table 3.2)*											
Elision subtest Scaled Score	SSD	30	9.70	3.24	9.00	5.00	17.00	1.46	.150	-0.38 – 2.43	0.38
	TSD	29	10.72	1.98	11.00	7.00	15.00				
* Blending Words subtest Scaled Score	SSD	30	8.43	3.59	8.00	1.00	18.00	2.76	**.008**	0.62 – 3.90	0.72
	TSD	29	10.69	2.61	11.00	6.00	17.00				
Sound Matching subtest	SSD	13	10.38	3.18	9.00	7.00	16.00	0.70	.490	-1.73 – 3.51	0.29

Assessment	*Group*	*n*	*Mean*	*SD*	*Median*	*Min*	*Max*	*t-statistic*	*p*	*95% CI*	*g*
Scaled Score	TSD	11	11.27	2.97	12.00	7.00	15.00				
Phoneme Isolation subtest Scaled Score	SSD	17	6.77	2.75	7.00	1.00	11.00	1.61	.117	-0.44 – 3.80	0.47
	TSD	18	8.22	3.36	7.50	2.00	15.00				
Phonological Memory Composite Score	SSD	30	90.07	16.54	88.00	61.00	131.00	1.57	.121	-1.65 – 13.79	0.41
	TSD	29	96.14	12.77	98.00	73.00	128.00				
Memory for Digits subtest Scaled Score	SSD	30	9.43	2.78	9.00	5.00	16.00	0.36	.718	-1.16 – 1.67	0.10
	TSD	29	9.69	2.63	10.00	6.00	18.00				

Assessment	*Group*	*n*	*Mean*	*SD*	*Median*	*Min*	*Max*	*t-statistic*	*p*	*95% CI*	*g*
* Nonword Repetition subtest Scaled Score	SSD	30	7.10	3.38	7.00	2.00	15.00	2.21	**.031**	0.16 – 3.23	0.57
	TSD	29	8.79	2.43	9.00	4.00	13.00				
Rapid Symbolic Naming Composite Score	SSD	29	93.38	15.26	95.00	52.00	131.00	1.73	.090	-1.09 – 14.67	0.46
	TSD	29	100.20	14.70	104.00	70.00	140.00				
Rapid Digit Naming subtest Scaled Score	SSD	30	8.80	2.55	9.00	4.00	15.00	1.68	.098	-0.19 – 2.25	0.44
	TSD	29	9.83	2.11	10.00	5.00	13.00				
Rapid Letter Naming subtest Scaled Score	SSD	28	8.96	2.17	9.00	4.00	15.00	1.68	.098	-0.24 – 2.80	0.45
	TSD	29	10.24	3.40	10.00	6.00	25.00				

Note. The statistical *t* test group comparisons reference was the children with typical speech development (TSD) as compared to children with speech sound disorder (SSD). The assessments that were shown to have significant group differences are marked with (*) and the *p*-value is **bolded**. All assessments that reach significance had differing distributions of scores between groups, and children with SSD had lower peaks as compared to peers with TSD. When the assessment scores did not significantly differ between groups, the distributions were similar and overlapping but children with SSD generally had a wider spread and lower peak of scores as compared to peers with TSD. The lower peaks noted show that the most frequent scores occurred less often in children with SSD as compared to peers with TSD. Further details of the listed assessments are the following: *Clinical Test of Phonological Processing, Second Edition* (CTOPP-2; Wagner et al., 2003), and *Woodcock Reading Mastery Tests, Third Edition* (WMRT-III; Woodcock, 2011), and Spelling Task of Real Words (Masterson & Apel, 2010; Wolter & Apel, 2010).

Table 3.2 *CTOPP-2 Phonological Awareness Composite Score Descriptives by Group and the significant Simple Linear Regression Interaction and Main Effect Model*

Group	*n*	*Mean*	*SD*	*Median*	*Min*	*Max*	*g*
SSD	30	93.30	19.75	88.00	60.00	137.00	0.59
TSD	29	102.90	11.37	105.00	84.00	122.00	

Predictors	*Estimates*	*95% CI*	*p*
(Intercept)	93.30	87.38 – 99.22	<.001
TSD Group	9.63	1.19 – 18.07	.026
F(1, 57)	5.22		.026
Observations	59		
R^2	0.08		

Notes. The children within the sample are children with speech sound disorder (SSD; *n* = 30) and children with typical speech development (TSD; *n* = 29). The phonological awareness composite scores of the *Clinical Test of Phonological Processing, Second Edition* (CTOPP-2; Wagner et al., 2003) are the outcome variable being predicted. Bell-shaped distribution of CTOPP-2 PA scores occurred in both groups, but the distribution was wider and started lower in the SSD group than the TSD group. The SSD group was the referent within the main effects model.

Table 3.3 *Phoneme-Grapheme Correspondence D-prime Score Descriptives by Group and the significant Simple Linear Regression Interaction and Main Effect Model*

Group	*Mean*	*SD*	*Median*	*Min*	*Max*	*g*
SSD	1.18	0.68	1.35	0.00	2.36	0.62
TSD	1.57	0.59	1.59	0.00	2.70	

Predictors	*Estimates*	*95% CI*	*p*
(Intercept)	1.18	0.94 – 1.41	<.001
TSD Group	0.39	0.06 – 0.72	.023
$F(1, 57)$	5.45		.023
Observations	59		
R^2	0.09		

Note. The phoneme-grapheme correspondence d-prime score was the outcome variable being predicted. The children within the sample are children with speech sound disorder (SSD; *n* = 30) and children with typical speech development (TSD; *n* = 29). The TSD group sample was decreased as one child's results were not included due to their data being suspected to be inaccurate. Refer to Section 2.5 for additional details. A review of the distribution of d-prime points for each group indicated that a bell-shaped distribution occurred for the TSD group, whereas the distribution was bimodal for the SSD group. The SSD group was the referent within the main effects model.

Table 3.4 *Orthographic Pattern Knowledge Proportion Accurate Descriptives by Group and Set of Items, and the significant Multiple Linear Regression Interaction and Main Effects Model*

Group	*Set of Items*	*Mean*	*SD*	*Median*	*Min*	*Max*	*g*
SSD	HI	0.76	0.21	0.85	0.37	0.97	0.55
	LI	0.73	0.20	0.73	0.38	1.04	
	HL	0.66	0.16	0.66	0.36	0.92	
TSD	HI	0.85	0.14	0.90	0.43	1.00	
	LI	0.87	0.13	0.92	0.58	1.04	
	HL	0.70	0.13	0.72	0.44	0.92	

Predictors	*Estimates*	*95% CI*	*p*
(Intercept)	0.76	0.70 – 0.82	<.001
TSD Group	0.09	0.00 – 0.17	.045
HL Items	-0.15	-0.23 - -0.06	.001
F(5, 174)	7.47		<.001
Observations	180		

R^2	0.18

Note. The proportion accurate on the orthographic knowledge task was the outcome variable being predicted. The orthographic pattern knowledge task was designed to capture their knowledge of orthographic patterns and how sensitive they were to the rules through three sets of items: high probability versus illegal forms (HI), low probability versus illegal (LI), and high probability versus low probability (HL). The children within the sample are children with speech sound disorder (SSD; *n* = 30) and children with typical speech development (TSD; *n* = 30). The proportion accurate distributions by condition were reviewed showing a negatively skew for both groups, but the SSD group had a wider distribution than the TSD group. Within the main effects model, the referent group was the SSD group, and the referent set of items was the HI items.

Table 3.5 *Experimental Phonological Awareness Proportion Accurate Descriptives by Condition in Children with SSD*

Condition	*Mean*	*SD*	*Median*	*Min*	*Max*
CC	0.57	0.30	0.58	0.00	1.00
CI	0.52	0.24	0.50	0.17	0.92
IN	0.48	0.24	0.50	0.00	0.92

Note. The experimental phonological awareness task contained the following conditions: Congruent-Consistent (CC), Congruent-Inconsistent (CI), and Incongruent-Inconsistent (IN). Only children with SSD (*n* = 30) were included in this model. The distributions for proportion accurate in children with SSD showed bell-shaped distributions for each condition.

Table 3.6 *Experimental Phonological Awareness Proportion Accurate Descriptives by Condition in Children with SSD and the significant Multiple Linear Regression Interaction and Main Effect Model after controlling for Oral Language Ability*

Predictors	*Estimates*	*95% CI*	*p*
(Intercept)	-0.40	-0.72 - -0.07	.017
Oral Language Ability	0.01	0.01 – 0.01	<.001
F(3, 86)	13.21		<.001
Observations	90		
R^2	0.32		

Note. The proportion accurate on the experimental phonological awareness task was the outcome variable being predicted. The experimental phonological awareness task contained the following conditions: Congruent-Consistent (CC), Congruent-Inconsistent (CI), and Incongruent-Inconsistent (IN). Only children with SSD (*n* = 30) were included in this model. Oral language ability was predicted using the Core Language composite score from the *Clinical Evaluation of Language Fundamentals, Fifth Edition* (CELF-5; Wiig et al., 2013).

Table 3.7 *Experimental Phonological Awareness Proportion Accurate Descriptives by Condition in Children with TSD and the significant Simple Linear Regression Interaction and Main Effect Model before controlling for Oral Language Ability*

Condition	*Mean*	*SD*	*Median*	*Min*	*Max*
CC	0.77	0.17	0.79	0.25	1.00
CI	0.74	0.14	0.75	0.42	1.00
IN	0.66	0.18	0.71	0.25	0.92

Predictors	*Estimates*	*95% CI*	*p*
(Intercept)	0.77	0.71 – 0.84	<.001
IN Condition	-0.11	-0.20 – -0.02	.016
F(2, 81)	3.14		.049
Observations	84		
R^2	0.07		

Note. The proportion accurate on the experimental phonological awareness task was the outcome variable being predicted. The experimental phonological awareness task contained the following conditions: Congruent-Consistent (CC), Congruent-Inconsistent (CI), and Incongruent-Inconsistent (IN). Only children with TSD were included in this model (*n* = 28). The two children from the total TSD sample were not included in this analysis due to 1) one child not completing the task after an attempt, and 2) one child's results were not included as they were suspected to be inaccurate. Refer to Section 2.5 for additional details. The distributions for proportion accurate in children with TSD varied by condition: CC condition was uniform, CI condition was normal with a slight negative skew, and IN condition was bimodal with a slight negative skew. The CC condition was the referent within the main effects model.

Table 3.8 *Experimental Phonological Awareness Proportion Accurate Descriptives by Condition in Children with TSD and the significant Multiple Linear Regression Main Effect Model after controlling for Oral Language Ability*

Predictors	*Estimates*	*95% CI*	*p*
(Intercept)	0.84	0.49 – 1.20	<.001
IN Condition	-0.11	-0.20 – 0.02	.017
F(3, 80)	2.13		.103
Observations	84		
R^2	0.07		

Note. The proportion accurate on the experimental phonological awareness task was the outcome variable being predicted. The experimental phonological awareness task contained the following conditions: Congruent-Consistent (CC), Congruent-Inconsistent (CI), and Incongruent-Inconsistent (IN). Only children with TSD were included in this model (*n* = 28). The two children from the total TSD sample were not included in this analysis due to 1) one child not completing the task after an attempt, and 2) one child's results were not included as they were suspected to be inaccurate. Refer to Section 2.5 for additional details. Oral language ability was predicted using the Core Language composite score from the *Clinical Evaluation of Language Fundamentals, Fifth Edition* (CELF-5; Wiig et al., 2013). This regression model was reported as a table because the intercept and the main effect were significant and is an important model to compare with other findings to answer one of the main research questions. The CC condition was the referent within the main effects model.

Table 3.9 *Experimental Phonological Awareness Proportion Accurate Descriptives by Group and Condition, and the significant Multiple Linear Regression Interaction and Main Effect Model*

Group	*Condition*	*Mean*	*SD*	*Median*	*Min*	*Max*	*d*
SSD (*n* = 30)	CC	0.57	0.30	0.58	0.00	1.00	0.52
	CI	0.52	0.24	0.50	0.17	0.92	
	IN	0.48	0.24	0.50	0.00	0.92	
TSD (*n* = 28)	CC	0.77	0.17	0.79	0.25	1.00	
	CI	0.74	0.14	0.75	0.42	1.00	
	IN	0.66	0.18	0.71	0.25	0.92	

Predictors	*Estimates*	*95% CI*	*p*
(Intercept)	0.52	0.44 – 0.60	<.001
TSD Group	0.22	0.10 – 0.33	<.001
F(5, 168)	8.67		<.001
Observations	174		
R^2	0.21		

Note. The proportion accurate on the experimental phonological awareness task was the outcome variable being predicted. The experimental phonological awareness task contained the following conditions: Congruent-Consistent (CC), Congruent-Inconsistent (CI), and Incongruent-Inconsistent (IN). The children within the sample are children with speech sound disorder (SSD; *n* = 30) and children with typical speech development (TSD; *n* = 28). The two children from the total TSD sample were not included in this analysis due to 1) one child not completing the task after an attempt, and 2) one child's results were not included as they were suspected to be inaccurate. Refer to Section 2.5 for additional details. The SSD group was the referent within the main effect model.

Table 3.10 *Significant Multiple Linear Regression Interaction and Main Effect Model Comparing Group CTOPP-2 Phonological Awareness Composite Scores while controlling for Language Ability*

Predictors	*Estimates*	*95% CI*	*p*
(Intercept)	48.99	17.93 – 80.06	.003
Oral Language Ability	0.44	0.14 – 0.74	.005
F(2, 56)	7.17		.002
Observations	59		
R^2	0.20		

Notes. The phonological awareness composite scores of the *Clinical Test of Phonological Processing, Second Edition* (CTOPP-2; Wagner et al., 2003) are the outcome variable being predicted. The children within the sample are children with speech sound disorder (SSD; *n* = 30) and children with typical speech development (TSD; *n* = 29). Oral language ability was predicted using the Core Language composite score from the *Clinical Evaluation of Language Fundamentals, Fifth Edition* (CELF-5; Wiig et al., 2013).

Table 3.11 *Significant Multiple Linear Regression Interaction and Main Effects Model for Comparing Groups Phoneme-Grapheme Correspondence D-prime Score while controlling for Oral Language Ability*

Predictors	*Estimates*	*95% CI*	*p*
(Intercept)	-0.44	-1.66 – 0.77	.470
TSD Group	0.33	0.01 – 0.65	.042
Oral Language Ability	0.02	0.00 – 0.03	.009
F(2, 56)	6.71		.002
Observations	59		
R^2	0.19		

Note. The phoneme-grapheme correspondence d-prime was the outcome variable being predicted. The children within the sample are children with speech sound disorder (SSD; *n* = 30) and children with typical speech development (TSD; *n* = 29). The TSD group sample was decreased as one child's results were not included due to their data suspected to be inaccurate. Refer to Section 2.5 for additional details. Oral language ability was predicted using the Core Language composite score from the *Clinical Evaluation of Language Fundamentals, Fifth Edition* (CELF-5; Wiig et al., 2013). The SSD group was the referent within the main effects model.

Table 3.12 *Significant Multiple Linear Regression Interaction and Main Effects Model for the Orthographic Pattern Knowledge Proportion Accurate by Group and Set of Items while controlling for Oral Language Ability*

Predictors	*Estimates*	*95% CI*	*p*
(Intercept)	0.57	0.38 – 0.77	<.001
HL Items	-0.10	-0.19 - -0.02	.018
Oral Language Ability	0.00	0.00 – 0.00	.048
F(6, 173)	6.99		<.001
Observations	180		
R^2	0.20		

Note. The proportion accurate on the orthographic knowledge task was the outcome variable being predicted. The orthographic pattern knowledge task was designed to capture their knowledge of orthographic patterns and how sensitive they were to the rules through three sets of items: high probability versus illegal forms (HI), low probability versus illegal (LI), and high probability versus low probability (HL). The children within the sample are children with speech sound disorder (SSD; *n* = 30) and children with typical speech development (TSD; *n* = 30). Oral language ability was predicted using the Core Language composite score from the *Clinical Evaluation of Language Fundamentals, Fifth Edition* (CELF-5; Wiig et al., 2013). The HI items were the referent condition within the main effects model.

Table 3.13 *Significant Multiple Linear Regression Interaction and Main Effects Model Comparing Experimental Phonological Awareness Proportion Accurate by Group and Condition after controlling for Oral Language Ability*

Predictors	*Estimates*	*95% CI*	*p*
(Intercept)	-0.04	-0.29 – 0.21	.757
TSD Group	0.18	0.07 – 0.28	.001
Oral Language Ability	0.01	0.00 – 0.01	<.001
F(6, 167)	12.48		<.001
Observations	174		
R^2	0.31		

Note. The proportion accurate on the experimental phonological awareness task was the outcome variable being predicted. The experimental phonological awareness task contained the following conditions: Congruent-Consistent (CC), Congruent-Inconsistent (CI), and Incongruent-Inconsistent (IN). The children within the sample are children with speech sound disorder (SSD; *n* = 30) and children with typical speech development (TSD; *n* = 28). The two children from the total TSD sample were not included in this analysis due to 1) one child not completing the task after an attempt, and 2) one child's results were not included as they were suspected to be inaccurate. Refer to Section 2.5 for additional details. Oral language ability was predicted using the Core Language composite score from the *Clinical Evaluation of Language Fundamentals, Fifth Edition* (CELF-5; Wiig et al., 2013). The SSD group was the referent within the main effects model.

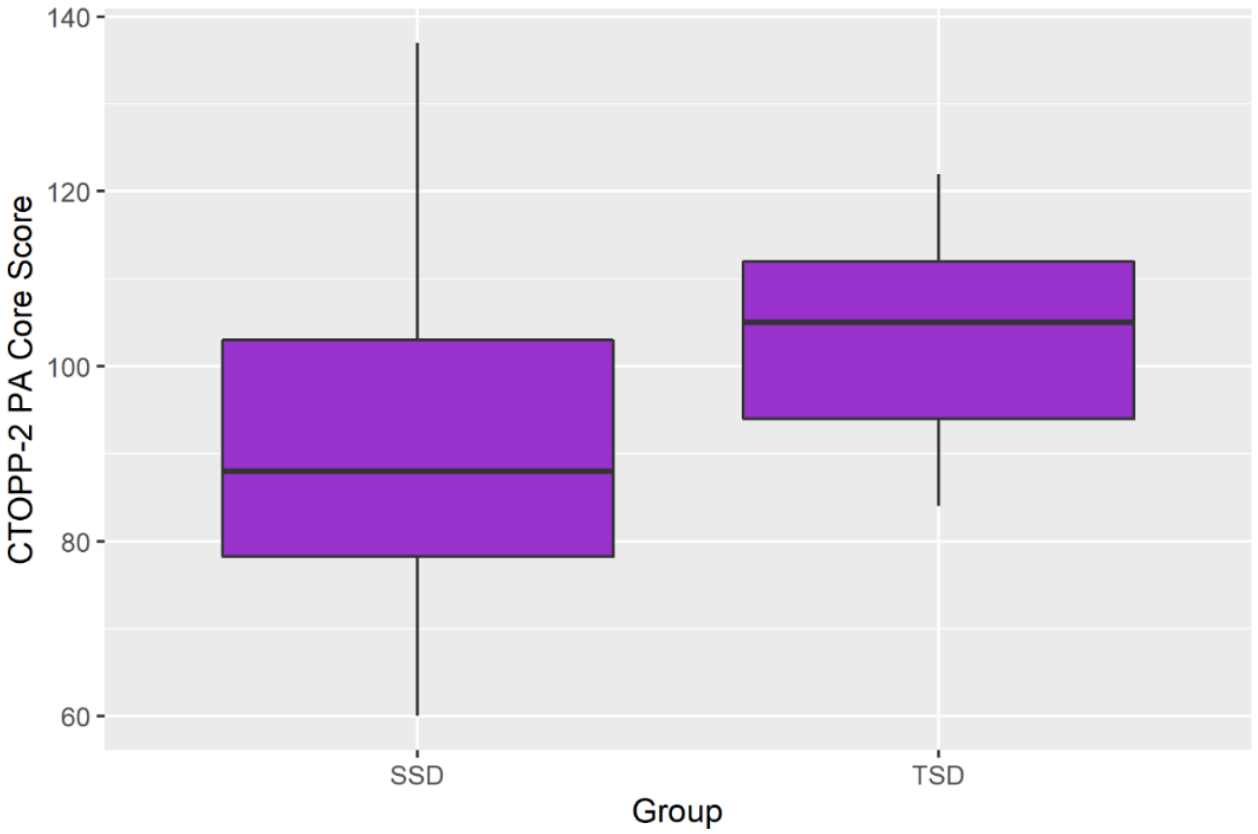

Figure 3.1 *Boxplot of CTOPP-2 Phonological Awareness Composite Score by Group*

Note. The phonological awareness composite scores of the *Clinical Test of Phonological Processing, Second Edition* (CTOPP-2; Wagner et al., 2003) is the outcome variable being predicted (y-axis). The predictor variable (x-axis) is group, speech sound disorder (SSD; *n* = 30), and children with typical speech development (TSD; *n* = 29).

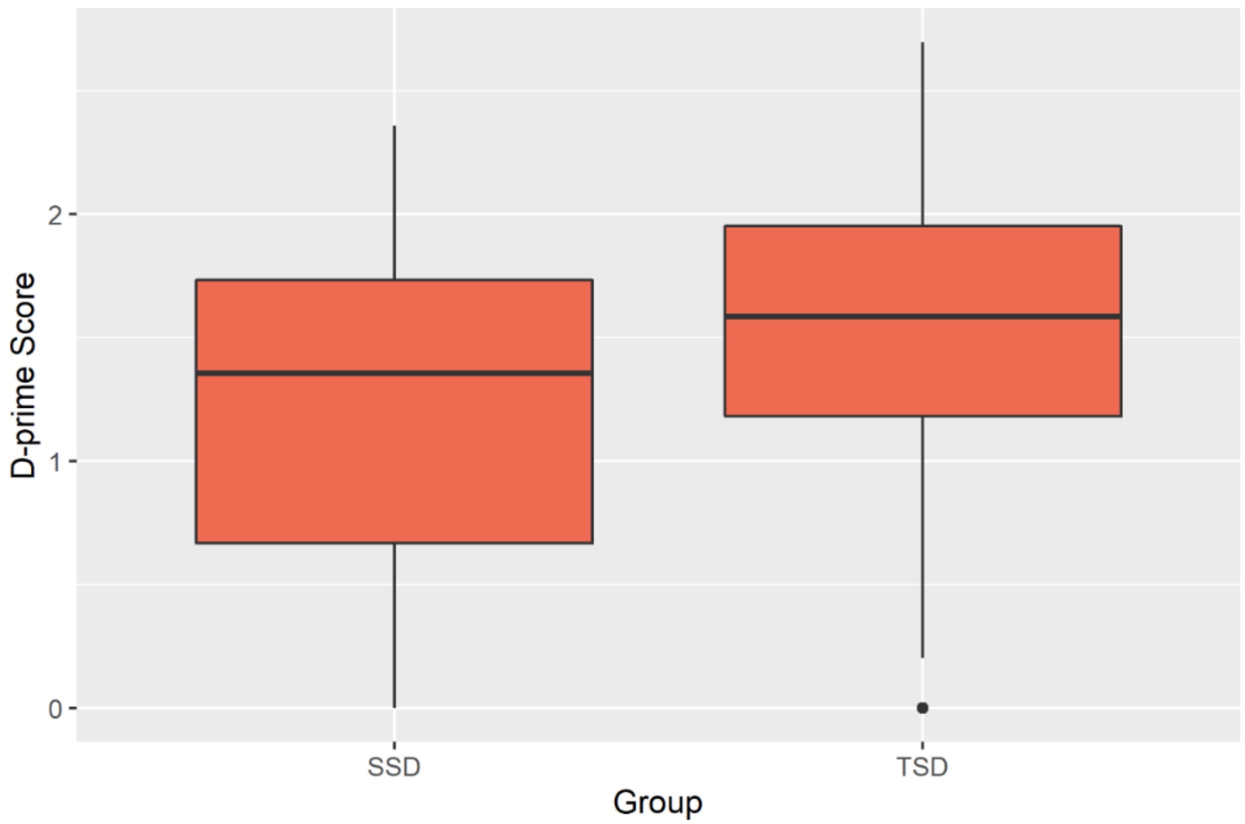

Figure 3.2 *Boxplot of Phoneme-Grapheme Correspondence D-prime Scores by Group*

Note. The phoneme-grapheme correspondence d-prime scores is the outcome variable being predicted (y-axis). The predictor variable (x-axis) is group, speech sound disorder (SSD; *n* = 30), and children with typical speech development (TSD; *n* = 29). The TSD group sample was decreased as one child's results were not included due to their data suspected to be inaccurate. Refer to Section 2.5 for additional details.

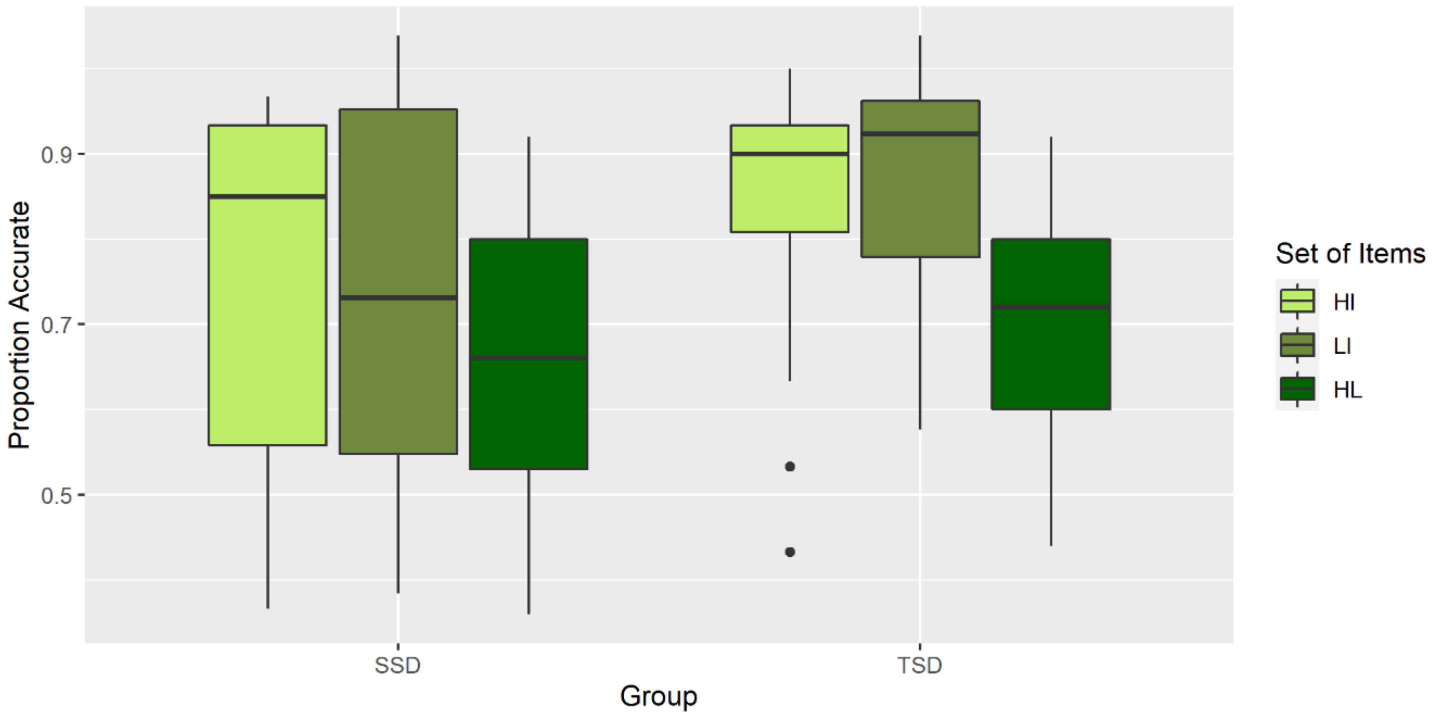

Figure 3.3 *Boxplot of Proportion Accurate for Orthographic Pattern Knowledge by Group and Set of Items*

Note. The orthographic pattern knowledge proportion accurate is the outcome variable being predicted (y-axis). Set of items and group are the predictor variables (legend and x-axis). Three sets of items were in the task, High Probability versus Illegal (HI), Low Probability versus Illegal (LI), and High Probability versus Low Probability (HL). These sets of items are presented as different shades of green (legend). The other predictor variable (x-axis) is group, speech sound disorder (SSD; *n* = 30), and children with typical speech development (TSD; *n* = 30).

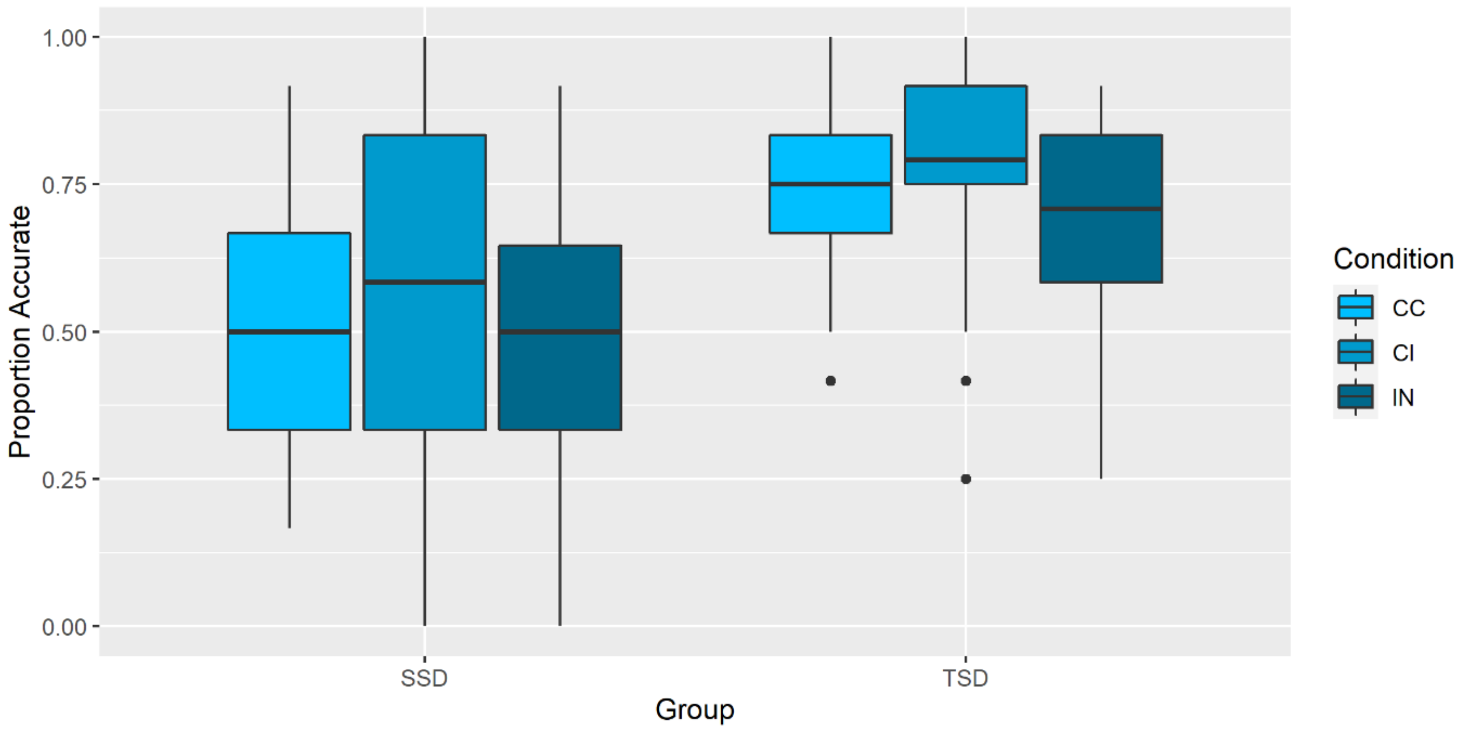

Figure 3.4 *Boxplot of Proportion Accurate on the Experimental Phonological Awareness task by Condition and Group*

Note. The experimental phonological awareness proportion accurate is the outcome variable being predicted (y-axis). Condition and group are the predictor variables (legend and x-axis). Three conditions occurred in the task, Congruent-Consistent (CC), Congruent-Inconsistent (CI), and Incongruent-Inconsistent (IN). These conditions are presented as different shades of blue (legend). The other predictor variable (x-axis) is group, speech sound disorder (SSD; *n* = 30), and children with typical speech development (TSD; *n* = 28). The two children from the total TSD sample were not included in this analysis due to 1) one child not completing the task after an attempt, and 2) one child's results were not included as they were suspected to be inaccurate. Refer to Section 2.5 for additional details.

Chapter 4

Discussion

Risk for word reading and spelling difficulties increases with the presence of SSD but not all experience these problems (Burgoyne et al., 2019; Cabbage et al., 2018; Tambyraja et al., 2020; Wren et al., 2021). Early literacy research in SSD has primarily focused on examining phonological awareness to explain word reading and spelling difficulties. Most research suggests that phonological awareness deficits occur in children with SSD but is not the sole predictor of word reading and spelling difficulties (Miller & Lewis, 2022). Researchers have begun to examine other factors that we know correlate with or predict word reading and spelling in children with TD. These include oral language abilities and orthographic knowledge. Oral language ability is known to be a prominent factor impacting early literacy development (Marks et al., 2019; Nation, 2019). As speech sound and oral language development are connected and partially dependent on one another, oral language deficits (DLD) often co-occur with SSD (Eadie et al., 2015; Schuele, 2004). This co-occurrence increases risk of word reading and spelling difficulties (Jin et al., 2020; Lewis et al., 2018; Miller & Lewis, 2022; Tambyraja et al., 2020). While risk increases with DLD, children with DLD do not always lead to word reading and spelling deficits (Catts et al., 2005; 2017). This suggests another foundational factor such as orthographic knowledge may be key in determining word reading and spelling development. Orthographic knowledge has been minimally studied in SSD, but past studies have reported deficits in one or more areas of orthographic knowledge (Ehrhorn & Adlof, 2021). In addition to phonological awareness, consideration of other foundational factors and abilities may be an essential approach to further understand risk and protective factors related to word reading and spelling in SSD, and generally in children with phonological awareness deficits.

The current study examined phonological awareness and orthographic knowledge, and the influence of orthographic word properties on phonological awareness performance in children with SSD and children with TSD. Additionally, oral language ability was considered within the models to determine its importance for word reading and spelling development in SSD. Current word reading and spelling abilities in children with SSD were compared to their peers with TSD to confirm that the sample of children reflects literature finding variability in these literacy outcomes.

4.1 Examination of Word Reading and Spelling in Children

The current study supports previous findings that some children with SSD may experience word reading and spelling difficulties (Burgoyne et al., 2019; Cabbage et al., 2018; Tambyraja et al., 2020; Wren et al., 2021). The significant word reading differences between children with SSD and children with TSD occurred in their ability to read real words (g = 0.82) and decode pseudowords (g = 0.68) resulting in an overall word reading difference (g = 0.80). Even though groups significantly differed in word reading, these differences didn’t necessarily indicate deficits on the WRMT-III norm-referenced assessment for children with SSD. The WRMT-III Basic Skills composite mean score for the SSD group was considered average ($\bar{x} = 97.76$) as compared to a high-average mean score ($\bar{x} = 111.47$) in the TSD group, but there was large variability in each group. Through examination of the TSD group variability, only 3% of children with TSD presented with word reading deficits, and 10% presented with low-average word reading. This indicates that some children with TSD had lower word reading but these children were young and early in their reading instruction. In comparison, 23% of children with SSD presented with word reading deficits, and 23% presented with low-average word reading. These children with SSD, who showed more word reading difficulty, varied in their age (6-8 years) and amount of word reading instruction (Kindergarten through 2nd grade). These descriptive comparisons of the word reading variability for each group suggest that children with SSD are more at risk for word reading difficulties that lead to lower ability.

The significant spelling differences between children with SSD and children with TSD were measured at word level ($g = 0.80$). Similar to word reading, there was large variability in each group's spelling accuracy. Through examination of the variability, all (100%) children with TSD accurately spelled at least 3 out of 10 words as compared to 73% of the children with SSD. This supports that children with SSD have increased risk for spelling difficulties. In sum, the current study's sample of children with SSD demonstrated increased word reading and spelling difficulties as compared to peers with TSD, which is consistent with previous research.

4.2 Examination of Phonological Awareness

The current study examined phonological awareness between children with SSD and children with TSD using a norm-referenced assessment (i.e., CTOPP-2 phonological awareness composite score) and an experimental phonological awareness task. Based on previous literacy research in SSD (Apel & Lawrence, 2011; Brosseau-Lapré & Roepke, 2019; Burgoyne et al., 2019; Jin et al., 2020; Masso et al., 2017; Miller & Lewis, 2022) and a primary speech sound deficit, children with SSD were predicted to have poorer phonological awareness performance as compared to their peers with TSD and that group differences would remain after controlling for oral language ability (i.e., CELF-5 Core Language Index score). Refer to Table 4.1 to compare models examining group differences before and after oral language ability was controlled.

Results from both phonological awareness measures supported my prediction that children with SSD showed lower phonological awareness performance as compared to their peers with TSD. After controlling oral language ability, my prediction was only partially supported as significant group differences remained only for the experimental phonological awareness task. The experimental phonological awareness model showed that the presence of SSD and oral language significantly predicted phonological awareness performance. This suggests that lower phonological awareness performance is explained by phonological deficits related to speech sound production and oral language ability. The CTOPP-2 PA model was significantly predicted by oral language ability and marginally predicted by the presence of SSD. This suggests that the previous CTOPP-2 PA significant group difference was primarily driven by oral language ability instead of the presence of SSD. Additionally, the model fit improved when oral language ability was included as a predictor for both models as the variance explained increased (CTOPP-2 PA model R^2_{adj} = 18%; experimental phonological awareness model R^2_{adj} = 29%) and aligns with previous research suggesting that oral language ability can be as strong or a stronger predictor of phonological awareness performance in children with SSD. This aligns with previous research indicating that oral language ability is connected and depends on speech sound awareness for continued development (Ainsworth et al., 2016).

We further hypothesized that the differences between groups were predicted to be greater in the experimental phonological awareness task as compared to the norm-referenced composite phonological awareness due task and scoring differences. When comparing the models for each phonological awareness task, it was clear that the experimental phonological awareness assessment models better captured group differences as variance explained more than doubled (experimental phonological awareness R^2_{adj} = 18% versus CTOPP-2 PA R^2_{adj} = 7%). While both phonological awareness assessments required comparable levels of skill, there are differences in the task design that may have led to measurement inconsistencies between groups before and after controlling oral language ability. The CTOPP-2 PA subtests are based on their production of speech sounds that are then taken into account when scoring. The experimental phonological awareness task doesn’t require any scoring adjustments because it is a receptive-based task. Similar to other studies, the CTOPP-2 PA subtests were scored to account for noted speech sound errors from other speech sound production assessments within the SSD group. This may have overestimated phonological awareness in the SSD resulting in only marginal significant differences between groups.

Additional explanations of why phonological awareness group differences only remained significant in one assessment model when including oral language ability could be related to task complexity and difficulty, and how the stimuli were presented (audio-only versus live audiovisual). Related to task complexity, the CTOPP-2 PA measured different types of phonological awareness skills (i.e., deleting, blending, and matching/isolating sounds) with increasing complexity (syllable-level to phonemic-level identification and manipulation). The experimental phonological awareness task had children match a phoneme in the final position of the words (matching sounds) with no change in skill complexity. Instead, difficulty was considered through the selection of stimuli within the items as orthographic properties of words were manipulated.

Additionally, all children expressed more difficulty with the experimental phonological awareness task as compared to the CTOPP-2 phonological tasks (e.g., one child was unable to complete the experimental phonological awareness task). As each phonological awareness task varied in complexity, it also varied in whether the task was developmentally appropriate for the range of age and grade levels included in the study. This may explain why the experimental phonological awareness task was reported to be more difficult for children. One reason for the increased difficulty is that the identification and manipulation of phonemes in the final position of words may not have been gained yet in kindergarten children or children starting first grade. An additional reason for the increased difficulty is that the working memory demands of the experimental phonological task (i.e., remembering and recalling all the words that go with the pictures) were greater as compared to the CTOPP-2 PA subtests.

While the phonological awareness assessments differed in task complexity and developmental level, the mode of stimuli presentation provides another possible explanation for why one assessment no longer showed significant group differences after controlling oral language ability. Ehrhorn and colleagues (2020) suggest that audiovisual presentation of phonological tasks supports performance. The experimental phonological awareness task solely presents stimuli using audio recordings, whereas the CTOPP-2 PA composite consists of one subtest using audio recordings (Blending Words subtest) and two subtests that require the administrator to present the stimuli live providing audiovisual presentation (Elision, and Sound Matching/Phoneme Isolation subtests). As the significant group differences were only shown in the phonological awareness tasks that used audio recordings and not in live audiovisual presentation, this suggests that children with SSD may benefit from all phonological information presented to support phonological awareness performance. Future studies should consider the phonological awareness task complexity and developmental level, and the modality of stimuli presentation to better understand phonological awareness difficulties in SSD.

Our examination of phonological awareness performance between children with SSD and children with TSD did not fully align with my hypotheses. Even though both showed significant group differences initially, only the experimental phonological awareness task's group differences remained significant once oral language ability was controlled. Oral language ability was the only significant factor to predict phonological awareness performance on the CTOPP-2 PA model suggesting performance on this task is heavily influenced by oral language ability instead of both oral language ability and SSD presence. This is consistent with previous early literacy literature in SSD finding that oral language ability influences phonological awareness abilities (Burgoyne et al., 2019; Miller & Lewis, 2022; Skebo et al., 2013). The current study results align with the prior literature suggesting that children with SSD have lower phonological awareness as compared to their peers with TSD, but that oral language ability needs to be considered as it was shown to significantly explain phonological awareness performance.

4.3 Examination of Foundational Orthographic Knowledge in Children

Orthographic knowledge has received minimal attention in SSD as compared to other foundational factors such as phonological awareness (Ehrhorn & Adlof, 2021). The current study examined phoneme-grapheme correspondence knowledge and orthographic pattern knowledge using two experimental tasks. Additionally, alphabet knowledge was measured to better understand initial orthographic knowledge. Children with SSD were hypothesized to demonstrate poorer orthographic knowledge as compared to their peers with TSD. These predictions were based on prior early literacy research finding deficits in orthographic knowledge in SSD (Anthony, et al., 2011; Apel & Lawrence, 2011; Bird et al., 1995; Carroll & Snowling, 2004; Carson et al., 2015; McNeil et al., 2017; Raitano et al., 2004; Treiman et al., 2007). Because oral language was shown to be more closely related to literacy deficits than speech sound production

(Anthony et al., 2011; Burgoyne et al., 2019), it was predicted that children with SSD would no longer significantly differ from their peers with TSD after controlling for oral language ability. Refer to Table 4.1 to compare models examining group differences before and after oral language ability was controlled.

Alphabet knowledge was examined in children with SSD and compared to children with TSD to determine if difficulties started with their knowledge of letter names. From the previous literature, we predicted that no significant group differences would be shown because of the age range included in the study resulting in various amounts of reading instruction (e.g., early- to mid-elementary grade levels). Alphabet knowledge differed between groups with marginal significance ($p = .097$, $g = 0.37$). This result aligns with an early literacy study in SSD examining alphabet knowledge (Apel & Lawrence, 2011) but differs from results finding a significant difference (Anthony et al., 2011; DeThorne et al, 2006; Harris et al, 2011; Treiman et al., 2008). This marginal significant difference may be due to a greater proportion of children in the TSD group in third grade as compared to the SSD group. This result highlights that alphabet knowledge is essential for all children to build upon during their orthographic knowledge development.

The phoneme-grapheme correspondence task had the children determine whether the grapheme or grapheme-set presented made the sound presented through a video recording (audiovisual presentation). Children with SSD were significantly less accurate at recognizing valid phoneme-grapheme correspondences as compared to their peers with TSD ($p = .023$; $g = 0.61$). This result was consistent with the hypothesized outcome and suggests that children with SSD have difficulty learning phoneme-grapheme correspondences. Contrary to our hypothesis, children with SSD still had significant difficulties in identifying accurate phoneme-grapheme correspondences as compared to their peers with TSD ($p = .042$) after controlling for oral language ability. This further supports that learning phoneme-grapheme correspondences is difficult for children with SSD. Importantly, phoneme-grapheme correspondence knowledge was more accurately predicted when oral language ability was included as the model that controlled for oral language had slightly smaller confidence intervals (from 95% CI [0.06 – 0.72] to [0.01 – 0.65]) and increased variance accounted for within the model (from $R^2_{adj} = 0.07$ to $R^2_{adj} = 0.16$). This suggests that oral language ability could be a pivotal factor determining phoneme-grapheme correspondence knowledge could be a pivotal factor determining and consequently risk for word reading and spelling difficulties for children with SSD and/or oral language deficits.

The second foundational orthographic knowledge area examined between children with SSD and children with TSD was orthographic pattern knowledge. This task was designed with three sets of items. Two sets of items contained an illegal orthographic string and a probable orthographic string (HI and LI). These sets of items were designed to determine whether groups differed in their knowledge of legal grapheme patterns within English orthography. The third set of items contained two legal orthographic strings that differed in probability (HL). This condition was designed to examine sensitivities to these regularities. As hypothesized, current study results showed that children with SSD selected the legal or highly probable orthographic string less often as compared to their peers with TSD (*p* = .045; *g* = 0.55). Additionally, all children were better able to identify the highly probable orthographic string when presented with an illegal orthographic string as compared to just a lower probable orthographic string (*p* = .001). This suggests that children with SSD have reduced awareness of probable orthographic patterns in written English as compared to their peers with TSD, and that all children solidify their knowledge of these orthographic regularities as they continue to be exposed to written word forms.

As hypothesized, the presence of SSD no longer significantly predicted orthographic pattern knowledge when oral language ability was controlled within the models. The model fit improved when controlling oral language ability as the explained variability increased (from R^2 = 0.15 to 0.17) and the confidence intervals decreased (95% CI decreased by 1.00%). The significant orthographic difference remained between the sets of items comparison (HI and HL item sets), and oral language ability was shown to significantly predict orthographic pattern knowledge (*p* = .048). This model supports the hypothesis that oral language ability is more predictive of orthographic pattern knowledge than speech sound production deficits.

In sum, orthographic knowledge findings suggest that oral language ability needs to be examined when measuring orthographic knowledge in children with SSD. Models that included oral language ability accounted for more variance in orthographic knowledge for phoneme-grapheme correspondence knowledge and orthographic pattern knowledge. This finding aligns with previous studies that highlight the importance in capturing oral language abilities in children with SSD (Anthony et al., 2011; Burgoyne et al., 2019). Across orthographic knowledge areas, results showed that children with SSD have significantly poorer orthographic knowledge than their peers with TSD, but some difficulties may be more related to oral language abilities than the presence of SSD. Phoneme-grapheme correspondence deficits were explained by the presence of SSD and oral language ability, whereas orthographic pattern knowledge deficits may be more explained by oral language ability than the presence of SSD. Another factor that should be considered is whether these significant differences were related to the amount of reading instruction. Even though grade levels between groups differed with marginal significance ($p = 0.075$), children in the SSD group tended to be enrolled in earlier grades as compared to the TSD group. This suggests that these differences in orthographic knowledge could be due to children with SSD having less reading instruction as compared to their peers in the TSD group. Future studies should further investigate whether orthographic knowledge differences may be related to the amount of instructional exposure more than the presence of SSD. Overall, the orthographic knowledge results indicate that phoneme-grapheme correspondence knowledge is a key factor for determining word reading and spelling difficulties in children with SSD and/or oral language deficits.

4.3 Orthographic Influences Phonological Awareness Performance

Research indicates that once orthography has been introduced it influences how speech sounds are processed (Frith, 1998; Port, 2010). Specifically, previous research supports the Triangle Model of Word Reading (Seidenberg, 2005) suggesting that skilled word readers coactivate orthographic knowledge along with phonological forms while reading a word (Castles et al., 2003; Seidenberg & Tanenhaus, 1979; Ziegler & Ferrand, 1998). Research has shown that this coactivation does not occur in developing readers until foundational orthographic knowledge has been learned (Castles et al., 2011). As explained through the Self-Teaching hypothesis (Share, 1995; 1999; 2004), developing readers rely on the phoneme(s) (i.e., sounds) that correspond to graphemes to decode unfamiliar words until the words become familiar. The current study examined whether orthographic properties of words influenced phonological awareness performance in each group of developing readers (children with SSD and children with TSD) before and after controlling oral language ability. Then, children with SSD were compared to their peers with TSD to determine whether groups experience similar orthographic influences on phonological awareness performance. Refer to Table 4.1 to compare models examining group differences before and after oral language ability was controlled, and Table 4.2 to compare models examining whether orthographic properties of words influenced each group differently before and after controlling oral language ability.

The hypotheses examining whether orthographic properties of words influence phonological awareness performance within the group of children with TSD were based on findings from Landerl et al. (1996) and Castles et al. (2003). Phonological awareness performance was hypothesized to be influenced by the orthographic properties of words in children with TSD, and this influence would remain significant after accounting for oral language ability. Children with TSD were expected to have lower accuracy on the condition with less phoneme-grapheme correspondences (IN) as compared to the congruent conditions (CC and CI), and lower accuracy on the phoneme-grapheme correspondences that could be congruent or incongruent (CI) as compared to the condition that was always congruent (CC).

As hypothesized, the current study results showed that the experimental phonological awareness performance in children with TSD was influenced by their orthographic knowledge in the models not controlling for oral language ability (R^2_{adj} = 0.05, *p* = .049). Once oral language ability was controlled, the models no longer reached significance (R^2_{adj} = 0.04, *p* = .103) which was contrary to the hypothesis. Models that included oral language ability decreased the fit suggesting that oral language ability may not be an important factor to consider within the TSD models. In both sets of models, children with TSD were significantly more accurate in matching the last speech sound when the phoneme-grapheme correspondences were congruent and consistent (CC; mug-tag) as compared to incongruent (IN; bricks-fox), but only marginally more accurate when the correspondences were congruent but inconsistent (CI; bricks-blocks) as compared to incongruent (IN; bricks-fox). This significance may have not remained as the congruent conditions (CC and CI) had some children with TSD experience a high level of difficulty during the task increasing the variability in accuracy. Other possibilities to explain the large variability are 1) marginally significant group differences in grade indicating that the SSD group may have less influence due to limited reading instruction, or 2) issues with some of the stimuli or even the presentation of the stimuli (e.g., audio-only presentation vs. audiovisual presentation). In the end, the TSD developing readers group showed coactivation of phonological forms and orthographic knowledge on their phonological awareness performance, and oral language ability was not a factor that predicted their performance.

Because this is the first known study to examine orthographic influences in SSD, hypotheses examining orthographic properties of words influence on phonological awareness performance within children with SSD were based on findings from Landerl and colleagues (1996) and literature suggesting that children with SSD have less orthographic knowledge (Anthony et al., 2011; Apel & Lawrence, 2011; Bird et al., 1995; Burgoyne et al., 2019; McNeil et al., 2017). Children with SSD were hypothesized to be minimally influenced by the orthographic properties of words on their phonological awareness performance. Results of the current study showed that orthographic properties of words did not significantly influence phonological awareness performance in children with SSD before or after controlling oral language ability. Consistent with the hypothesis based on Landerl et al. (1996) study, phonological awareness performance in children with SSD was minimally influenced by orthographic properties of words which may be due to their poor knowledge of phoneme-grapheme correspondences. Even though not significant, children with SSD had higher average performance on the condition that had congruent phoneme-grapheme correlations inconsistently throughout the task (e.g., CI: bricks-clocks) as compared to similar average performances on the other two conditions (e.g., CC: mug-tag and IN: bricks-fox). This was not an expected pattern which may be due to possible issues with some of the stimuli. Additionally, large variability in phonological awareness performance was noted especially in the two conditions that have inconsistent phoneme-grapheme correspondences (CI and IN). Importantly, phonological awareness performance was better predicted when the model included oral language ability ($R^2_{adj} = -0.002$ versus $R^2_{adj} = 0.29$). This indicates that the experimental phonological awareness task is highly demanding of oral language ability (e.g., children need to understand instructions, know and hold the words produced in working memory, and then complete the phonological comparison), and aligns with Catts et al. (2005) that phonological awareness performance is highly associated with oral language ability in earlier grades. difficulties

In the end, the SSD developing readers group showed minimal coactivation of phonological forms and orthographic knowledge on their phonological awareness performance even after controlling oral language ability. One interpretation of this is that children with SSD have not gained enough orthographic knowledge to lead to coactivation for more skilled word reading like their peers with TSD, especially when oral language difficulties co-occur. Another interpretation is that children with SSD have decreased oral language abilities that impact the development of phoneme-grapheme correspondence knowledge reducing the coactivation of phonological and orthographic factors for skilled word reading and spelling.

When comparing groups within the same analysis, two hypotheses were made based on two dyslexia studies (Landerl et al., 1996; van der Leij and van Daal, 1999). Current study results did not fully support either study's findings as the model showed no significant influence of orthographic properties of words across developing reader groups and no difference between groups (children with SSD and children with TSD) in their phonological awareness performance. This result did not support the group differences shown when examined within each group which aligned more with previous findings from Landerl and colleagues (1996) than van der Leij and van Daal (1999). First, children with SSD experienced minimal influence on their phonological awareness performance whereas children with TSD had higher performance on congruent conditions (CC: mug-tag and CI: bricks-blocks) as compared to the incongruent condition (IN: bricks-fox). These differences noted in the within-group models may not have held when put into a single model due to the large variability within each group. The variability in performance may be related to differing amounts of reading instruction between groups, possible task issues, or that task was generally difficult.

Additionally, oral language ability was important to control in the SSD models where this was not an important factor in the TSD models. Contrary to van der Leij and van Daal (1999) findings, the current study results suggested that children with SSD may not use or not have acquired enough orthographic knowledge to influence their phonological awareness performance as compared to their peers with TSD, and that oral language ability may only influence performance if there is a presence of SSD. According to these findings and previous studies, SSD or oral language difficulties (i.e., the lower end of the typical range and below) alone are unlikely to explain word reading and spelling difficulties, but in combination can cause these difficulties. This highlights the importance of assessing oral language abilities in children with SSD as it may be a pivotal protective factor for word reading and spelling.

Even though this study only examined the correlation between phonological awareness and orthographic knowledge in developing readers, the results have implications for treatment in children with SSD. These results suggest that children with SSD would benefit from speech sound treatment to include explicit orthographic knowledge instruction especially related to phoneme-grapheme correspondences. This additional instruction could boost orthographic knowledge that is necessary for developing readers to gain when becoming a skilled word reader and speller, and may have the added benefit of improving phonological awareness. Because oral language difficulties are an additive risk for phonological awareness difficulties in SSD, children with DLD may also benefit from explicit phoneme-grapheme instruction. More intensive and explicit instruction focused on phoneme-grapheme correspondences may serve as a protective factor for the development of word reading and spelling for children who have phonological awareness difficulties.

4.5 Additional Aspects of Phonological Processing

Recent studies suggest that children with SSD have other phonological processing deficits beyond phonological awareness (Farquharson et al., 2021). Farquharson and colleagues (2021) measured phonological processing through nonword repetition, finding that children with SSD had poorer nonword repetition performance as compared to children with TD. The current study showed similar findings that children with SSD have poorer phonological memory performance on the nonword repetition subtest of the CTOPP-2 as compared with their peers with TSD. No other significant differences occurred in the rest of the CTOPP-2 phonological processing subtests.

Two possible reasons why only the CTOPP-2 Nonword Repetition subtest showed a significant group difference related to the subtest being production-based and the modality of stimuli presentation. First, the Nonword Repetition subtest may have underestimated the phonological word memory abilities of children with SSD as scoring is based on production. Similar to the CTOPP-2 Blending Words subtest, the Nonword Repetition subtest presented the stimuli using an audio recording (audio-only presentation) instead of a video recording (audiovisual presentation). The CTOPP-2 Nonword Repetition subtest presentation modality of the stimuli may underestimate phonological memory skills as we know that the addition of visual cues is beneficial (Ehrhorn et al., 2020). There is a chance that this significance between groups would no longer remain if given more phonological information through audiovisual presentation. Therefore, it would be interesting to design and measure phonological memory without the use of a production-based task while maximizing phonological information to determine if this difficulty is related to speech sound deficits versus the working memory aspects of the task.

Additionally, the current study measured rapid symbolic naming using the two subtests that comprise the CTOPP-2 rapid symbolic naming composite score. Results suggested marginal differences between groups (p = .090) where children with SSD were slower in their naming of symbols as compared to their peers with TSD. This suggests that rapid naming may be an additional factor to predict word reading and spelling in

SSD. McWeeny et al. (2022) recently suggested that rapid symbolic naming is most predictive of reading achievement in preschool children as compared to other commonly measured factors (e.g., phonological awareness). This was especially true for rapid letter naming.

Early literacy research in SSD has mixed findings on whether rapid symbolic naming is an important factor to measure (Anthony et al., 2011; Burgoyne et al., 2019; Raitano et al., 2004; Leitao et al., 1997). The lack of clarity of whether rapid symbolic naming in SSD may be due to oral motor planning and execution difficulties as this can be a characteristic of the SSD subtypes (e.g., childhood apraxia of speech or dysarthria). Also, these differences in results may be due to the measurement of non-alphanumeric stimuli versus alphanumeric stimuli (which may be measuring orthographic knowledge more than the processing aspect). Future studies may also want to consider including multiple types of rapid symbolic naming and the possibility of oral motor difficulties to determine the importance of this factor in SSD.

4.6 Main Findings and Implications

The current study confirmed that children with SSD have lower phonological awareness performance as compared to their peers with TSD and that oral language ability significantly influences the development of early literacy skills. This suggests that the speech sound deficits in SSD decrease phonological awareness abilities and could limit the growth of oral language ability. The direct connection between the speech sound system and oral language development highlights the importance of measuring and controlling oral language skills beyond receptive vocabulary in children with SSD.

The current study also added to the small body of research examining orthographic knowledge in children with SSD. Results suggest that children with SSD have less orthographic knowledge, particularly knowledge of phoneme-grapheme correspondences. The decreased knowledge of orthographic constraints and sensitivity to regularities shown initially in children with SSD was more related to oral language ability than the presence of SSD. The results of the two tasks examining orthographic knowledge suggest that children with SSD have more difficulty gaining orthographic knowledge that involves connecting phoneme(s) to a grapheme or set of graphemes, but less difficulty recognizing legal combinations of graphemes. Additionally, oral language ability was shown to be as significant or more significant than SSD presence in predicting orthographic knowledge.

This was one of the first studies to examine the correlation between phonological and orthographic factors while controlling oral language ability. Current study results showed that phonological awareness performance was influenced by orthographic properties of words in developing readers with TSD suggesting that these children are accessing knowledge of phoneme-grapheme correspondences during an oral task. This indicates that these developing readers with TSD have coactivation of both phonological and orthographic factors occurring as proposed by the Triangle Model of Word Reading (Seidenberg, 2005). In children with SSD, orthographic properties of words were shown to influence phonological awareness following a similar general pattern descriptively but was non-significant. The minimal influence in SSD may be due to less phoneme-grapheme knowledge resulting in less change in accuracy between conditions. This suggests that orthographic knowledge involving direct correspondence to speech sounds is lessened in children with SSD, and that these developing readers with SSD have a reduced amount of coactivation between these factors.

Additionally, oral language ability was shown to significantly influence phonological awareness performance in children with SSD, not children with TSD. The significance of oral language ability was also found to significantly predict orthographic knowledge. These results when combined with previous research examining SSD and/or oral language deficits suggest that SSD or oral language difficulties alone cannot explain word reading and spelling difficulties, but in combination can explain these difficulties. This emphasizes the importance of assessing oral language abilities in children with SSD as it may be a pivotal protective factor for word reading and spelling.

Phoneme-grapheme correspondence knowledge could be another protective factor for word reading and spelling development in children with SSD. If speech sound intervention explicitly teaches and supports phoneme-grapheme correspondence knowledge, children with SSD could experience more coactivation of these word reading factors similar to peers with TSD. This gained orthographic knowledge could be used to improve phonological awareness performance and reduce risk for word reading and spelling difficulties. Additional and explicit instruction focused on phoneme-grapheme knowledge could also be beneficial for children who have poor phonological awareness performance beyond children with SSD (e.g., children with DLD). Oral language ability and phoneme-grapheme correspondence knowledge could both serve as protective factors that decrease word reading and spelling difficulties in children with poor phonological awareness abilities.

4.7 Limitations and Future Considerations

The current study examined phonological awareness and orthographic knowledge using some more novel approaches compared to previous studies. Limitations identified related to the participant sample and various aspects of the experimental tasks within the study. Each will be discussed with suggestions for future studies to address.

First, there was a marginally significant ($p = 0.075$) difference in school grade between children with SSD and children with TSD, although the two samples did not differ in chronological age. More children in the SSD group were in or recently completed Kindergarten or first grade as compared to the TSD group, and no children in the SSD group were in third grade whereas four children within the TSD group were in third grade. It is possible that the significant group differences in orthographic knowledge could represent differences in the amount of formal reading instruction the children in the two groups had. It is also possible that caregivers of children with SSD intentionally waited to enroll them in kindergarten decreasing the amount of reading instruction that occurred. To gain clarity in determining whether children with SSD have less orthographic knowledge, future studies need to address this limitation by using grade inclusion criteria instead of age, incorporating a control group that consists of younger reading-matched children, or including a questionnaire that captures the amount of reading instruction that has occurred.

Second, the sample size was relatively small for detecting small differences between groups. However, the current study sample size was similar to many other studies of early literacy in SSD (Ehrhorn & Adlof, 2021) Confidence in the results would increase with future studies expanding the sample size or considering the incorporation of speech sound production errors as a continuous variable instead of a dichotomous grouping variable in analyses. Additionally, the sample of children was not representative of population demographics. The study captured the abilities of children who were primarily identified as not Hispanic/Latino, white children from highly educated mothers. This indicates the generalizability of the study findings to children outside of this demographic should not be done. Online recruitment may have impacted the sample diversity but was selected due to the ongoing pandemic and time constraints. Also, the small sample size may have lowered the precision of the results as abilities ranged from gifted to extremely poor across the battery of assessments for both groups. Therefore, future studies should increase the sample size and recruit through programs for diverse learners to improve the power and representation within the study to be more generalizable to the target populations.

Third, the design and programming of the experimental tasks examining orthographic knowledge and phonological awareness have limitations. The orthographic pattern knowledge task had an uneven number of trials within the sets of items due to stimulus development trial errors that were corrected after data collection and before data analysis. Lastly, limitations of the experimental phonological awareness task should consider the developmental level of phoneme-grapheme correspondences within the phonological awareness task as this may impact the amount of influence that could possibly occur.

4.8 Future Directions

The current study showed promising results that not only added to existing literature but also expanded our knowledge that determines the risk of word reading and spelling in children with SSD. These results suggest that future studies need to examine orthographic knowledge in addition to phonological awareness while controlling oral language ability. Future studies may also consider other factors that were shown to differ between children with SSD and children with TSD. These include phonological memory, rapid symbolic naming tasks, and letter identification.

Using the current study's data, we could ask similar questions but take a different approach to measure speech sound difficulties. Instead of grouping children by the presence of SSD versus TSD, the number of speech sound production errors could be used as a predictor in the models. This would decrease the possible limitations associated with dichotomizing variables that are continuous and increase sample size leading to improved power and models.

Another future study could use this continuous speech sound production variable to be more comprehensive in examining children who have poor phonological awareness performance with various origins of risk. For example, this would allow for the inclusion of other children with oral language deficits who also are at risk for word reading and spelling difficulties (Catts et al., 2005). In combination with the current study results, the results could provide evidence to support that phoneme-grapheme knowledge may be a protective factor for children with poor phonological awareness abilities.

Lastly, an intervention study that examines the effects of integrating orthography into speech sound treatment could be another future study. The treatment effects could be measured through similar assessments of speech sounds and orthographic outcomes with consideration of oral language ability and amount of reading instruction. As children with SSD have speech sound deficits that extend beyond their production (Brosseau-Lapré et al., 2020; Benway et al., 2021; Mari et al., 2022; Miller & Lewis, 2022; Roepke & Brosseau-Lapré, 2021), the addition of tasks that measure speech sound representations may provide a deeper understanding of a potential core deficit that impacts the development of all word reading and spelling factors. Additionally, the intervention study may want to consider the use of eye tracking to capture performance differences and changes that may not be captured through accuracy.

Eyetracking methodology is a widely accepted method to measure reading and lexical representations in children (e.g., Milledge et al., 2022; Nation & Castles, 2017). The adjustment of multiple phonological awareness and orthographic knowledge tasks would provide the opportunity to capture other aspects related to processing.

Therefore, future studies that examine phonological awareness and orthographic knowledge, and the co-development of these factors should consider using eye tracking methodology to provide insight on related processing that underlies making an accurate response.

Table 4.1 *Comparison of Regression Models by Assessment between No Oral Language Ability and Oral Language Ability Controlled*

Models by Assessment	*Model Significance Remains*	*Model Fit Improves*	*Group Differences Remain*	*Oral Language Ability Significant*
CTOPP-2 PA Models	YES	YES	NO	YES
Phoneme-Grapheme Correspondence Models	YES	YES	YES	YES
Orthographic Pattern Knowledge Models	YES	YES	NO	YES
Experimental Phonological Awareness Models	YES	YES	YES	YES

Note. Eight models were compared to determine what changes occurred in the model and whether group differences remained. The *Clinical Test of Phonological Processing, Second Edition* Phonological Awareness composite score (CTOPP-2 PA; Wagner et al., 2003) was one of the outcome variables being predicted. Oral language ability was predicted using the Core Language composite score from the *Clinical Evaluation of Language Fundamentals, Fifth Edition* (CELF-5; Wiig et al., 2013). All other tasks were experimental and designed by the author.

Table 4.2 *Comparison of Regression Models between No Oral Language Ability and Oral Language Ability Controlled for each Group determining whether Orthography Influences Phonological Awareness Performance*

Group	*Are they significantly influenced by orthography?*		*Oral Language Ability Significant*
	No Language	Controlled Language	
SSD	NO	NO	YES
TSD	YES	NO	NO

Note. Two models for each group were compared to determine whether orthographic properties of words influenced their experimental phonological awareness performance. The model statistics are presented for each aspect examined for the model with no oral language ability (No Language) and the model controlling for oral language ability (Controlled Language). The sample includes children with speech sound disorder (SSD; n = 30) and children with typical speech development (TSD; n = 28). Two children from the total TSD sample were not included in this analysis due to 1) one child not completing the task after an attempt, and 2) one child's results were not included as they were suspected to be inaccurate. Refer to Section 2.5 for additional details. Oral language ability was predicted using the Core Language composite score from the *Clinical Evaluation of Language Fundamentals, Fifth Edition* (CELF-5; Wiig et al., 2013).

Chapter 5

Conclusion

The current study examined multiple factors that lead to successful word reading and spelling development in children with SSD and children with TSD. Children with SSD had significant word reading and spelling difficulties as compared to their peers with TSD. These difficulties in children with SSD were explained by more than poor phonological awareness. Knowledge of phoneme-grapheme correspondences was less in children with SSD as compared to children with TSD. Additionally, children with SSD had minimal orthographic influence during their phonological awareness performance compared to children with TSD. Oral language ability was a consistent factor that explained performance for all foundational factors of word reading and spelling. This emphasizes the importance to comprehensively measure and consider oral language ability in children with SSD when examining early literacy risk. In conclusion, oral language ability may be a pivotal protective factor for children with SSD as phonological awareness and orthographic knowledge performances were better predicted when included. Increased knowledge of phoneme-grapheme correspondences may also be a protective factor of word reading and spelling development for children with poor phonological awareness (i.e., children with SSD, children with oral language deficits). Intervention for these children that incorporates explicit phoneme-grapheme instruction may reduce risk for word reading and spelling difficulties, as the gained orthographic knowledge could improve phonological awareness abilities. Strengthening the co-development and interactions between these foundational factors in developing readers with phonological awareness difficulties could reduce risk of word reading and spelling difficulties in developing readers.

References

Adlof, S. M., Catts, H. W., & Lee, J. (2010). Kindergarten Predictors of Second Versus Eighth Grade Reading Comprehension Impairments. *Journal of Learning Disabilities*. https://doi.org/10.1177/0022219410369067

Ainsworth, S., Welbourne, S., & Hesketh, A. (2016). Lexical restructuring in preliterate children: Evidence from novel measures of phonological representation. *Applied Psycholinguistics, 37*(4), 997 – 1023. https://doi.org/10.1017/S0142716415000338

Alonzo, C. N., McIlraith, A. L., Catts, H. W., & Hogan, T. P. (2020). Predicting dyslexia in children with developmental language disorder. *Journal of Speech, Language, and Hearing Research, 63*(1), 151–162. https://doi.org/10.1044/2019_JSLHR-L-18-0265

American Psychiatric Association (2019). *What is specific learning disorder?*. Retrieved from https://www.psychiatry.org/patients-families/specific-learning-disorder/what-is-specific-learning-disorder

Anthony, J. L., Aghara, R. G., Dunkelberger, M. J., Anthony, T. I., Williams, J. M., & Zhang, Z. (2011). What factors place children with speech sound disorders at risk for reading problems? *American Journal of Speech-Language Pathology, 20*(2), 146–160. http://10.0.4.20/1058-0360(2011/10-0053)

Anwyl-Irvine, A.L., Massonié J., Flitton, A., Kirkham, N.Z., Evershed, J.K. (2019). Gorilla in our midst: an online behavioural experiment builder. *Behavior Research Methods.* https://doi.org/10.3758/s13428-019-01237-x

Apel, K. (2011). What is orthographic knowledge? *Language, Speech, and hearing Services in Schools, 42*, 592-603. https://doi.org/10.1044/0161-1461(2011/10-0085)

Apel, K., & Lawrence, J. (2011). Contributions of Morphological Awareness Skills to Word-Level Reading and Spelling in First-Grade Children with and without Speech Sound Disorder. *Journal of Speech, Language, and Hearing Research, 54*(5), 1312–1327. https://doi.org/10.1044/1092-4388(2011/10-0115)

Apel, K., Wilson-Fowler, E. B., Brimo, D., & Perrin, N. A. (2012). Metalinguistic contributions to reading and spelling in second and third grade students. *Reading and writing*, *25*(6), 1283-1305. https://doi.org/10.1007/s11145-011-9317-8

Baron, L. S., Ehrhorn, A. M., Shlanta, P., Bell, B. A., Ashby, J., Adlof, S. M. (2021, July 13-16). *Orthographic influences on phonological awareness in school-age children with persisting dyslexia, resolving dyslexia, and typical word reading skills.* Poster presentation presented at the Society for Scientific Studies of Reading Conference, Virtual Meeting.

Bear, D. R., Invernizzi, M., Templeton, S., & Johnston, F. (2000). *Words Their Way: Word Study for Phonics, Vocabulary, and Spelling Instruction.* Columbus, OH: Merrill.

Benway, N. R., Garcia, K., Hitchcock, E., McAllister, T., Leece, M. C., Wang, Q., & Preston, J. L. (2021). Associations between speech perception, vocabulary, and phonological awareness skill in school-aged children with speech sound disorders. *Journal of Speech, Language, and Hearing Research*, *64*(2), 452-463. https://doi.org/10.1044/2020_JSLHR-20-00356

Bishop, D. V. M., Snowling, M. J., Thompson, P. A., & Greenhalgh, T. & CATALISE-2 consortium (2016). CATALISE: a multinational and multidisciplinary delphi consensus study. Identifying language impairments in children. *PLoS One*, *11*, e0168066. https://doi.org/10.1371/journal.pone.0168066

Bishop, D.M.V., Snowling, M.J., Thompson, P.A., Greenhalgh, T., & CATALISE-2 consortium. (2017). Phase 2 of CATALISE: A multinational and multidisciplinary Delphi consensus study of problems with language development: Terminology. *The Journal of Child Psychology and Psychiarty, 58*(10), 1068-1080. https://doi.org/10.1111/jcpp.12721

Bird, J., Bishop, D.V.M., & Freeman, N.H.A. (1995). Phonological Awareness and Literacy Development in Children with Expressive Phonological Impairments. *Journal of Speech and Hearing Research, 38*(2), 446–462. https://doi.org/10.1044/jshr.3802.446

Black, L. I., Vahratian, A., & Hoffman, H. J. (2015). *Communication disorders and use of intervention services among children aged 3-17 years: United States, 2012*. Hyattsville, MD: US Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Health Statistics. https://www.cdc.gov/nchs/data/databriefs/db205.pdf

Brosseau-Lapré, F., & Roepke, E. (2019). Speech errors and phonological awareness in children ages 4- and 5-years with and without speech sound disorder. *Journal of Speech, Language & Hearing Research, 62*(9), 3276–3289. http://10.0.4.20/2019_JSLHR-S-17-0461

Brosseau-Lapré, F., Schumaker, J., & Kluender, K. R. (2020). Perception of medial consonants by preschoolers with and without speech sound disorders. *Journal of Speech, Language, and Hearing Research*, *63*(11), 3600-3610. https://doi.org/10.1044/2020_JSLHR-20-00146

Burgoyne, K., Lervag, A., Malone, S. & Hulme, C. (2019). Speech difficulties at school entry are a significant risk factor for later reading difficulties. *Early Childhood Research Quarterly, 49*, 40-48. https://doi.org/10.1016/j.ecresq.2019.06.005

Cabbage, K.L., Farquharson, K., Iuzzini-Seigel, J., Zuk, J. & Hogan, T.P. (2018). Exploring the overlap between dyslexia and speech sound production deficits. *Language, Speech, and Hearing Services in Schools, 49,* 774-786. https://doi.org/10.1044/2018_LSHSS-DYSLC-18-0008

Cabbage, K. L., & Hitchcock, E. R. (2022). Clinical Considerations for Speech Perception in School-Age Children with Speech Sound Disorders: A Review of the Current Literature. *Language, Speech, and Hearing Services in Schools*, 1-18. https://doi.org/10.1044/2022_LSHSS-21-00120

Cabbage, K. L., Hogan, T. P., & Carrell, T. D. (2016). Speech perception differences in children with dyslexia and persistent speech delay. *Speech Communication, 82*, 14–25. http://10.0.3.248/j.specom.2016.05.002

Carroll, J. M., & Snowling, M. J. (2004). Language and phonological skills in children at high risk of reading difficulties. *Journal of Child Psychology and Psychiatry, 45*(3), 631–640. https://doi.org/10.1111/j.1469-7610.2004.00252.x

Carson, K., Boustead, T., & Gillon, G. (2015). Content validity to support the use of a computer-based phonological awareness screening and monitoring assessment (Com-PASMA) in the classroom. *International Journal of Speech-Language Pathology, 17*(5), 500–510. https://doi.org/10.3109/17549507.2015.1016107

Castles, A., Holmes, V.M., Neath, J. & Kinoshita, S. (2003). How does orthographic knowledge influence performance on phonological awareness tasks? *The Quarterly Journal of Experimental Psychology, 56A* (3), 445–467. https://doi.org/10.1080/02724980244000486

Castles, A., Wilson, K., & Coltheart, M. (2011). Early orthographic influences on phonemic awareness tasks: Evidence from a preschool training study. *Journal of Experimental Child Psychology, 108*(1), 203-210. https://doi.org/10.1016/j.jecp.2010.07.006

Catts, H. W., Adlof, S. M., Hogan, T. P., & Weismer, S. E. (2005). Are specific language impairment and dyslexia distinct disorders? *Journal of Speech, Language, and Hearing Research, 48,* 1378–1396. https://doi.org/10.1044/1092-4388(2005/096)

Catts, H.W., Adlof, S.M. & Weismer, S.E. (2006). Language deficits in poor comprehenders: A case for the simple view of reading. *Journal of Speech, Language, and Hearing Research, 49*, 278-293. https://doi.org/10.1044/1092-4388(2006/023)

Catts, H. W., McIlraith, A., Bridges, M. S., & Nielsen, D. C. (2017). Viewing a phonological deficit within a multifactorial model of dyslexia. *Reading and writing*, *30*(3), 613-629. https://doi.org/10.1007/s11145-016-9692-2

Cunningham, A. E., & Stanovich, K. E. (1990). Assessing print exposure and orthographic processing skill in children: A quick measure of reading experience. *Journal of Educational Psychology*, *82*(4), 733. https://doi.org/10.1037/0022-0663.82.4.733

Cunningham, A. E., & Stanovich, K. E. (1991). Tracking the unique effects of print exposure in children: Associations with vocabulary, general knowledge, and spelling. *Journal of Educational Psychology, 83*(2), 264–274. https://doi.org/10.1037/0022-0663.83.2.264

Dunn, D. M. (2019). *Peabody Picture Vocabulary Test (5th ed.)* [Measurement instrument]. Pearson.

Eadie, P., Morgan, A., Ukoumunne, O. C., Ttofari Eecen, K., Wake, M., & Reilly, S. (2015). Speech sound disorder at 4 years: Prevalence, comorbidities, and predictors in a community cohort of children. *Developmental Medicine & Child Neurology*, *57*(6), 578-584. https://doi.org/10.1111/dmcn.12635

Ehrhorn, A.M. & Adlof, S.M. (2021, November 18). *11046: Measuring Foundational Literacy Skills in Children with Speech Sound Disorder: A Scoping Review*. Poster presentation presented for at the Annual Convention of the American Speech-Language-Hearing Association, Washington, D.C., United States.

Ehrhorn, A. M., Adlof, S. M., Fogerty, D., & Laing, S. (2021). Probing phonological processing differences in nonword repetition for children with separate or co-occurring dyslexia and developmental language disorder. *Scientific Studies of Reading*, *25*(6), 486-503. https://doi.org/10.1080/10888438.2020.1849223

Farquharson, K., Hogan, T. P., & Fox, A. B. (2021). Factors that influence non-word repetition performance in children with and without persistent speech sound disorders. *International Journal of Language & Communication Disorders*, *56*(6), 1218-1234. https://doi.org/10.1111/1460-6984.12663

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39,* 175–191. https://doi.org/10.3758/BF03193146

Fisher, E. (2019). Orthographic and phonological processing in beginning readers [Unpublished undergraduate thesis]. University of South Carolina.

Frith, U. (1998). Literally changing the brain. *Brain: A Journal of Neurology*, 121(6), 1011-1012. https://doi.org/10.1093/brain/121.6.1011

Gleason, J. B., & Ratner, N. B. (2009). *The development of language* (7th ed.). Boston, MA: Pearson.

Goldman, R., & Fristoe, M. (2015). *Goldman-Fristoe Test of Articulation 3 (GFTA-3)* [Measurement instrument]. Pearson.

Gordon-Brannan, M., & Hodson, B. W. (2000). Intelligibility/severity measurements of prekindergarten children's speech. *American Journal of Speech-Language Pathology*, *9*(2), 141-150. https://doi.org/10.1044/1058-0360.0902.141

Gray, S., Plante, E., Vance, R., & Henrichsen, M. (1999). The diagnostic accuracy of four vocabulary tests administered to preschool-age children. *Language, Speech, and Hearing Services in Schools*, *30*(2), 196-206. https://doi.org/10.1044/0161-1461.3002.196

Hayiou-Thomas, M. E., Carroll, J. M., Leavett, R., Hulme, C., & Snowling, M. J. (2017). When does speech sound disorder matter for literacy? The role of disordered speech errors, co-occurring language impairment and family risk of dyslexia. *Journal of Child Psychology & Psychiatry & Allied Disciplines, 58*(2), 197–205. http://10.0.4.87/jcpp.12648

Hesketh, A., Adams, C., & Nightingale, C. (2000). Metaphonological abilities of phonologically disordered children. *Educational Psychology: An International Journal of Experimental Educational Psychology, 20*(4), 483–498. https://doi.org/10.1080/713663751

Jevtović, M., Antzaka, A., & Martin, C. D. (2022). Gepo with a G, or Jepo with a J? Skilled Readers Generate Orthographic Expectations for Novel Spoken Words Even When Spelling is Uncertain. *Cognitive Science*, *46*(3), e13118. https://doi.org/10.1111/cogs.13118

Jin, F., Schjølberg, S., Eadie, P., Nes, R. B., & Røysamb, E. (2020). Preschool Speech Intelligibility and 8-Year Literacy: A Moderated Mediation Analysis. *Journal of Speech, Language, and Hearing Research*, *63*(10), 3380-3391. https://doi.org/10.1044/2020_JSLHR-19-00394

Landerl, K., Frith, U., & Wimmer, H. (1996). Intrusion of orthographic knowledge on phoneme awareness: Strong in normal readers, weak in dyslexic readers. *Applied psycholinguistics*, *17*(1), 1-14. http://dx.doi.org/10.1017/S0142716400009437

Leitao, S., Hogben, J., & Fletcher, J. (1997). Phonological processing skills in speech and language impaired children. European Journal of Disorders of Communication, 32(2), 91–111. http://dx.doi.org/10.1111/j.1460-6984.1997. tb01626.x

Lewis, B. A., Avrich, A. A., Freebairn, L. A., Hansen, A. J., Sucheston, L. E., Kuo, I., Taylor, H. G., Iyengar, S. K., & Stein, C. M. (2011). Literacy outcomes of children with early childhood speech sound disorders: impact of endophenotypes. *Journal of Speech, Language & Hearing Research, 54*(6), 1628–1643. http://10.0.4.20/1092-4388(2011/10-0124)

Lewis, B. A., Freebairn, L., Tag, J., Benchek, P., Morris, N. J., Iyengar, S. K., Gerry Taylor, H., & Stein, C. M. (2018). Heritability and longitudinal outcomes of spelling skills in individuals with histories of early speech and language disorders. *Learning & Individual Differences, 65*, 1–11. http://10.0.3.248/j.lindif.2018.05.001

Lewis, B.A., Freebairn, L.A., & Taylor, H.G. (2000). Academic outcomes in children with histories of speech sound disorders. *Journal of Communication Disorders, 33*(1), 11-30. https://doi.org/10.1016/S0021-9924(99)00023-4

Lyon, G. R., Shaywitz, S. E., & Shaywitz, B. A. (2003). A definition of dyslexia. *Annals of dyslexia*, *53*(1), 1-14. https://doi.org/10.1007/s11881-003-0001-9

Mari, G., Picciotti, P. M., Martina, B. M., Loperfido, A., Zagari, F., Proietti, I., ... & D'Alatri, L. (2022). Speech perception in noise in children with dyslexia: Does speech sound disorder matter?. *Dyslexia*, *28*(2), 202-211. https://doi.org/10.1002/dys.1710

Martikainen, A. L., Savinainen-Makkonen, T., & Kunnari, S. (2021). Speech inconsistency and its association with speech production, phonological awareness and nonword repetition skills. *Clinical Linguistics & Phonetics*, *35*(8), 743-760. https://doi.org/10.1080/02699206.2020.1827296

Masso, S., Baker, E., McLeod, S., & Wang, C. (2017). Polysyllable speech accuracy and predictors of later literacy development in preschool children with speech sound disorders. *Journal of Speech, Language, and Hearing Research*, *60*(7), 1877-1890. https://doi.org/10.1044/2017_JSLHR-S-16-0171

Masterson, J. J., & Apel, K. (2010). The spelling sensitivity score: Noting developmental changes in spelling knowledge. *Assessment for Effective Intervention*, *36*(1), 35-45. https://doi.org/10.1177/1534508410380039

McNeill, B. C., Wolter, J., & Gillon, G. T. (2017). A comparison of the metalinguistic performance and spelling development of children with inconsistent speech sound disorder and their age-matched and reading-matched peers. *American Journal of Speech-Language Pathology, 26*(2), 456–468. http://10.0.4.20/2016_AJSLP-16-0085

McWeeny, S., Choi, S., Choe, J., LaTourrette, A., Roberts, M. Y., & Norton, E. S. (2022). Rapid Automatized Naming (RAN) as a Kindergarten Predictor of Future Reading in English: A Systematic Review and Meta-analysis. *Reading Research Quarterly*. https://doi.org/10.1002/rrq.467

Medler, D.A., & Binder, J.R. (2005). MCWord: An On-Line Orthographic Database of the English Language. http://www.neuro.mcw.edu/mcword/

Miller, J. & Iglesias, A. (2012). Systematic Analysis of Language Transcripts (SALT), Research Version 2012 [Computer Software]. Middleton, WI: SALT Software, LLC.

Miller, G. J., & Lewis, B. A. (2022). Reading Skills in Children With Suspected Childhood Apraxia of Speech and Children With Reading Disorders: Same or Different?. *Language, Speech, and Hearing Services in Schools*, *53*(4), 985-1005. https://doi.org/10.1044/2022_LSHSS-21-00149

Moe, A. J., Hopkins, C. J., & Rush, R. T. (1982). *The vocabulary of first-grade children*. Charles C Thomas Pub Limited.

Milledge, S. V., Liversedge, S. P., & Blythe, H. I. (2022). The importance of the first letter in children's parafoveal preprocessing in English: Is it phonologically or orthographically driven? *Journal of Experimental Psychology. Human Perception and Performance*, *48*(5), 427–442. https://doi.org/10.1037/xhp0000998

Nathan, L., Stackhouse, J., Goulandris, N., & Snowling, M. J. (2004). The Development of Early Literacy Skills Among Children With Speech Difficulties: A Test of the "Critical Age Hypothesis." Journal of Speech, Language, and Hearing Research, 47(2), 377–391. https://doi.org/10.1044/1092-4388(2004/031)

Nation, K., & Castles, A. (2017). Putting the learning into orthographic learning. *Theories of reading development*, *15*, 147-168. https://doi.org/10.1075/swll.15.09nat

Pennington, B. F., & Lefly, D. L. (2001). Early reading development in children at family risk for dyslexia. *Child development*, *72*(3), 816-833. https://doi.org/10.1111/1467-8624.00317

Pennington, B. F. (2006). From single to multiple deficit models of developmental disorders. Cognition, 101(2), 385–413. https://doi.org/10.1016/j.cognition.2006.04.008

Pennington, B. F., & Lefly, D. L. (2001). Early reading development in children at family risk for dyslexia. Child Development, 72(3), 816–833. https://doi.org/10.1111/1467-8624.00317

Pennington, B. F., Santerre-Lemmon, L., Rosenberg, J., MacDonald, B., Boada, R., Friend, A., ... & Olson, R. K. (2012). Individual prediction of dyslexia by single versus multiple deficit models. Journal of abnormal psychology, 121(1), 212. https://doi.org/10.1037/a0025823

Peterson, R. L., Pennington, B. F., Shriberg, L. D., & Boada, R. (2009). What influences literacy outcome in children with speech sound disorder? *Journal of Speech, Language & Hearing Research, 52*(5), 1175–1188. http://10.0.4.20/1092-4388(2009/08-0024)

Robert F. Port (2010) Language as a Social Institution: Why Phonemes and Words Do Not Live in the Brain, *Ecological Psychology*, *22*(4), 304-326. https://doi.org/10.1080/10407413.2010.517122

Preston, J. L., & Edwards, M. L. (2007). Phonological processing skills of adolescents with residual speech sound errors. *Language, Speech & Hearing Services in Schools, 38*(4), 297–308. http://10.0.4.20/0161-1461(2007/032)

Preston, J., & Edwards, M.L. (2010). Phonological awareness and types of sound errors in preschoolers with speech sound disorders. *Journal of Speech, Language & Hearing Research, 53*(1), 44–60. http://10.0.4.20/1092-4388(2009/09-0021)

Rayner, K., Pollatsek, A., Ashby, J., & Clifton Jr, C. (2012). *Psychology of reading* (2nd ed.) Taylor and Francis Group. https://doi.org/10.4324/9780203155158

Raitano, N. A., Pennington, B. F., Tunick, R. A., Boada, R., & Shriberg, L. D. (2004). Pre-literacy skills of subgroups of children with speech sound disorders. *Journal of Child Psychology & Psychiatry, 45*(4), 821–835. http://10.0.4.87/j.1469-7610.2004.00275.x

Roepke, E., & Brosseau-Lapré, F. (2019). Perception of sibilants by preschool children with overt and covert sound contrasts. *Journal of Speech, Language, and Hearing Research*, *62*(10), 3763-3770. https://doi.org/10.1044/2019_JSLHR-S-19-0127

Rvachew, S., Ohberg, A., Grawburg, M., & Heyding, J. (2003). Phonological awareness and phonemic perception in 4-year-old children with delayed expressive phonology skills. *American Journal of Speech-Language Pathology, 12*, 463-471. https://doi.org/10.1044/1058-0360(2003/092)

Schuele, C. M. (2004). The impact of developmental speech and language impairments on the acquisition of literacy skills. *Mental retardation and developmental disabilities research reviews*, *10*(3), 176-183. https://doi.org/10.1002/mrdd.20014

Seidenberg, M. S. (2005). Connectionist models of word reading. *Current directions in psychological science*, *14*(5), 238-242. https://doi.org/10.1111/j.0963-7214.2005.00372.x

Seidenberg, M. S., & Tanenhaus, M. K. (1979). Orthographic effects on rhyme monitoring. *Journal of Experimental Psychology: Human Learning and Memory*, *5*(6), 546. https://doi.org/10.1037/0278-7393.5.6.546

Share, D. L. (1995). Phonological recoding and self-teaching: Sine qua non of reading acquisition. *Cognition*, *55*(2), 151-218. https://doi.org/10.1016/0010-0277(94)00645-2

Share, D. L. (1999). Phonological recoding and orthographic learning: A direct test of the self-teaching hypothesis. *Journal of experimental child psychology*, *72*(2), 95-129. https://doi.org/10.1006/jecp.1998.2481

Share, D. L. (2004). Orthographic learning at a glance: On the time course and developmental onset of self-teaching. *Journal of experimental child psychology*, *87*(4), 267-298. https://doi.org/10.1016/j.jecp.2004.01.001

Shriberg, L. D., Austin, D., Lewis, B. A., McSweeny, J. L., & Wilson, D. L. (1997). The percentage of consonants correct (PCC) metric: Extensions and reliability data. *Journal of Speech, Language, and Hearing Research*, *40*(4), 708-722. https://doi.org/10.1044/jslhr.4004.708

Shriberg, L. D., Fourakis, M., Hall, S. D., Karlsson, H. B., Lohmeier, H. L., McSweeny, J. L., ... & Wilson, D. L. (2010). Extensions to the speech disorders classification system (SDCS). *Clinical linguistics & phonetics*, *24*(10), 795-824. https://doi.org/10.3109/02699206.2010.503006

Shriberg, L. D., & Kwiatkowski, J. (1982). Phonological disorders III: A procedure for assessing severity of involvement. *Journal of Speech and Hearing Disorders*, *47*(3), 256-270. https://doi.org/10.1044/jshd.4703.256

Shriberg, L. D., & Kwiatkowski, J. (1985). Continuous speech sampling for phonologic analyses of speech-delayed children. *Journal of Speech and Hearing Disorders*, *50*(4), 323-334. https://doi.org/10.1044/jshd.5004.323

Skebo, C. M., Lewis, B. A., Freebairn, L. A., Tag, J., Ciesla, A. A., Stein, C. M., Nippold, M., & Marinellie, S. (2013). Reading skills of students with speech sound disorders at three stages of literacy development. *Language, Speech & Hearing Services in Schools, 44*(4), 360–373. http://10.0.4.20/0161-1461(2013/12-0015)

Snowling, M. J., Hulme, C., & Nation, K. (2020). Defining and understanding dyslexia: past, present and future. *Oxford Review of Education*, *46*(4), 501-513. https://doi.org/10.1080/03054985.2020.1765756

Stanislaw, H. & Todorov, N. (1999). Calculation of signal detection theory measures. *Behavior Research Methods, Instruments, & Computers, 31*(1), 137-149. https://doi.org/10.3758/BF03207704

Sutherland, D., & Gillon, G. T. (2007). Development of phonological representations and phonological awareness in children with speech impairment. *International Journal of Language & Communication Disorders, 42*(2), 229–250. https://doi/10.1080/13682820600806672

Tambyraja, S. R., Farquharson, K., & Justice, L. (2020). Reading risk in children with speech sound disorder: Prevalence, persistence, and predictors. *Journal of Speech, Language, and Hearing Research*, 63(11), 3714-3726. https://doi.org/10.1044/2020_JSLHR-20-00108

Tomblin, J. B., Records, N. L., Buckwalter, P., Zhang, X., Smith, E., & O'Brien, M. (1997). Prevalence of specific language impairment in kindergarten children. *Journal of speech, language, and hearing research*, *40*(6), 1245-1260. https://doi.org/10.1044/jslhr.4006.1245

Treiman, R., Pennington, B. F., Shriberg, L. D., & Boada, R. (2008). Which children benefit from letter names in learning letter sounds? *Cognition, 106*(3), 1322–1338. http://10.0.3.248/j.cognition.2007.06.006

Unicomb, R., Kefalianos, E., Reilly, S., Cook, F., & Morgan, A. (2020). Prevalence and features of comorbid stuttering and speech sound disorder at age 4 years. *Journal of communication disorders*, *84*, 105976. https://doi.org/10.1016/j.jcomdis.2020.105976

Vaden, K.I., Halpin, H.R., Hickok, G.S. (2009). Irvine Phonotactic Online Dictionary, Version 2.0. [Data file]. Available from http://www.iphod.com.

Van Bergen, E., De Jong, P. F., Regtvoort, A., Oort, F., Van Otterloo, S., & van der Leij, A. (2011). Dutch children at family risk of dyslexia: Precursors, reading development, and parental effects. *Dyslexia*, *17*(1), 2-18. https://doi.org/10.1002/dys.423

van der Leij, A., & van Daal, V. H. (1999). Automatization aspects of dyslexia: Speed limitations in word identification, sensitivity to increasing task demands, and orthographic compensation. *Journal of learning disabilities*, *32*(5), 417-428. https://doi.org/10.1177/002221949903200507

Wagner, R.K., Torgesen, J.K., Rashotte, C.A. & Pearson, N.A. (2013). *Comprehensive Test of Phonological Processing* (2nd ed.) [Measurement instrument]. Austin, TX: Pro-Ed.

Wang, H. C., Marinus, E., Nickels, L., & Castles, A. (2014). Tracking orthographic learning in children with different profiles of reading difficulty. *Frontiers in Human Neuroscience*, *8*, 468. https://doi.org/10.3389/fnhum.2014.00468

Wiig, E. H., Semel, E., & Secord, W. A. (2013). *Clinical Evaluation of Language Fundamentals* (5th ed.) [Measurement instrument]. Pearson.

Woodcock, R.W. (2011). *Woodcock Reading Mastery Tests* (3rd ed.) [Measurement instrument]. Pearson.

Wolter, J.A. & Apel, K. (2010). Initial acquisition of mental graphemic representations in children with language impairment. *Journal of Speech, Language, and Hearing Research, 53*(1), 179-195. https://doi.org/10.1044/1092-4388(2009/07-0130)

Wren, Y., Pagnamenta, E., Peters, T. J., Emond, A., Northstone, K., Miller, L. L., & Roulstone, S. (2021). Educational outcomes associated with persistent speech disorder. *International Journal of Language & Communication Disorders*, *56*(2), 299-312. https://doi.org/10.1111/1460-6984.12599

Zeno, S., Ivens, S. H., Millard, R. T., & Duvvuri, R. (1995). *The educator's word frequency guide*. Touchstone Applied Science Associates.

Ziegler, J. C., & Ferrand, L. (1998). Orthography shapes the perception of speech: The consistency effect in auditory word recognition. *Psychonomic Bulletin & Review*, *5*(4), 683-689. https://doi.org/10.3758/BF03208845

Appendix A

Supplementary Tables

Table A.1 *Experimental Phonological Awareness Task Stimuli by Condition and Final Phoneme/Grapheme Pattern Targeted*

A. Congruent-Consistent Condition Stimuli

Final Phoneme/Grapheme Pattern	Stimulus Word	Target Word	Foil 1 Word	Foil 2 Word	Foil 3 Word
n	chin	horn	nose	chop	ham
n	lion	moon	net	lake	swing
sh	fish	cash	shoe	fly	hoof
sh	brush	trash	shirt	brain	mud
v	give	move	van	goose	leaf
v	love	cave	vote	lake	knees
t	boat	colt	twig	bear	pond
t	suit	cast	tie	sky	sweep

Final Phoneme/Grapheme Pattern	Stimulus Word	Target Word	Foil 1 Word	Foil 2 Word	Foil 3 Word
th	bath	tooth	thorn	bush	goose
th	moth	earth	thumb	mail	glass
g	mug	tag	glue	maze	clock
g	dog	log	gift	desk	hand

B. Congruent-Inconsistent Condition Stimuli

Final Phoneme/Grapheme Pattern	Stimulus Word	Target Word	Foil 1 Word	Foil 2 Word	Foil 3 Word
tch	ditch	patch	chin	dog	dish
ch	beach	branch	chair	boat	edge
dge	judge	badge	jet	jail	dish
ge	cage	huge	jeans	coin	patch
gh	cough	laugh	fan	clip	teeth
ff	sniff	cuff	face	snow	glove
ce	juice	space	sand	junk	rose
ss	moss	glass	sun	milk	knife

Final Phoneme/Grapheme Pattern	Stimulus Word	Target Word	Foil 1 Word	Foil 2 Word	Foil 3 Word
ze	freeze	maze	zero	farm	class
se	nose	noise	zoo	neck	gas
x	six	box	skunk	suit	path
cks	bricks	clocks	skirt	bear	safe

C. Incongruent-Inconsistent Condition Stimuli

Final Phoneme/Grapheme Pattern	Stimulus Word	Target Word	Foil 1 Word	Foil 2 Word	Foil 3 Word
tch/ch	witch	beach	chain	wood	fridge
ch/tch	arch	watch	child	arm	ledge
dge/ge	fridge	cage	jug	face	porch
ge/dge	cage	ridge	jeep	camp	switch
gh/f	laugh	scarf	fish	lake	bath
ff/gh	cliff	rough	fence	creek	sloth
ce/ss	piece	cross	school	paint	cliff
ss/ce	grass	ice	snake	golf	elf

Final Phoneme/Grapheme Pattern	Stimulus Word	Target Word	Foil 1 Word	Foil 2 Word	Foil 3 Word
se/ze	cheese	prize	zoo	chips	grass
ze/se	sneeze	rose	zip	stone	floss
x/cks	ax	socks	skirt	ash	dirt
cks/x	blocks	fox	ski	bridge	seat

Note. Reminder that the children were to select the Word Heard/Picture Seen (Target Word, Foil 1, Foil 2, or Foil 3) that has the same final sound as the Stimulus Word. The targeted phoneme/grapheme pattern targeted is listed followed by the Stimulus Word, Target Word, and three Foils. Foil 1 words start with the same first sound as the Stimulus Word's final sound. It is illegal to start a word with /ks/ phonemes and no monosyllable words start with 'x' grapheme, so the phonemes were reversed with /ks/ to become /sk/. Foil 2 words have the 1st phoneme/grapheme same as the stimulus word's initial phoneme/grapheme except when the grapheme is illegal (e.g., 'tch' never appears in word initial position so 'ch' grapheme set was used). Foil 3 words have the final phoneme of foil vary from the Stimulus Word final phoneme by one feature (voice, manner, place). The selection of the phoneme /t/ occurred because /t/ and /s/ are different only in manner, and /t/ and /k/ are different only in place.

Table A.2 *Unstressed Neighborhood Density and Phonotactic Probabilities for the Experimental Phonological Awareness Task Stimuli for each Type of Stimuli by Condition*

A. Congruent-Consistent Condition Stimuli

	Neighborhood Density (Mean, SD)	Word-Average, Biphone Probability (Mean, SD)	Word-Average Positional Probability (Mean, SD)
Combined Stimuli	23.3167 (9.587)	0.00218 (0.002)	0.0447 (0.016)
Stimulus	22.0833 (8.857)	0.0029 (0.004)	0.0497 (0.018)
Target	22.1667 (7.542)	0.0018 (0.002)	0.0453 (0.023)
Foil1	24.000 (11.322)	0.0016 (0.001)	0.0382 (0.013)
Foil2	25.4167 (12.573)	0.0016 (0.001)	0.0445 (0.013)
Foil3	22.9167 (7.925)	0.0029 (0.002)	0.0458 (0.012)

B. Congruent-Inconsistent Condition Stimuli

	Neighborhood Density (Mean, SD)	Word-Average, Biphone Probability (Mean, SD)	Word-Average Positional Probability (Mean, SD)
Combined Stimuli	22.1167 (10.578)	0.0025 (0.003)	0.0450 (0.016)
Stimulus	22.5833 (9.709)	0.0021 (0.001)	0.0406 (0.012)
Target	18.8333 (10.268)	0.0020 (0.002)	0.0323 (0.010)
Foil1	24.2500 (12.248)	0.0046 (0.005)	0.0554 (0.020)
Foil2	21.5833 (9.848)	0.0020 (0.001)	0.0533 (0.011)
Foil3	23.3333 (11.602)	0.0020 (0.002)	0.0437 (0.015)

C. Incongruent-Inconsistent Condition Stimuli

	Neighborhood Density (Mean, SD)	Word-Average, Biphone Probability (Mean, SD)	Word-Average Positional Probability (Mean, SD)
Combined Stimuli	19.3167 (9.513)	0.0020 (0.001)	0.0418 (0.014)
Stimulus	19.3333 (9.838)	0.0019 (0.001)	0.0347 (0.014)
Target	22.9167 (11.790)	0.0017 (0.001)	0.036 (0.011)
Foil1	18.0833 (5.946)	0.0017 (0.001)	0.0456 (0.014)
Foil2	20.4167 (9.120)	0.0027 (0.002)	0.0462 (0.016)
Foil3	15.8333 (9.962)	0.0021 (0.001)	0.0459 (0.010)

Table A.3 *Phoneme-Grapheme Correspondence Task Stimuli by Trial Condition and Orton-Gillingham Instructional Level*

Item Phoneme Presented	Item Grapheme Presented	Item Orton-Gillingham Instructional Level	Item Condition
/g/	pp	I	FALSE
/s/	sh	I	FALSE
/w/	th	I	FALSE
/t/	ng	I	FALSE
/@/	ay	I	FALSE
/i/	a	I	FALSE
/Y/	oi	I	FALSE
/x/	u	I	FALSE
/a/	c	II	FALSE
/z/	gh	II	FALSE
/n/	ge	II	FALSE
/b/	ph	II	FALSE

Item Phoneme Presented	Item Grapheme Presented	Item Orton-Gillingham Instructional Level	Item Condition
/z/	wr	II	FALSE
/W/	y	II	FALSE
/R/	our	II	FALSE
/e/	ere	II	FALSE
/I/	ey	III	FALSE
/a/	ough	III	FALSE
/Ir/	uy	III	FALSE
/d/	ough	III	FALSE
/^/	oo	III	FALSE
/p/	ue	III	FALSE
/Er/	ough	III	FALSE
/W/	ow	III	FALSE
/C/	tch	I	TRUE

Item Phoneme Presented	Item Grapheme Presented	Item Orton-Gillingham Instructional Level	Item Condition
/s/	c	I	TRUE
/n/	nn	I	TRUE
/w/	wh	I	TRUE
/j/	y	I	TRUE
/@/	a	I	TRUE
/O/	oy	I	TRUE
/^/	a	I	TRUE
/k/	ch	II	TRUE
/g/	gh	II	TRUE
/Z/	ge	II	TRUE
/f/	ph	II	TRUE
/v/	ve	II	TRUE
/Y/	y	II	TRUE

Item Phoneme Presented	Item Grapheme Presented	Item Orton-Gillingham Instructional Level	Item Condition
/o/	o	II	TRUE
/R/	er	II	TRUE
/g/	gu	III	TRUE
/Z/	s	III	TRUE
/e/	eigh	III	TRUE
/u/	ieu	III	TRUE
/Y/	uy	III	TRUE
/c/	au	III	TRUE
/o/	owe	III	TRUE
/u/	oo	III	TRUE

Note. The phoneme presented is transcribed in Klattese. See [http://www.people.ku.edu/~mvitevit/Klatt_IPA.pdf] for translation to International Phonetic Alphabet (IPA) transcription.

Table A.4 *Orthographic Pattern Knowledge Task Stimuli by Set of Items*

Stimuli in HI Items		Stimuli in LI Items		Stimuli in HL Items	
High	Illegal	Low	Illegal	High	Low
tind	vpyf	miri	ogdb	eash	anar
nins	efpi	chea	ntui	cout	atar
hent	otha	sero	imfa	hing	roco
abes	alyi	cher	vpyf	dest	owis
tost	ecdx	mesu	ngha	eare	sero
bing	isho	ponc	ospg	tive	tlit
surs	ithi	aper	isho	tind	agen
dest	uggo	anar	efpi	hean	mesu
nent	atwa	chou	nwbo	hert	cheg
rean	nsba	cheg	cthi	tost	miri
wive	nwbo	eari	imbo	nees	alar
ming	imfa	oury	alyi	nins	anit

Stimuli in HI Items		Stimuli in LI Items		Stimuli in HL Items	
High	Illegal	Low	Illegal	High	Low
heer	rsdi	touf	utha	surs	cher
cout	emwa	roco	ecdx	wive	arat
tive	uspo	anit	uspo	dend	sman
hite	uchr	owis	dsgu	hite	gros
hert	ndyo	trou	owha	aile	eari
eare	dsgu	sman	ndyo	mant	chou
dend	ngha	tlit	ithi	deak	oury
tose	iwyf	arat	atwa	tose	trou
pode	imbo	agen	rbpw	pode	aper
nees	utha	orat	ibgp	nent	chea
deak	ospg	dedo	uchr	ming	orat
mant	ogdb	gros	nmba	diss	ponc
diss	rbpw	atar	uggo	abes	dedo

Stimuli in HI Items		Stimuli in LI Items		Stimuli in HL Items	
High	Illegal	Low	Illegal	High	Low
aile	ntui	alar	nsba		
eash	cthi				
hean	nmba				
hing	owha				
rean	tnot				

Note. The total number of trials differed between the three sets of items: High Probability versus Illegal (HI) = 30 trials, Low Probability versus Illegal (LI) = 26 trials, and High Probability versus Low Probability (HL) = 25 trials.

Table A.5 *Orthographic Properties for the Orthographic Pattern Knowledge Task Stimuli*

	Orthographic Neighborhood (Coltheart's N)	Frequency of Orthographic Neighbors	Frequency of Constrained Unigrams per Wordform (per million)	Count of Shared Constrained Unigrams among Wordforms
Combined Stimuli	5.72 (5.59)	23.76 (41.23)	10101.49 (7156.58)	144.45 (82.54)
High Probability Stimuli	13.17 (1.289)	62.70 (52.63)	16656.90 (43.90)	231.80 (34.77)
Low Probability Stimuli	4.00 (0.00)	8.58 (7.41)	12214.87 (3312.83)	157.21 (33.78)
Illegal Probability Stimuli	0.00 (0.00)	0.00 (0.00)	1432.71 (344.37)	44.35 (11.51)

Note. Orthographic properties were gathered from the MCWord database (Medler & Binder, 2005).

Appendix B
Residual Plots to Analyze Assumptions for each Regression Model

Nine plots are presented to examine the residuals for each regression model to determine if all four assumptions were met: 1) Linearity, 2) Normality, 3) Independence, and 4) Homoscedasticity (Equal Variance). Linearity was examined through the Residual Plot and the Response vs Predicted Plot. Normality was determined through examination of Q-Q Plot, Histogram, and Boxplot. Independence was examined using the Index Plot and Boxplot. Heteroscedasticity was examined using the Location-Scale Plot. Additionally, examination occurred to determine the presence of any erroneous outliers. The examination of the Residual-Leverage Plot and COOK's D Plot identified outliers and if any were suspected to significantly influence the regression results. Figures B.1 through B.12 contain the plots and a detailed description of each assumption. See the next page to determine whether assumptions were met for each regression model.

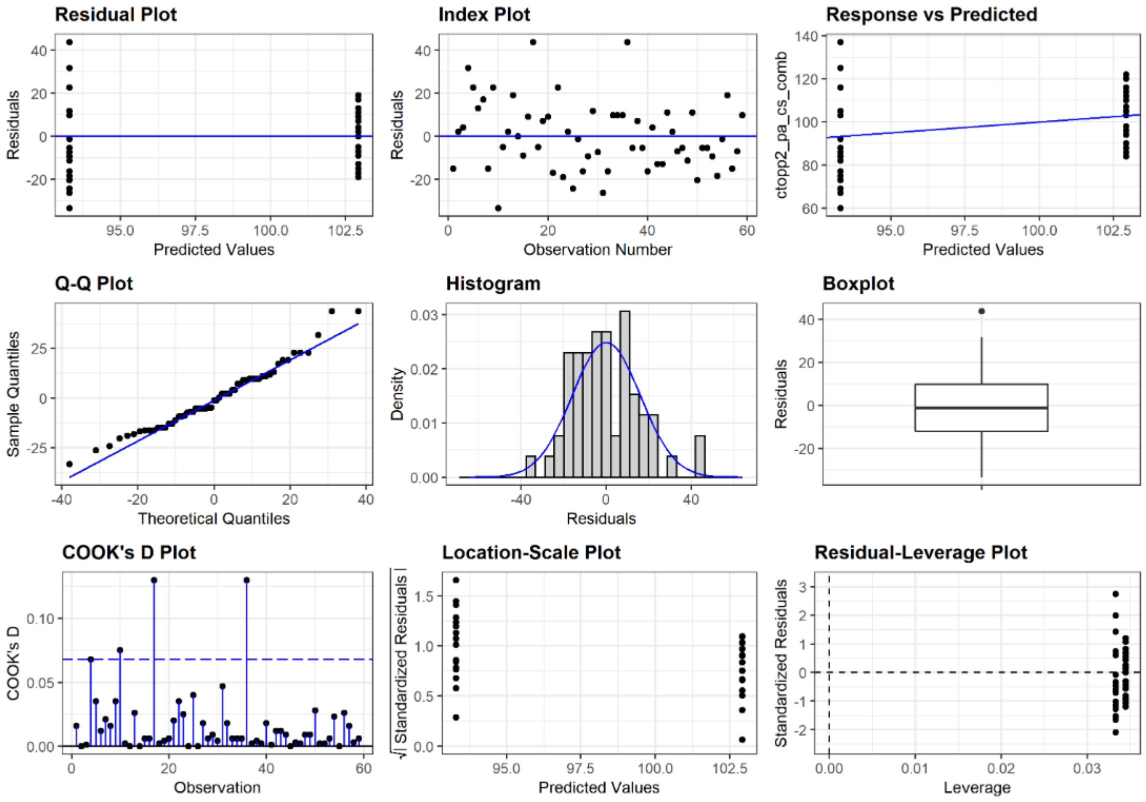

Figure B.1 *Residual Plots for the Simple Regression Model examining CTOPP-2 Phonological Awareness Composite Score by Group*

Note. All assumptions were met to interpret the simple regression model examining the CTOPP-2 PA composite score by group. The nature of the data within the model (i.e., discrete values and only a categorical predictor included) explained the vertical lines of predicted values and suspected outlier points in multiple plots. Examination of the Residual Plot and the Response vs Predicted Plot indicated a non-linear relationship occurred between the predictors (group and condition) and CTOPP-2 PA composite scores. Residuals were determined to be normally distributed through the examination of Q-Q Plot, Histogram, and Boxplot with the tails becoming less normal. Interpretation of more extreme values should be done cautiously when extrapolating using this sample data. The slight stairstep increments were explained by the discrete values possible within the data. The Index Plot and Boxplot examination indicated independence of residuals. No violation of heteroscedasticity was found through the evaluation of the Location-Scale Plot with data limitations noted. The examination of the COOK's D Plot identified three points above the horizontal cutoff line, but none were determined to be erroneous outliers as no points crossed a COOK's D contour line (a red dashed line would appear if close) in the Residual-Leverage Plot. No exclusion of data occurred.

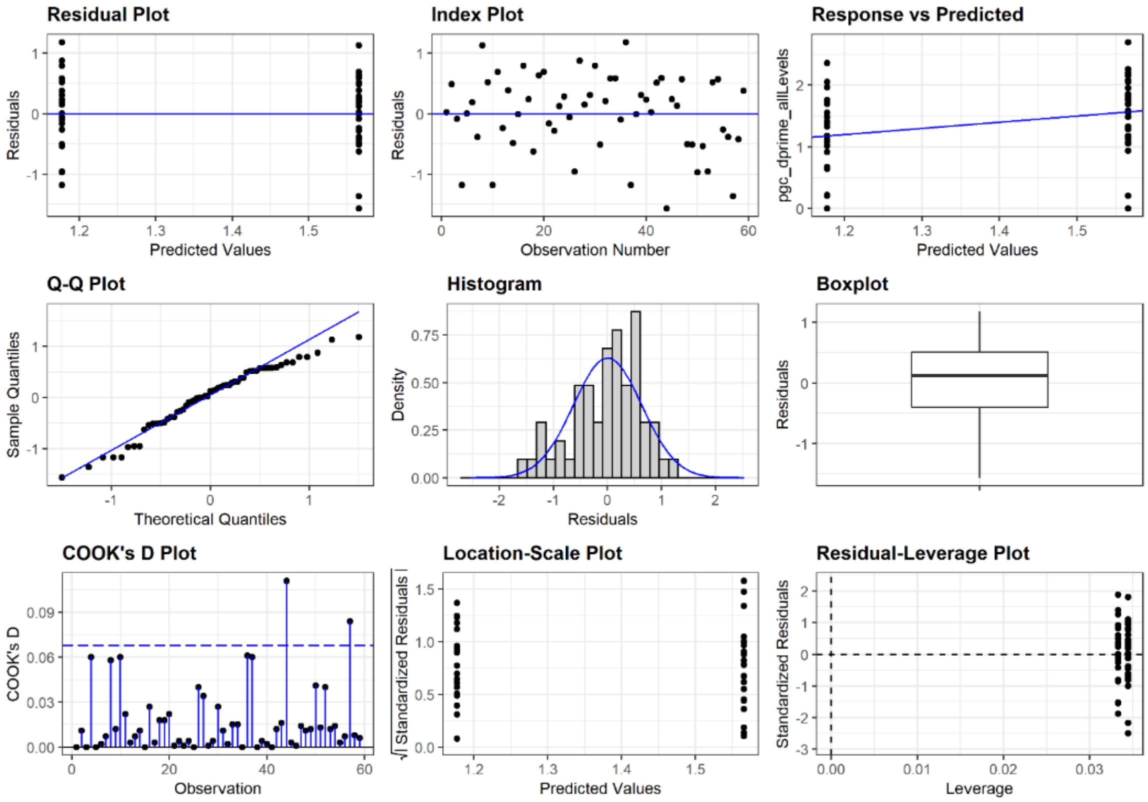

Figure B.2 *Residual Plots for the Simple Regression Model examining Phoneme-Grapheme Correspondence D-Prime Score by Group*

Note. All assumptions were met to interpret the simple regression model examining the phoneme-grapheme correspondence d-prime score by group. The nature of the data within the model (i.e., discrete values and only a categorical predictor included) explained the vertical lines of predicted values and suspected outlier points in multiple plots. Examination of the Residual Plot and the Response vs Predicted Plot indicated a non-linear relationship occurred between the predictors (group and condition) and phoneme-grapheme correspondence d-prime score. Residuals were determined to be normally distributed through the examination of Q-Q Plot, Histogram, and Boxplot with the tails becoming less normal. Interpretation of more extreme values should be done cautiously when extrapolating using this sample data. The slight stairstep increments were explained by the discrete values possible within the data. The Index Plot and Boxplot examination indicated independence of residuals. No violation of heteroscedasticity was found through the evaluation of the Location-Scale Plot with data limitations noted. The examination of the COOK’s D Plot identified two points above the horizontal cutoff line, but none were determined to be erroneous outliers as no points crossed a COOK’s D contour line (a red dashed line would appear if close) in the Residual-Leverage Plot. No additional exclusion of data occurred.

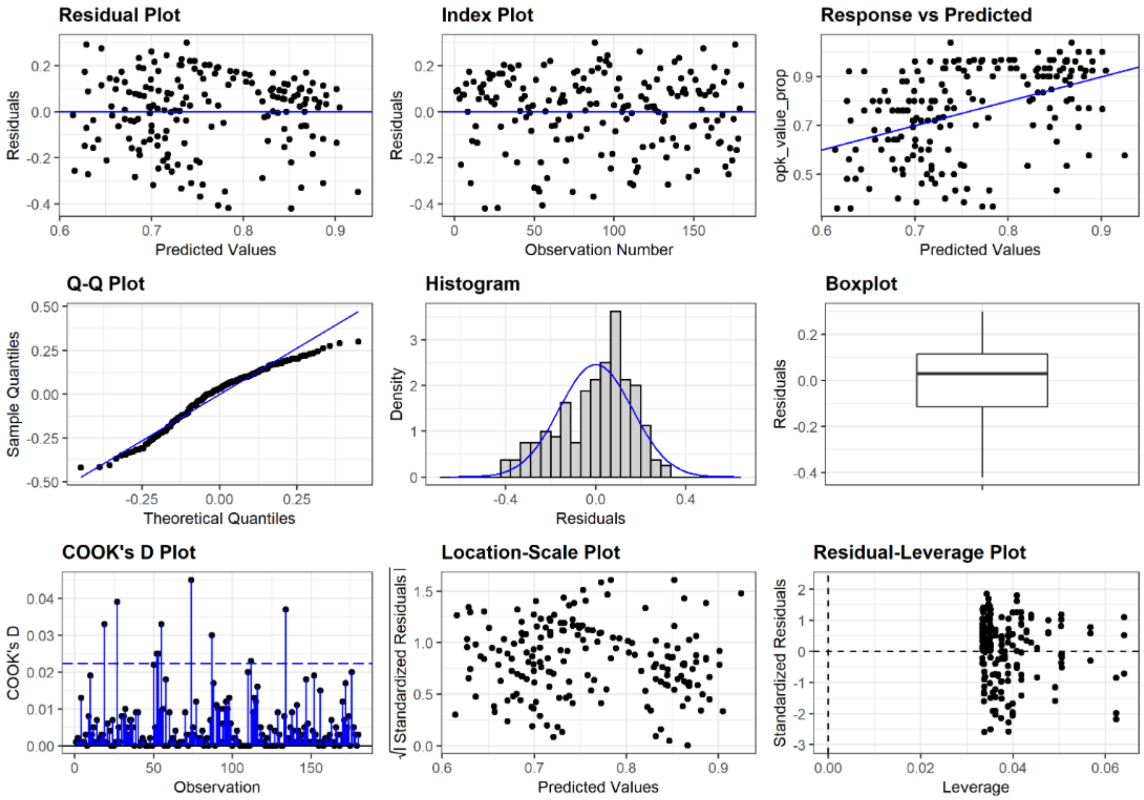

Figure B.3 *Residual Plots for the Multiple Regression Model examining Orthographic Pattern Knowledge Proportion Accurate by Group and Condition*

Note. All assumptions were met to interpret the multiple regression model examining the orthographic pattern knowledge proportion accurate by group and condition. Examination of the Residual Plot and the Response vs Predicted Plot indicated a non-linear relationship occurred between the predictors (group and condition) and orthographic pattern knowledge proportion accurate. The approximate blue line though indicates that there is some relationship occurring, but this is only approximate and not the best line. Residuals were determined to be normally distributed through the examination of Q-Q Plot, Histogram, and Boxplot with the tails becoming less normal. Interpretation of more extreme values should be done cautiously when extrapolating using this sample data. The Index Plot and Boxplot examination indicated independence of residuals. No violation of heteroscedasticity was found through evaluation of the Location-Scale Plot. The examination of the COOK's D Plot identified eight points above the horizontal cutoff line, but none were determined to be erroneous outliers as no points crossed a COOK's D contour line (a red dashed line would appear if close) in the Residual-Leverage Plot. No exclusion of data occurred.

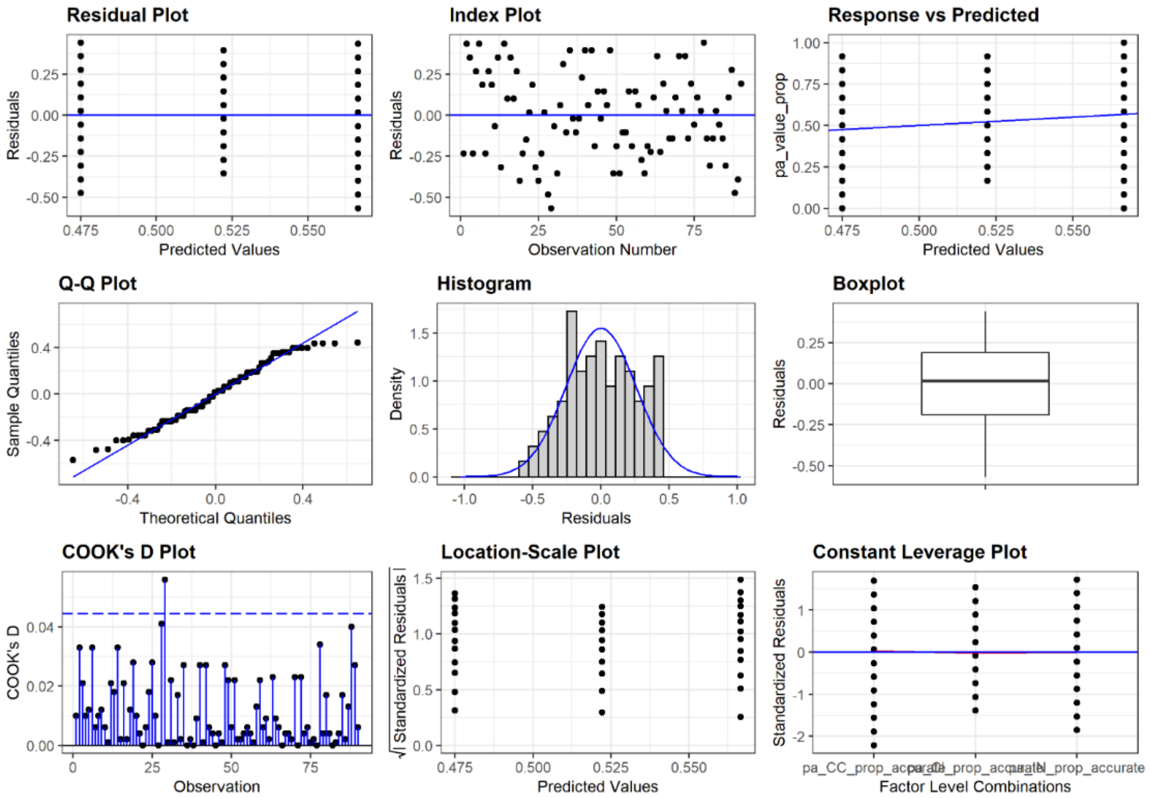

Figure B.4 *Residual Plots for the Simple Regression Model examining SSD Experimental Phonological Awareness Proportion Accurate by Condition*

Note. All assumptions were met to interpret the simple regression model examining the experimental phonological awareness proportion accurate by condition for the TSD group. The nature of the data within the model (i.e., discrete values and only a categorical predictor included) explained the vertical lines of predicted values and factor level combinations in multiple plots. Examination of the Residual Plot and the Response vs Predicted Plot indicated a non-linear relationship occurred between the predictors (group and condition) and phonological awareness proportion accurate. Residuals were determined to be normally distributed examination of Q-Q Plot, Histogram, and Boxplot with the tails becoming less normal.

Interpretation of more extreme values should be done cautiously when extrapolating using this sample data. The stairstep increments were explained by the discrete values possible within the data. The Index Plot and Boxplot examination indicated independence of residuals. No violation of heteroscedasticity was found through the evaluation of the Location-Scale Plot. The examination of the COOK's D Plot identified one point above the horizontal cutoff line, but none were determined to be erroneous outliers as no points crossed a COOK's D contour line (a red dashed line would appear if close) in the Residual-Leverage Plot. No data exclusion occurred.

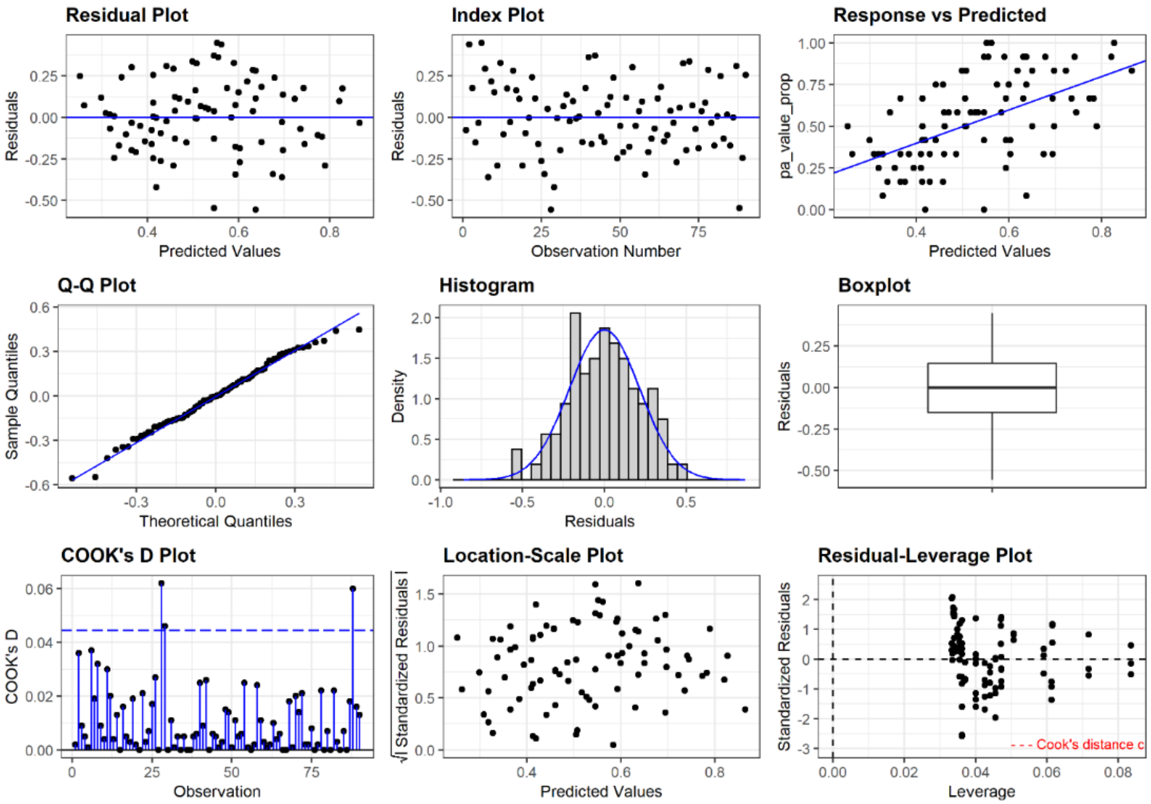

Figure B.5 *Residual Plots for the Multiple Regression Model examining SSD Experimental Phonological Awareness Proportion Accurate by Condition while controlling Oral Language Ability*

Note. All assumptions were met to interpret the multiple regression model examining the experimental phonological awareness proportion accurate by condition for the SSD group while controlling oral language ability. The nature of the data within the model (i.e., discrete values and a categorical predictor included) explained the vertical lines of predicted values and suspected outlier points in multiple plots. Examination of the Residual Plot and the Response vs Predicted Plot indicated a non-linear relationship occurred between the predictors (group and condition) and phonological awareness proportion accurate. The approximate blue line though indicates that there is some relationship occurring. If the line was taken away, it does not seem to be as strong as indicated in the blue line. Residuals were determined to be normally distributed through the examination of Q-Q Plot, Histogram, and Boxplot with the tails becoming less normal. Interpretation of more extreme values should be done cautiously when extrapolating using this sample data. The slight stairstep increments were explained by the discrete values possible within the data. The Index Plot and Boxplot examination indicated independence of residuals. No violation of heteroscedasticity was found through evaluation of the Location-Scale Plot. The examination of the COOK's D Plot identified three points above the horizontal cutoff line, but none were determined to be erroneous outliers as no points crossed a COOK's D contour line (a red dashed line would appear if close) in the Residual-Leverage Plot. No exclusion of data occurred.

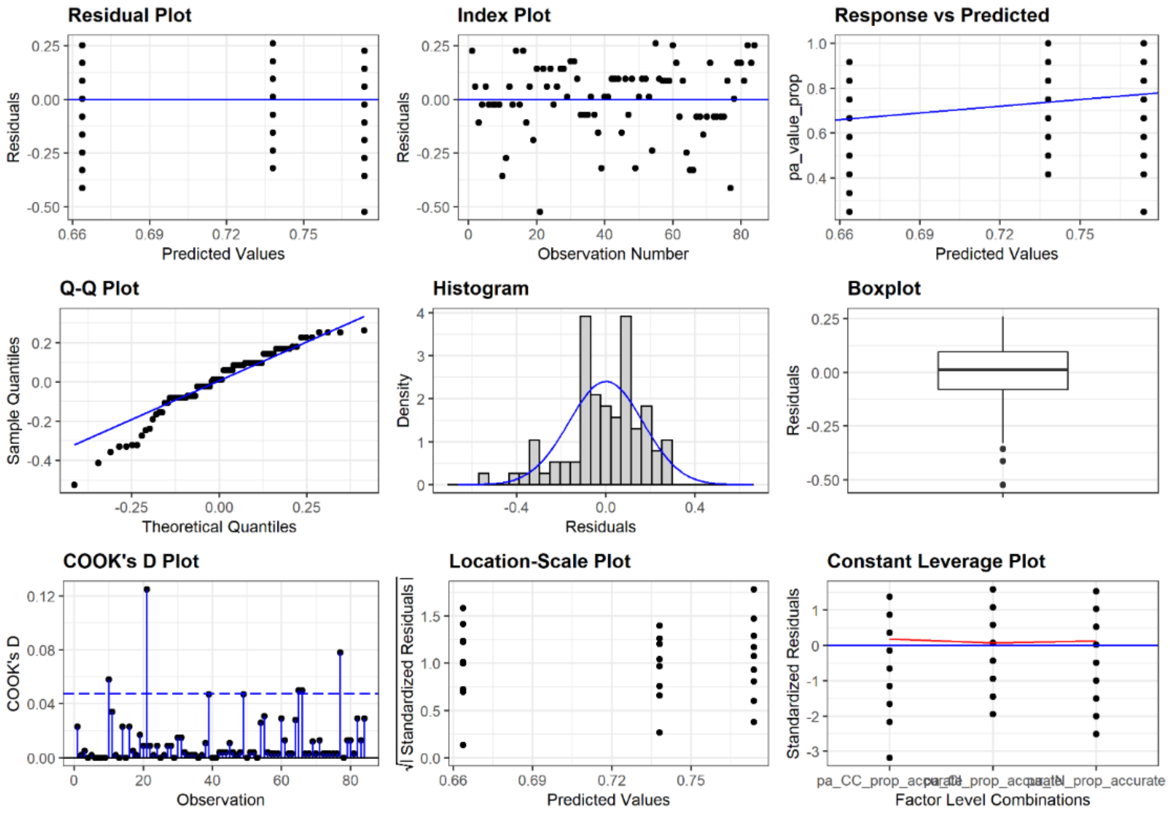

Figure B.6 *Residual Plots for the Simple Regression Model examining TSD Experimental Phonological Awareness Proportion Accurate by Condition*

Note. All assumptions were met to interpret the simple regression model examining the experimental phonological awareness proportion accurate by condition for the TSD group. The nature of the data within the model (i.e., discrete values and only a categorical predictor included) explained the vertical lines of predicted values and factor level combinations in multiple plots. Examination of the Residual Plot and the Response vs Predicted Plot indicated a non-linear relationship occurred between the predictors (group and condition) and phonological awareness proportion accurate. Residuals were determined to be normally distributed through the examination of Q-Q Plot, Histogram, and Boxplot with the tails becoming less normal. Interpretation of more extreme values should be done cautiously when extrapolating using this sample data. The stairstep increments were explained by the discrete values possible within the data. The Index Plot and Boxplot examination indicated independence of residuals. No violation of heteroscedasticity was found through the evaluation of the Location-Scale Plot. The examination of the COOK’s D Plot identified five points above the horizontal cutoff line, but none were determined to be erroneous outliers as no points crossed a COOK’s D contour line (a red dashed line would appear if close) in the Residual-Leverage Plot. No exclusion of data occurred.

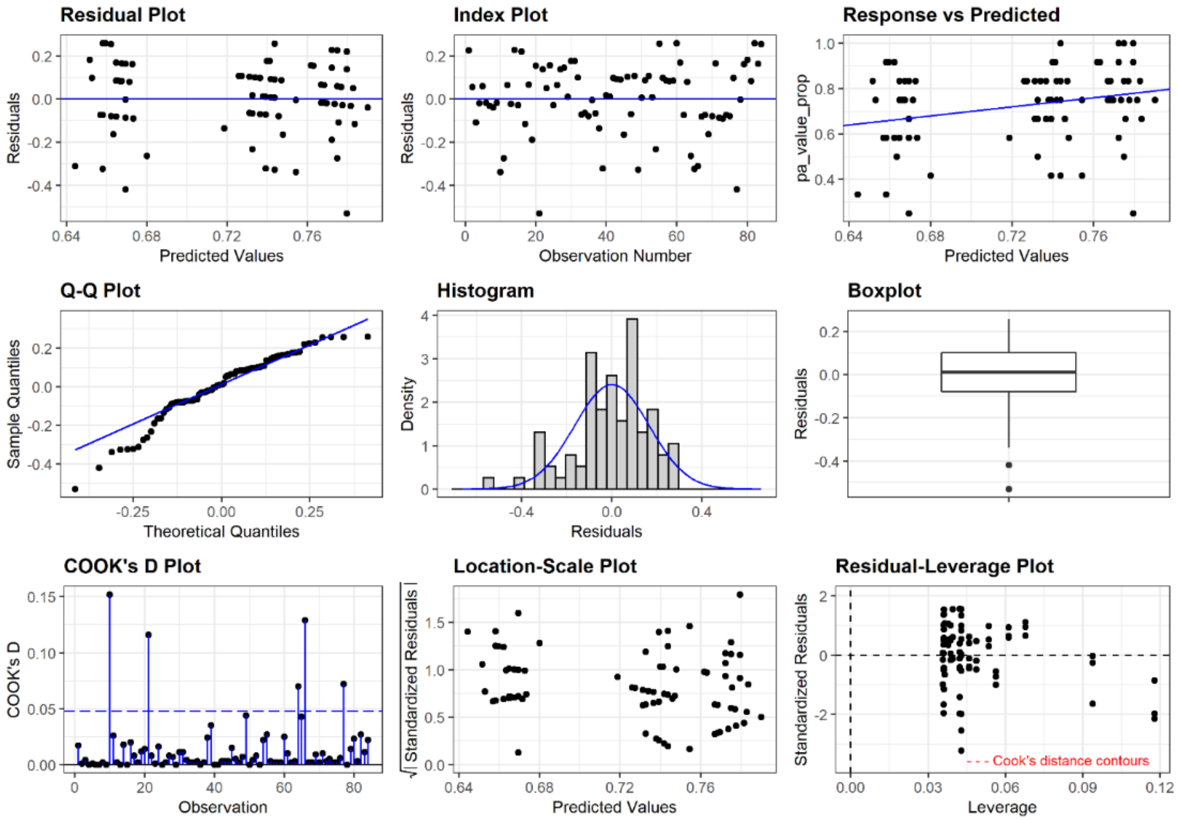

Figure B.7 *Residual Plots for the Multiple Regression Model examining TSD Experimental Phonological Awareness Proportion Accurate by Condition while controlling Oral Language Ability*

Note. All assumptions were met to interpret the multiple regression model examining the experimental phonological awareness proportion accurate by condition for the TSD group while controlling oral language ability. The nature of the data within the model (i.e., discrete values and a categorical predictor included) explained the three pod-like grouping of data and slight vertical lines of data. Examination of the Residual Plot and the Response vs Predicted Plot indicated a non-linear relationship occurred between the predictors (group and condition) and phonological awareness proportion accurate. Residuals were determined to be normally distributed through the examination of Q-Q Plot, Histogram, and Boxplot with the tails becoming less normal. Interpretation of more extreme values should be done cautiously when extrapolating using this sample data. The stairstep increments were explained by the discrete values possible within the data. The Index Plot and Boxplot examination indicated independence of residuals. No violation of heteroscedasticity was found through the evaluation of the Location-Scale Plot. The examination of the COOK's D Plot identified five points above the horizontal cutoff line, but none were determined to be erroneous outliers as no points crossed a COOK's D contour line (a red dashed line would appear if close) in the Residual-Leverage Plot. No exclusion of data occurred.

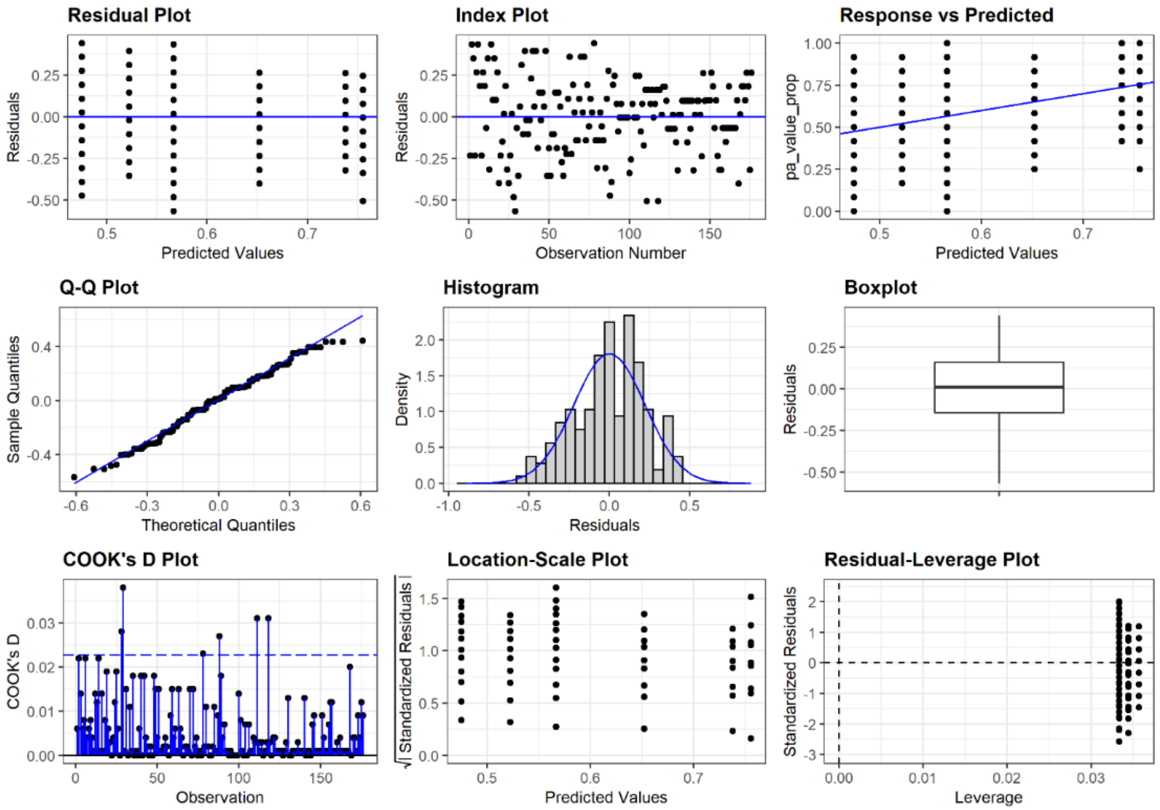

Figure B.8 *Residual Plots for the Multiple Regression Model examining Experimental Phonological Awareness Proportion Accurate by Group and Condition*

Note. All assumptions were met to interpret the multiple regression model examining the experimental phonological awareness proportion accurate by group and condition. The nature of the data within the model (i.e., discrete values and only categorical predictors included) explained the vertical lines of predicted values and suspected outlier points in multiple plots. Examination of the Residual Plot and the Response vs Predicted Plot indicated a non-linear relationship occurred between the predictors (group and condition) and phonological awareness proportion accurate. Residuals were determined to be normally distributed through the examination of Q-Q Plot, Histogram, and Boxplot with the tails becoming less normal.

Interpretation of more extreme values should be done cautiously when extrapolating using this sample data. The stairstep increments were explained by the discrete values possible within the data. The Index Plot and Boxplot examination indicated independence of residuals. No violation of heteroscedasticity was found through evaluation of the Location-Scale Plot. The examination of the COOK's D Plot identified six points above the horizontal cutoff line, but none were determined to be erroneous outliers as no points crossed a COOK's D contour line (a red dashed line would appear if close) in the Residual-Leverage Plot. No exclusion of data occurred.

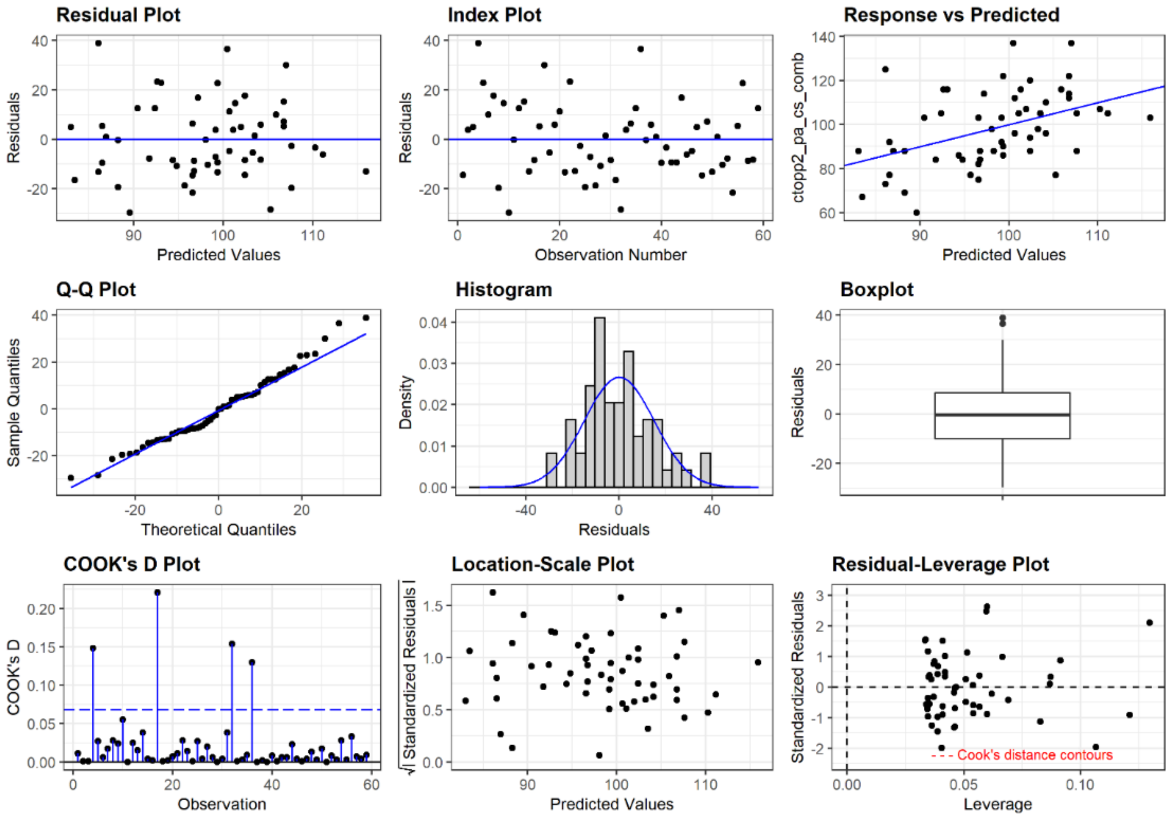

Figure B.9 *Residual Plots for the Multiple Regression Model examining CTOPP-2 Phonological Awareness Composite Score by Group while controlling Oral Language Ability*

Note. All assumptions were met to interpret the multiple regression model examining the CTOPP-2 PA composite score by group and condition. Examination of the Residual Plot and the Response vs Predicted Plot indicated a non-linear relationship occurred between the predictors (group and condition) and CTOPP-2 PA composite score. Residuals were determined to be normally distributed through the examination of Q-Q Plot, Histogram, and Boxplot with the tails becoming less normal. Interpretation of more extreme values should be done cautiously when extrapolating using this sample data. The Index Plot and Boxplot examination indicated independence of residuals. No violation of heteroscedasticity was found through the evaluation of the Location-Scale Plot. The examination of the COOK’s D Plot identified four points above the horizontal cutoff line, but none were determined to be erroneous outliers as no points crossed a COOK’s D contour line (a red dashed line would appear if close) in the Residual-Leverage Plot. No exclusion of data occurred.

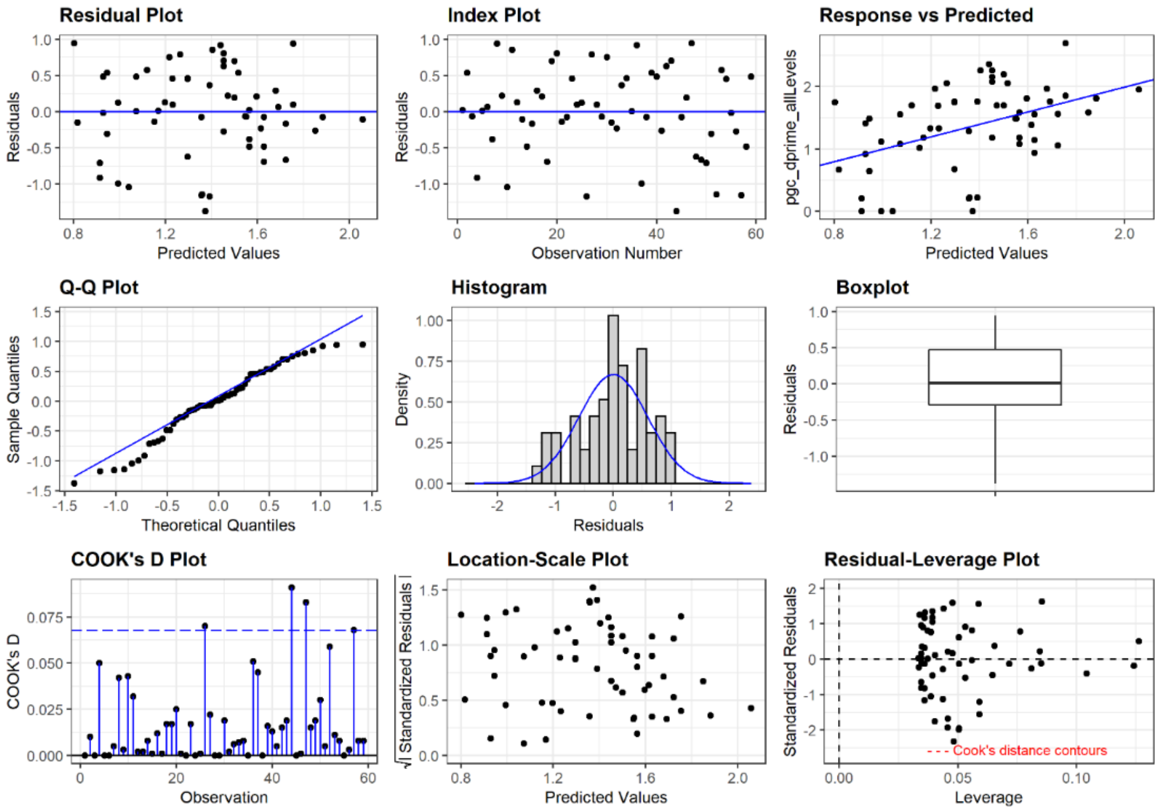

Figure B.10 *Residual Plots for the Multiple Regression Model examining Phoneme-Grapheme Correspondence D-Prime Score by Group while controlling Oral Language Ability*

Note. All assumptions were met to interpret the multiple regression model examining the phoneme-grapheme correspondence d-prime score by group and condition. Examination of the Residual Plot and the Response vs Predicted Plot indicated a non-linear relationship occurred between the predictors (group and condition) and phoneme-grapheme correspondence d-prime score. Residuals were determined to be normally distributed through the examination of Q-Q Plot, Histogram, and Boxplot with the tails becoming less normal. Interpretation of more extreme values should be done cautiously when extrapolating using this sample data. The Index Plot and Boxplot examination indicated independence of residuals. No violation of heteroscedasticity was found through the evaluation of the Location-Scale Plot. The examination of the COOK's D Plot identified three points above the horizontal cutoff line, but none were determined to be erroneous outliers as no points crossed a COOK's D contour line (a red dashed line would appear if close) in the Residual-Leverage Plot. No exclusion of data occurred.

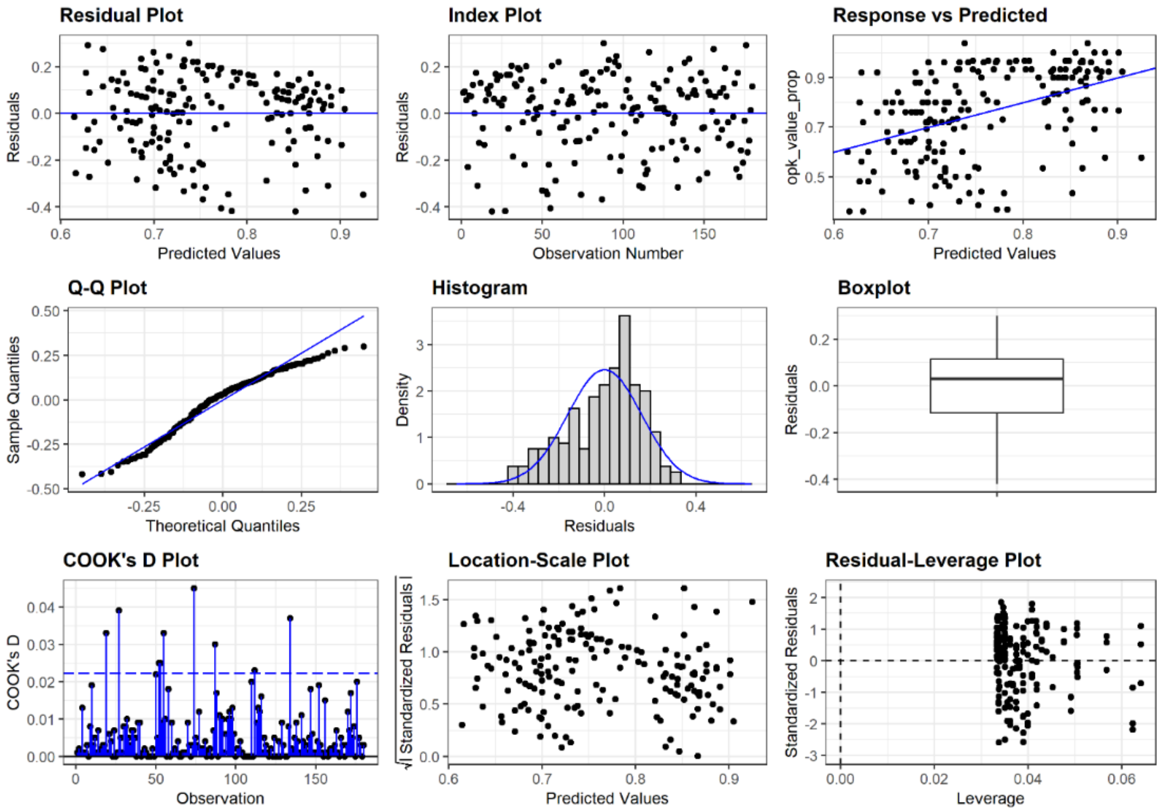

Figure B.11 *Residual Plots for the Multiple Regression Model examining Orthographic Pattern Knowledge Proportion Accurate by Group and Condition while controlling Oral Language Ability*

Note. All assumptions were met to interpret the multiple regression model examining the orthographic pattern knowledge proportion accurate by group, condition, and oral language ability. Examination of the Residual Plot and the Response vs Predicted Plot indicated a non-linear relationship occurred between the predictors (group and condition) and orthographic pattern knowledge proportion accurate. Residuals were determined to be normally distributed through the examination of Q-Q Plot, Histogram, and Boxplot with the tails becoming less normal. Interpretation of more extreme values should be done cautiously when extrapolating using this sample data. The Index Plot and Boxplot examination indicated independence of residuals. No violation of heteroscedasticity was found through the evaluation of the Location-Scale Plot. The examination of the COOK’s D Plot identified eight points above the horizontal cutoff line, but none were determined to be erroneous outliers as no points crossed a COOK’s D contour line (a red dashed line would appear if close) in the Residual-Leverage Plot. No exclusion of data occurred.

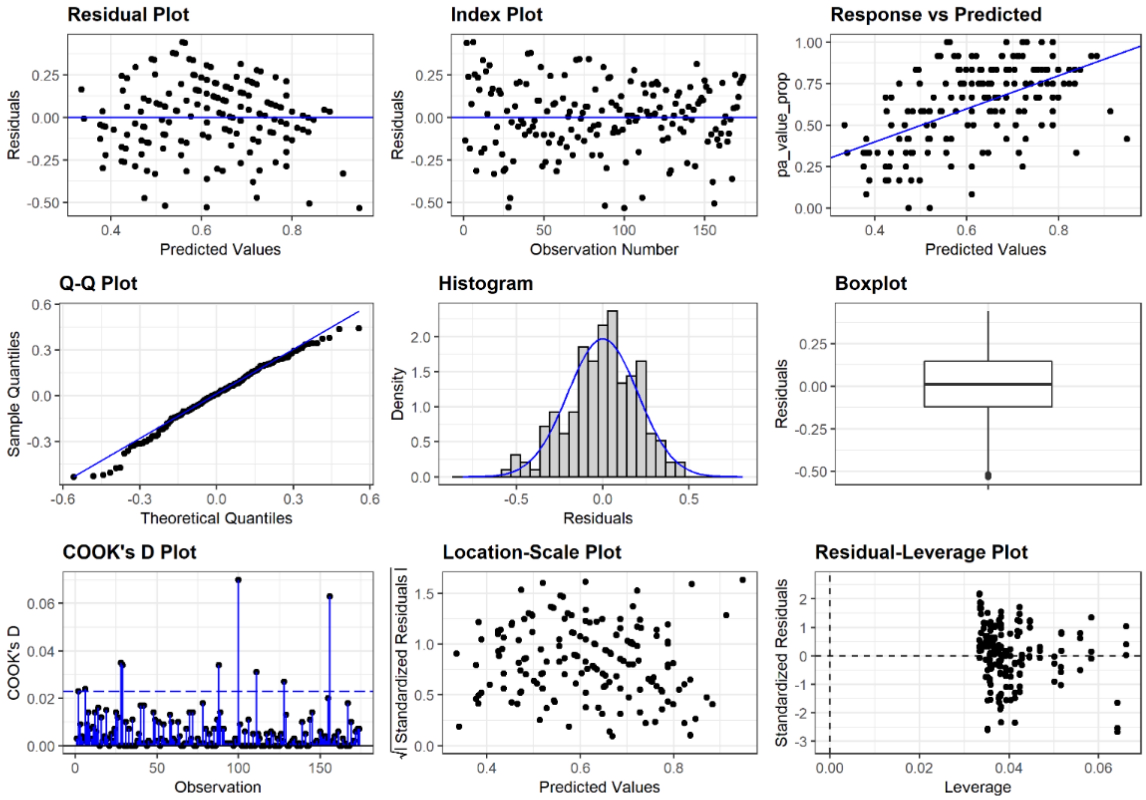

Figure B.12 *Residual Plots for the Multiple Regression Model examining Experimental Phonological Awareness Proportion Accurate by Group and Condition while controlling Oral Language Ability*

Note. All assumptions were met to interpret the multiple regression model examining the experimental phonological awareness proportion accurate by group, condition, and oral language ability. Examination of the Residual Plot and the Response vs Predicted Plot indicated a non-linear relationship occurred between the predictors (group and condition) and phonological awareness proportion accurate. Residuals were determined to be normally distributed through the examination of Q-Q Plot, Histogram, and Boxplot with the tails becoming less normal. Interpretation of more extreme values should be done cautiously when extrapolating using this sample data. The Index Plot and Boxplot examination indicated independence of residuals. No violation of heteroscedasticity was found through the evaluation of the Location-Scale Plot. The examination of the COOK's D Plot identified eight points above the horizontal cutoff line, but none were determined to be erroneous outliers as no points crossed a COOK's D contour line (a red dashed line would appear if close) in the Residual-Leverage Plot. No exclusion of data occurred.