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Effects of Phonotactic and Orthotactic Probabilities on Word Recognition for Children who do and do not use AAC

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Abstract

This study examined the influences of phonotactic and orthotactic probabilities, as well as the impact of computerized sounding out of words, on word recognition. Three children with cerebral palsy, 2 of whom had severe dysarthria and used augmentative and alternative communication (AAC) to aid their spoken speech, participated in the AB small-n design study. Computerized sounding out (i.e., target words said phoneme by phoneme) was presented during the Intervention. Results demonstrated that phonotactic and orthotactic probability did not influence the type of words identified by the participants. Additionally, computerized sounding out did not influence word recognition for the participants. Limitations of the study and suggestions for further research are provided.

Introduction

Many research studies have investigated the literacy skills of individuals who have severe speech impairments and use augmentative and alternative communication (AAC) systems (Dahlgren Sandberg, 2001; Dahlgren Sandberg & Hjelmquist, 1997; Foley & Pollatsek, 1999). It has been well recognized that these children may struggle to attain functional literacy skills, including spelling (Foley & Pollatsek, 1999; Koppenhaver & Yoder, 1992, 1993). It is estimated that 70 to 90% of individuals with CCN, who use AAC, demonstrate low levels of performance in literacy learning activities, including spelling (Koppenhaver, Steelman, Pierce, Yoder, & Staples, 1993). Without functional literacy, children and adults with CCN are at a considerable disadvantage, severely limiting their social, educational, employment and volunteer opportunities (Light, McNaughton, Weyer, & Karg, 2008). The purpose of this investigation was to examine how phonotactic and orthotactic probabilities influence recognition of pseudo-words by children who do and do not utilize AAC systems. Additionally, this investigated aimed to explore how computerized sounding out (i.e., target words said phoneme by phoneme) influenced the recognition of pseudo-words when provided compared to when no provided.

Several factors have been described as contributing to literacy development for children and adults who do and do not use AAC, including: phonological processing (Dahlgren Sandberg, 2001; Foley & Pollatsek, 1999;), working memory (Dahlgren Sandberg, 2001), orthographic knowledge (Apel, 2011), phonotactic and orthotactic probabilities (Apel, Wolter, & Masterson, 2006), intelligibility (Peeters, Verhoeven, de Moor, & van Balkom, 2009), and working memory (Dahlgren Sandberg 2001).

Phonological Awareness

Phonological awareness has been examined extensively and has been identified as being important to reading development (Dahlgren Sandberg, 2001; Dahlgren Sandberg & Hjelmquist, 1997; Dahlgren Sandberg, Smith, & Larsson, 2010; National Reading Panel, 2000). Specifically research has identified three critical features within phonological awareness: phonological awareness, phonological recoding in written word identification, and phonological coding to keep information in working memory (Wagner & Torgesen, 1987). These three processes are considered to be separate processes, and each one relates to reading in its own way.

Phonological awareness consists of not only an awareness of the sound structure of a language, but also the ability to segment and manipulate those sounds (Vandervelden & Siegel, 2001). Tasks such as rhyming and phoneme or syllable deletion can be used to demonstrate one's level of phonological awareness. Awareness of a language's sound structure aids in the use of letter-to-sound correspondence, which is important in decoding written words. Difficulty manipulating phonemes may lead to further difficulty following the addition of a written word component.

Phonological recoding involves the conversion of printed words into phonological representations in order to recover word meanings. This process is known as decoding (Vandervelden & Siegel, 2001). There are conflicting views regarding the role that phonological recoding plays in reading. Some suggest that it plays a major role in written word identification (Van Orden, 1987). Others suggest that a separate, orthographic path to meaning is established once children learn to read, and phonological recoding plays no significant role in adult reading (Paap, Newsome, McDonald, & Schvaneveldt, 1982). While it may not play a significant role in reading once adulthood is reached, this process of decoding words has been found to be a significant part of literacy development in children first learning to read (Foley & Pollatsek, 1999; Paap et al., 1982; Van Orden, 1987; Vandervelden & Siegel, 2001).

Orthographic Knowledge

Orthographic knowledge plays an important role in the acquisition of literacy. Orthographic knowledge is the knowledge of how to properly write, or display, oral language (Apel, 2011). It allows a person to information stored in memory that allows one to represent spoken language in written form (Apel, 2011). Decoding tasks, such as reading pseudo-words, can be used to assess not only sound blending abilities but also to see how well subjects use orthographic pattern knowledge. These patterns dictate how speech is represented in writing. For example, orthographic rules govern the representation of consonant doublets, long vowels, or any other sound that does not have a one-to-one sound-to-letter, or phoneme-to-grapheme, correspondence. Also, there are orthographic rules that dictate how letters can or cannot be combined and positional constraints on the use of letters. These positional rules are known as orthotactic rules (e. g., *ck* cannot be written in the word-initial position to represent the /k/ sound).

Phonotactic and Orthotactic Probabilities

In addition to orthotactic rules, other measures can influence spelling and word learning. Some sequences of phonemes and graphemes are more common in English words than other sequences (Apel, Wolter, & Masterson, 2006). Phonotactic probability measures the frequency with which phones (e.g., /s/) and biphones (e.g., /st/) in a word occur in a language (Apel et al., 2006). Results of some research studies has suggested that subjects are able to quickly and accurately process words with high phonotactic probability compared to words with lower phonotactic probability (Apel et al., 2006; Storkel, 2001; Storkel & Lee, 2011). For example, the word "*sit*" has high phonotactic probability with the commonly occurring /s/ in initial position, /I/ in medial position, and /t/ in final position. Consequently, participants within these studies learned pseudo-words that had high phonotactic probability better than those with lower phonotactic probability in experimental word learning tasks (i.e., the high phonotactic probability word '*fick*' compared to the low phonotactic probability word '*tuce*')(Luce & Large, 2001; Storkel, 2001; Storkel & Lee, 2011; Vitevitch & Luce, 1999).

Orthotactic probability works in much the same way, and it provides a measure of the frequency with which graphemes or grapheme sequences occur in different positions of words in a language (Apel, 2011). A grapheme is the letter representation of a sound (e.g., C, K, and CK are all graphemes for the /k/ sound). Orthotactic rules may influences the occurrence of certain grapheme sequences in different positions (e. g., *ck* may occur in word-final position, but not in word-initial). These factors may all work together in influencing word recognition skills. In word recognition tasks, a subject may use orthotactic pattern knowledge to judge the plausibility of pseudo-word spellings; one may expect the subject to have an easier time when pseudo-words feature phoneme and/or grapheme sequences with higher phonotactic and/or orthotactic probabilities. In Apel et al. (2006), typically developing 5-year-old preschool children were assessed on their ability to spell and read novel, or pseudo, words. The children were introduced to the novel words during storybook readings. When assessed, orthotactic probability had a significant influence on fast mapping. That is, the novel words with higher orthotactic probability were spelled and identified (read) with greater accuracy by the participants than words with lower orthotactic probability were.

Intelligibility and Subvocal Rehearsal

The role of intelligibility in the development of literacy skills remains unclear. Some research has shown a gap in phonological awareness abilities, reading skills, and writing abilities in comparison to peers matched for age, intelligence, or reading-level (Vandervelden & Siegel, 1999; Dahlgren Sandberg & Hjelmquist, 1997). It is suggested that productive speech ability may play an important role in the development of phonological awareness skills, as well as other early literacy skills (Peeters et al., 2009). Phonological coding involves the use of short-term memory to store phonological information temporarily before it can be reproduced in written form (Vandervelden & Siegel, 2001). Productive speech abilities in conjunction with phonological coding form a process of subvocal rehearsal. A person may ‘rehearse’ a word or sound by moving the articulators and practicing speech sounds. This articulatory coding and subvocal rehearsal during phonological processing for children and adults who use AAC to aid their communication have been debated (Bishop & Robson, 1989; Foley & Pollatsek, 1999; Peeters et al., 2009). Peeters et al. (2009) followed 52 children with cerebral palsy over a period of about eighteen months. The researchers assessed the children on several factors related to successful literacy, including: nonverbal reasoning, speech production, phonological short-term memory, speech perception, rhyme perception, phonemic awareness, and word decoding. Results suggested that speech production abilities at the time of the first assessment significantly influenced reading decoding abilities during subsequent assessments. The process of subvocal rehearsal may be beneficial to reading ability because the motor practice provides reinforcement of the use of and manipulation of sounds.

Working Memory

Many studies have looked at the role of memory capacity in reading, especially in populations with severe speech impairments (Dahlgren Sandberg, 2001; Dahlgren Sandberg et al., 2010). The hypothesis that people with severe speech impairments, or complex communication needs (CCN), have difficulties with auditory and visual memory tasks has been supported (Dahlgren Sandberg, 2001). Further, Dahlgren Sandberg (2001) suggests that productive speech plays a role in working memory abilities, phonological coding, and reading and spelling acquisition. Working memory abilities appear to be important in facilitating the application of phonological awareness skills to tasks of spelling and reading.

Dahlgren et al. (2010) found that performance on tasks of working memory was a factor in discriminating among good readers and non-readers. Dahlgren et al. completed a broad, cross-linguistic investigation of language and literacy abilities in children with anarthria or severe dysarthria and average cognitive abilities. Phonological awareness tasks, memory tasks assessing short term memory and working memory, spelling tasks, and reading tasks were all completed. Then, children were distributed into one of three groups: nonreaders, decoders, or good readers. The decoders and good readers performed significantly better than nonreaders on the memory tasks. This suggests that what the nonreaders lack in terms of working memory ability may hinder their ability to manipulate and apply phonological knowledge to a decoding or connected reading task.

Computerized Sounding-out

Another area that has been explored is the conjunction of phonological awareness with the use of computerized sounding out. Bishop, Adams, Lehtonen, and Rosen (2005) completed a study examining phonological awareness in children with receptive language impairments where the children were provided with words segmented into individual phonemes and graphemes. The children in the intervention group first used a training “game” that provided computerized sounding out, phoneme segmentation, and orthographic feedback to teach spelling. The goal was for spelling to be further enhanced due to the use of computerized sounding out. The results of the study suggested that such computer-based training could facilitate improvement in phonological awareness skills, at least when the intervention was employed. However, it did not appear that the resulting skills of this intervention would generalize to other tasks. It appeared that individual words may have been learned by simple memorization instead of a deeper understanding of the underlying rule-based phonology (Bishop et al., 2005). Though the influences of computerized sounding out has been examined during spelling tasks (Bishop et al, 2005; McCarthy, Beukelman, & Hogan, 2011; Raghavendra & Oaten, 2007; Schlosser & Blischak, 2004), it has not been fully evaluated for use during word recognition tasks.

Research Question and Hypothesis

Considering the aforementioned influences on literacy, this study sought to determine how children with CCN who use AAC systems perform during tasks of word recognition when provided a computerized sounding out (i.e., a phoneme by phoneme sounding out of the target word).

1.) *Do children with low speech intelligibility identify pseudo-words with more accuracy when the pseudo-words are of high phonotactic and orthotactic probability compared to low phonotactic and orthotactic probability?*

2.) Does computerized sounding out increase pseudo-word recognition for children with low speech intelligibility who use AAC to aid their communication?

It was expected that pseudo-words with higher phonotactic and orthotactic probabilities would be more accurately identified than pseudo-words with lower phonotactic and orthotactic probabilities. Additionally, it was expected that the presentation of computerized sounding out during the Intervention stage would aid in pseudo-word recognition performance.

Methods

This study utilized an AB single subject experimental research design. Participants were two children who used AAC and one child who did not from across the United States. The independent variables were (a) a spelling identification task without computerized sounding out (i.e., Baseline) and (b) a spelling identification task with the computerized sounding out (i.e., Intervention). The dependent variables were correctly recognized and identified pseudo-words.

Participants

Three children (1 female, 2 males) with cerebral palsy who did and did not utilize AAC devices were participated in the study. The ages of participants ranged from 8 years, 0 months to 8 years, 10 months (*M* = 8.5 years of age). Standard American English was spoken in all three participant's homes. Inclusionary criteria for the participants included: (a) normal to corrected vision, (b) normal hearing (American Speech-Hearing Association, 2007), and (c) grade-level academic participation with assignment lengths adjusted as needed with or without paraprofessional support as verified by reports from parents and in school records. Table 1 outlines the participant's characteristics.

Hank was 8 years, 10 months of age and was enrolled in the third grade. Hank had a diagnosis of cerebral palsy, communicated through the use of a Vantage Lite ™ [1] with direct selection, and moved with the aid of a motorized wheelchair. He was included in his classroom with the help of a paraprofessional for half of the school day. During the other half of the school day, he was provided special educational services to address concerns in language arts. Through his school district Hank received occupational therapy, physical therapy, and speech-language therapy. Intelligibility was assessed using the Index of Augmented Speech Comprehensibility in Children (I-ASCC; Dowden, 1997), which assesses the overall percentage of words that are intelligible to unfamiliar listeners who are not provided with context, and the sentences from the Hearing In Noise Test (HINT), which was designed to assess an individual's speech reception abilities. Hank's speech intelligibility for words on the I-ASCC was 3%, and his intelligibility on the HINT sentences was 7.6%.

Sam had just completed first grade and was 8 years of age. He used a Dynavox V™[2] with direct selection for communication. He primarily used iconic symbols to communicate, but he was moving to spelling messages with the help of word prediction. Sam received occupational therapy, physical therapy, and speech-language therapy at school. His speech intelligibility for words on the I-ASCC was 6% and was 10.2% for the HINT sentences.

Sheri was in the third grade and was 8 years, 7 months of age. Her diagnosis was of cerebral palsy. Sheri used oral speech to communicate. Additionally, she utilized crutches or a wheelchair to assist her in moving around at home and/or school. With some paraprofessional support Sheri was completely included in a general-education classroom. She received occupational therapy, physical therapy, and speech therapy at school. Sheri's speech intelligibility for words on the I-ASCC was 86%, and on HINT sentences she had 97.1% intelligibility.

Table 1. *Participant Demographic Information including Age (years; months), Grade Level in School and Communication Mode*

Participant's Name*	Age	Grade	Communication Mode
Sam	8;0	1st (end of)	Dynavox V ™
Hank	8;10	3rd	Vantage Lite ™
Sheri	8;7	3rd	Speech

Note. *All names were changed for participant confidentiality.

Measures

To assess speech intelligibility, each participant completed a single word and a sentence speech intelligibility measure (Table 2). The single word intelligibility test, the Index of Augmented Speech Comprehensibility in Children (I-ASCC; Dowden, 1997), consists of 10 lists of 31 common single words. Participants were audio-recorded pronouncing each of the 31 words using a digital recorder (i.e., Marantz[3]). The sentence speech intelligibility measure, the Hearing In Noise Test (HINT) Sentences, consists of 25 sets of 10 simple sentences used with children and adults. Each participant either: (a) read aloud 10 HINT sentences independently from a set chosen at random by the administrator, or (b) the administrator read the sentences from a set chosen at random to the participant, and the participant repeated the sentence verbatim. Participants were recorded saying each of the 10 HINT sentences using a digital recorder[3]. The single word and sentence intelligibility tests were transcribed by three female judges - using procedures similar to those in other studies examining speech samples from children with cerebral palsy (Hustad & Gearhart, 2004; Hustad, Jones, & Dailey, 2003).

Table 2. *Participant Scores on Standardized Testing & Intelligibility Scores at the Word and Sentence Levels* (N = 3)

Participant's Name	TWS-4 Raw Score	TWS-4 SS	PPVT Raw Score	PPVT SS	I-ASCC	HINT Sentences
Sam	3	77	117	91	6%	10.2%
Hank	2	73	108	80	3%	7.6%
Sheri	6	78*	93	74	86%	97.1%

Note. SS = Standardized Score; * indicates at or above a first grade equivalency level

Additionally, each participant completed a standardized spelling and receptive vocabulary measure to describe their current spelling and vocabulary abilities. The *Test of Written Spelling - Fourth Edition* (TWS-4; Larsen, Hammill, & Moats, 1999), form A, was administered to each participant. Consistent with the testing procedures in the TWS-4 manual, the administrator read the target word (e.g., *bed*), followed by the target word in a short sentence (e.g., *She slept on a **bed***). The participants were instructed to spell the target word on their AAC device or using their typical writing method for writing activities (e.g., pencil and paper, typing on a laptop). The administrator transcribed each participant’s spelling onto the TWS-4 spelling form protocol. A raw score, standard score, and percentile rank were calculated using the TWS-4 administration manual for each participant (Table 2).

Each participant completed the *Peabody Picture Vocabulary Test - Fourth Edition* (PPVT-4; Dunn & Dunn, 2007) to quantify current receptive vocabulary ability. Participants were instructed to identify the picture that best represented a target word from an array of four colored pictures. A raw score, standard score, and percentile rank was calculated using the PPVT-4 administration manual (Table 2).

Experimental Stimuli

The experimental stimuli consisted of 10 lists of 10 pseudo-words with a consonant-vowel-consonant (CVC) pattern that were matched on phonotactic probability (i.e., the frequency with which a particular phoneme or phoneme sequence occurs in a language; Storkel, 2001; Vitevitch & Luce, 2004). Each list of 10 pseudo-words consisted of five consistent words and five inconsistent words. Consistent pseudo-words are words with high phonotactic and orthotactic probability, such as '*fick*.' Inconsistent pseudo-words are words with low phonotactic orthotactic probability, such as '*tuce*.' A list of all pseudo-words used can be found in Appendix A. Pseudo-words were selected for this study to control for any prior reading and spelling experiences had by each child. Five lists of these pseudo-words were created and recorded for computerized presentation as whole words for the Baseline condition. The other five lists of 10 pseudo-words created were recorded as whole words as well as segmented into phonemes for use in the Intervention condition, which made use of computerized sounding out.

The administrator recorded the pseudo-words in a standard single-walled isolated sound booth using a digital recorder with an adult Crown headset microphone[4]. Adobe Audition software[5] was used to edit the recordings. Each pseudo-word was normalized to 80 dB with a 3 millisecond silence added at the beginning and end of each pseudo-word. The duration of the pseudo-words ranged from 0.86 seconds to 1.18 seconds (*M* = 1.03).

Computerized sounding out. For the Intervention condition, participants were provided computerized sounding out of each pseudo-word presented auditorily through external speakers that were attached to the research laptop computer. Computerized sounding out provides a digitized voice presentation of the individual phonemes for each target pseudo-word. For example, if the target pseudo-word was *tath*, the computerized sounding out was /*t*/ /*æ*/ /*θ*/. The participants were told to listen to this computerized sounding out twice, with the opportunity to listen to the same computerized sounding out as many as six times, if they chose.

This stimulus was recorded in the same method as the whole pseudo-words. After recording, Adobe Audition software[5] was used again to edit the sounds. Each sound was normalized to 80 dB and 3 milliseconds of silence was added to the beginning and ending of each sound. The duration of the sounds ranged from 0.35 seconds to 0.98 seconds (M = 0.65).

Word identification task. Each participant was instructed to point to target pseudo-words that he or she thought best represented the pseudo-word or “alien word” that was heard from the computer speakers. Four pseudo-words were visible on the screen: the target pseudo-word and three foils. The foils included: one pseudo-word differing by an initial change (i.e., *yive* and *wive*), one pseudo-word differing by a final change (i.e., *yive* and *yize*), and one pseudo-word differing maximally from the target (i.e., *yive* and *buke*). The pseudo-words were presented individually through external speakers attached to the research laptop by the administrator. Participants indicated their responses to the administrator by pointing or verbally indicating the word they believed to be correct.

Reliability of Measures

The first author served as the second judge. Twenty percent of the spelling identification responses across participants were recorded and re-scored using video and audio recordings of each participant. Reliability between the first judge (i.e., administrator) and second judge for

20% of all sessions across participants was 100%. Reliability between the first judge and second judge for 20% of all sessions across words was 100%.

Procedures

This study utilized an AB single subject design (i.e., two conditions: Baseline and Intervention). Participants were seen at their homes in a quiet room with no distractions. Each participant sat at a table with the research computer and attached speakers in front of her or him. For each session, the administrator advised each child that he or she would be hearing pseudo-words or "alien words," but they were to look for the word that sounded like the "alien word" and looked like a real English word or a word that they would see in a book. Following the identification of each of the pseudo-words, the administrator read back what the child had indicated and then presented the next pseudo-word. The verbal presentation of what the child had read was made certain that the administrator had transcribed the identification of each target pseudo-word correctly. Also, the administrator sought to verify with each participant that he or she was ready for the presentation of the next pseudo-word and did not want to change the response. No feedback on accuracy was given. The administrator did provide encouraging statements periodically to the participants, such as: "try your best" and "let's try another one."

Baseline condition. During each Baseline session, lasting roughly 10-minutes, a pseudo-word list consisting of 10 words was administered to each participant. Participants were told that they would be identifying a list of 10 pseudo-words. They were advised that they would be hearing pseudo-words, or "alien words," and that they should point to the pseudo-word that looked most like a real English word or a word that would be seen in a book. In order to fulfill the Baseline condition, all five of the Baseline lists were administered to two of the participants – Sheri and Sam. One participant, Hank, only completed three Baseline lists due to time constraints and fatigue. The Intervention condition was not implemented until all Baseline lists had been administered, with the exception of Hank.

Intervention condition. The Intervention condition consisted of five 10 minute sessions over a two-week period. During each Intervention session the participants were told that they would be identifying a list of 10 pseudo-words. As with the Baseline sessions, participants were advised that they would be hearing pseudo-words or “alien words,” and they were to point to the pseudo-word that looked like real English words or words that they would see in a book. However, unlike the Baseline condition, after the presentation of each pseudo-word, the participants heard the computerized sounding out. The computerized sounding out was presented at least twice though the participants could choose to listen to it as many as six times.

Data Analyses

Each participant’s responses were examined for (a) overall accuracy of the pseudo-word selection (i.e., correct or incorrect spelling identification) and (b) types of errors made at the elemental level (initial change, final change, or maximal change). Correctly identified pseudo-words were scored as a “1,” and incorrect pseudo-words received a score of “0.” After calculating the number of correct pseudo-words identified, each response was examined for accuracy at the level of consistent or inconsistent phonotactic and orthotactic makeup.

Results

Overall results from this study indicate that for the three participants, phonotactic and orthotactic probability of the words did not enhance accuracy of consistent or inconsistent identification of words. Additionally, the overall results suggest that computerized sounding out did not increase overall word identification accuracy for any of the participants.

Overall Correct. Participants’ data were examined to determine how many words were correctly identified in each list. Figure 1 illustrates Hank's overall number of correct responses from Baseline to Intervention. Hank did not show an increase in correctly identified pseudo-words when computerized sounding out was presented during Intervention.

Figure 1. *Number of correctly identified words by Hank.*

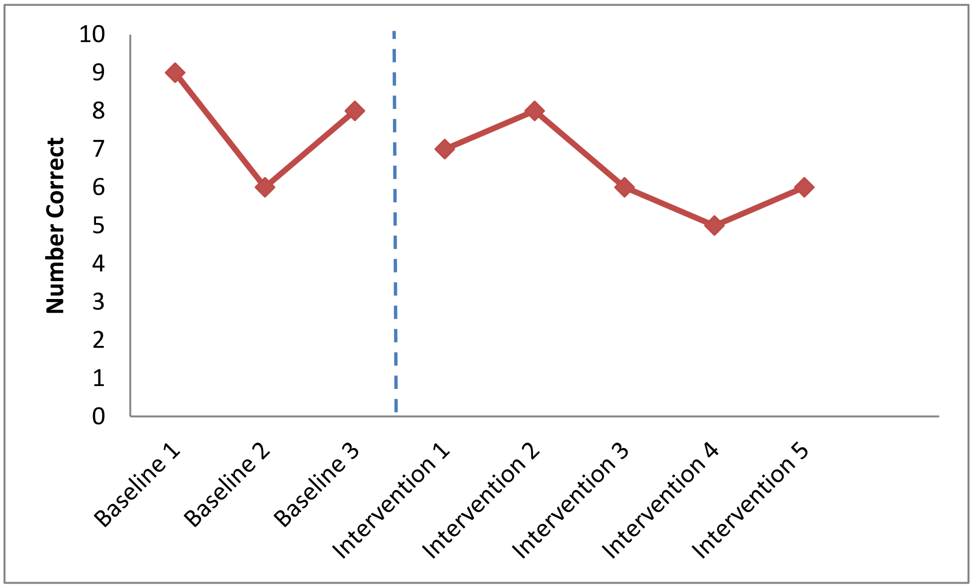


Figure 2 illustrates Sam's overall number of correct responses from Baseline to Intervention. Sam did not show an increase in correct responses for pseudo-words after moving to Intervention.

Figure 2. *Number of correctly identified words by Sam*.

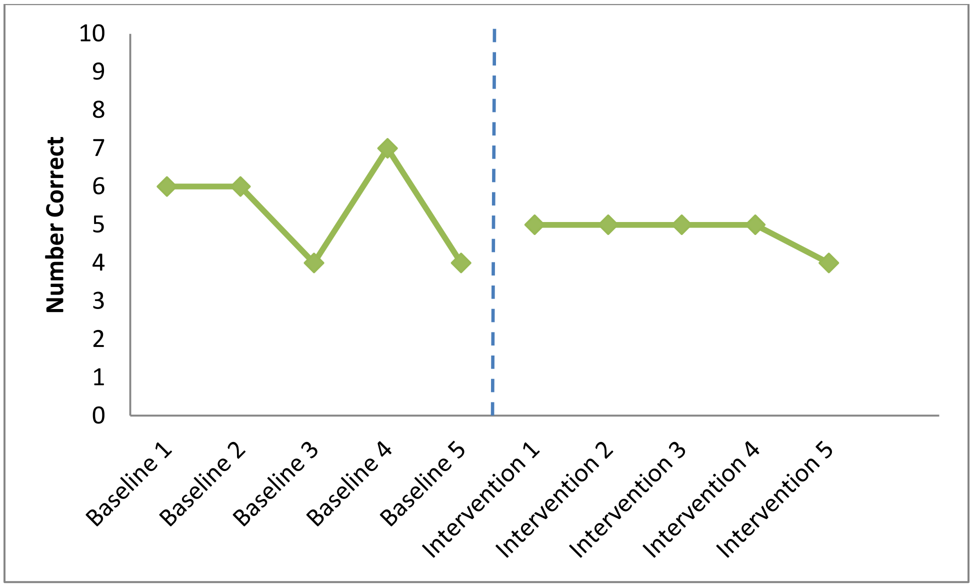
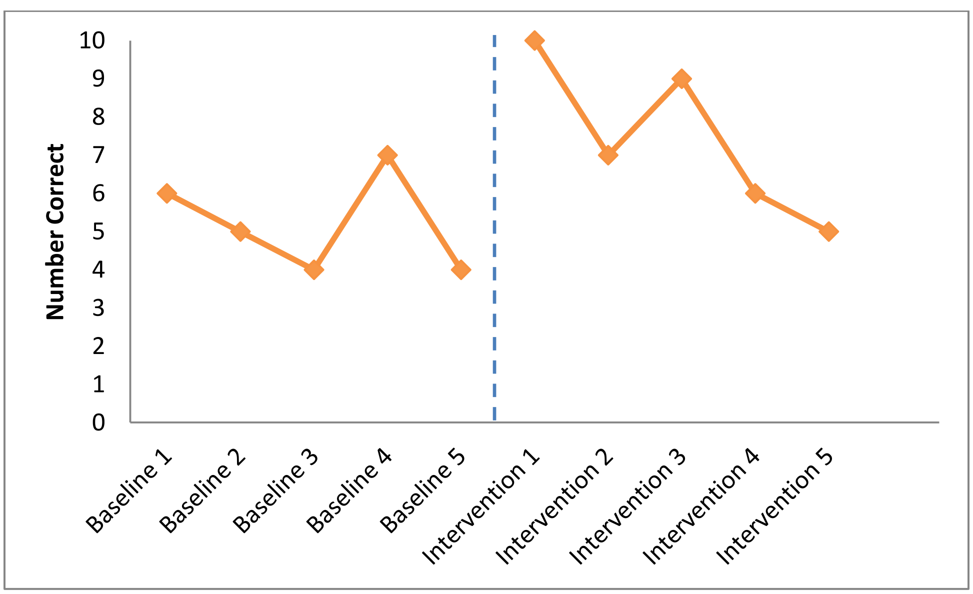


Figure 3 illustrates Sheri's overall number of correct responses from Baseline to Intervention. Sheri did show an increase in correct pseudo-word responses after moving to Intervention were computerized sounding out was present. However, the number of correct responses decreased as she moved through the Intervention condition.

Figure 3. *Number of correctly identified words by Sheri*.



Consistent versus Inconsistent. Participants' responses were also examined for the number of correctly identified pseudo-words with consistent orthography, or high phonotactic and orthotactic probability, compared to pseudo-words with inconsistent orthography, or low phonotactic and orthotactic probability. Figure 4 illustrates Hank's number of correct responses on pseudo-words with consistent and inconsistent orthography. Neither word type increased in accuracy in the Intervention condition when computerized sounding out was present. However, accuracy on pseudo-words with inconsistent orthography appears to decrease more than accuracy on consistent orthography during Intervention.

Figure 4. *Number of words correctly identified with consistent vs. inconsistent orthography by Hank.*

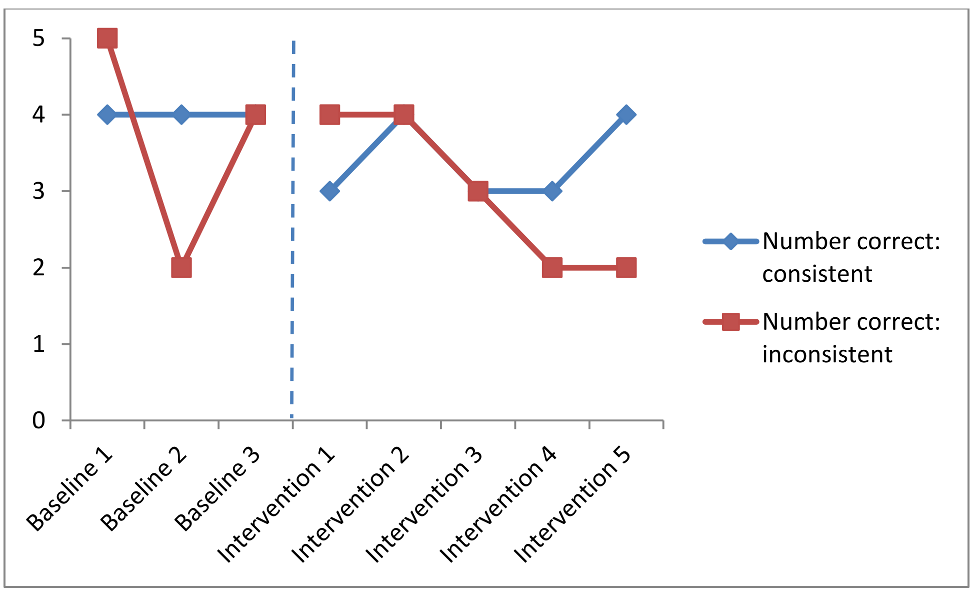
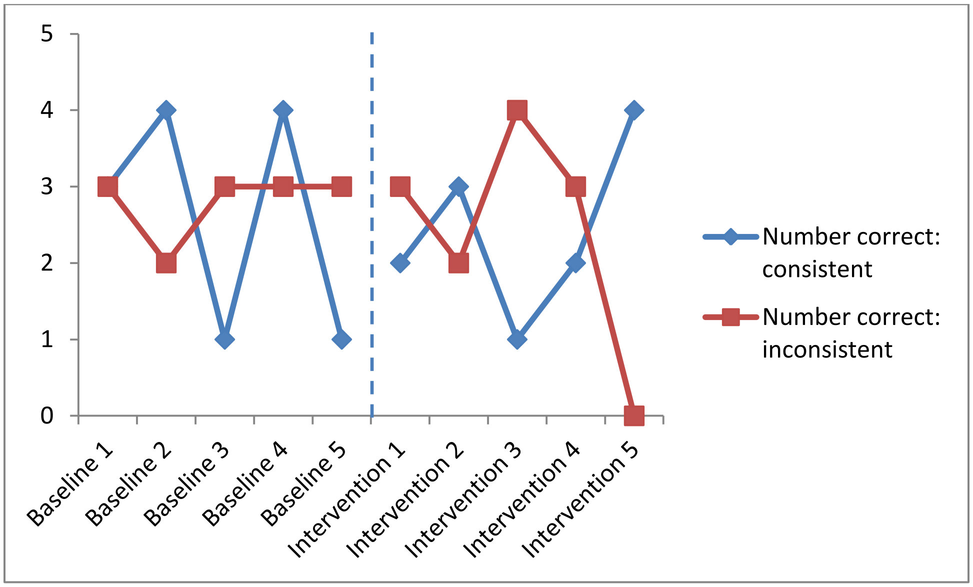


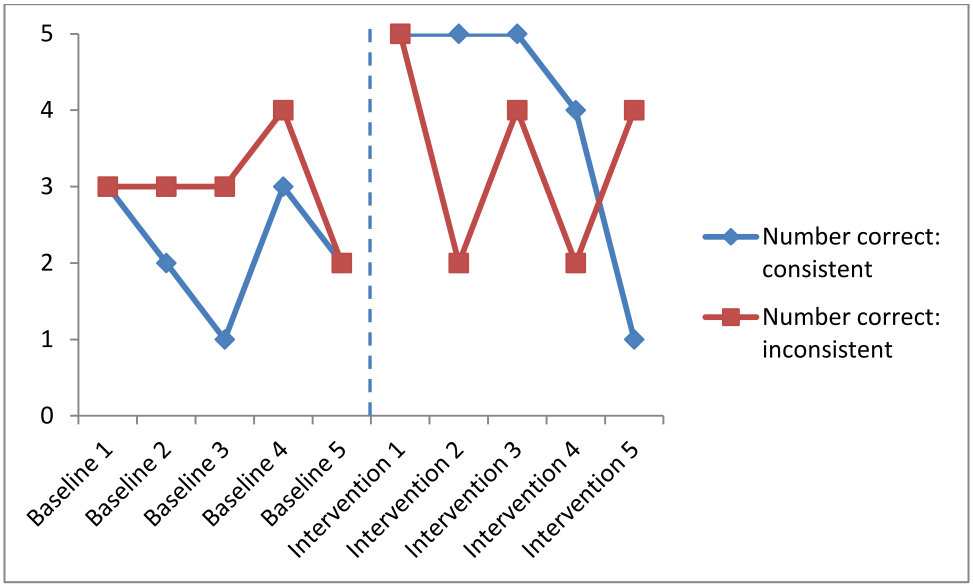
Figure 5 illustrates Sam's number of correct responses on pseudo-words with consistent and inconsistent orthography. There is no discernible pattern in the accuracy of either pseudo-word type.

Figure 5. *Number of words correctly identified with consistent vs. inconsistent orthography by Sam.*



Sheri's number of correct responses on pseudo-words with consistent and inconsistent orthography is displayed in Figure 6. Sheri appears to have increased accuracy on identifying pseudo-words with consistent orthography during Intervention. It could be said that accuracy increased for pseudo-words with inconsistent orthography during Intervention as well, but that increase does not appear to be consistent.

Figure 6. *Number of words correctly identified with consistent vs. inconsistent orthography by Sheri.*



Error type. Errors were separated by type, specifically by word position: (a) initial change, (b) final change, or (c) maximal change. Initial change errors were characterized by the selection of a pseudo-word that differed from the target only by the initial phoneme. Final change errors were characterized by selection of a pseudo-word that differed from the target only by the final phoneme. Maximal change errors were characterized by selection of a pseudo-word that differed from the target in all phonemes. Figures 7 and 8 illustrate Hank's error types from Baseline to Intervention. During Baseline, Hank selected words in error with a final change. Hank showed an increase in the number of final change errors after moving to the Intervention phase of the study.

Figure 7. *Number of each error type made during Baseline condition by Hank.*

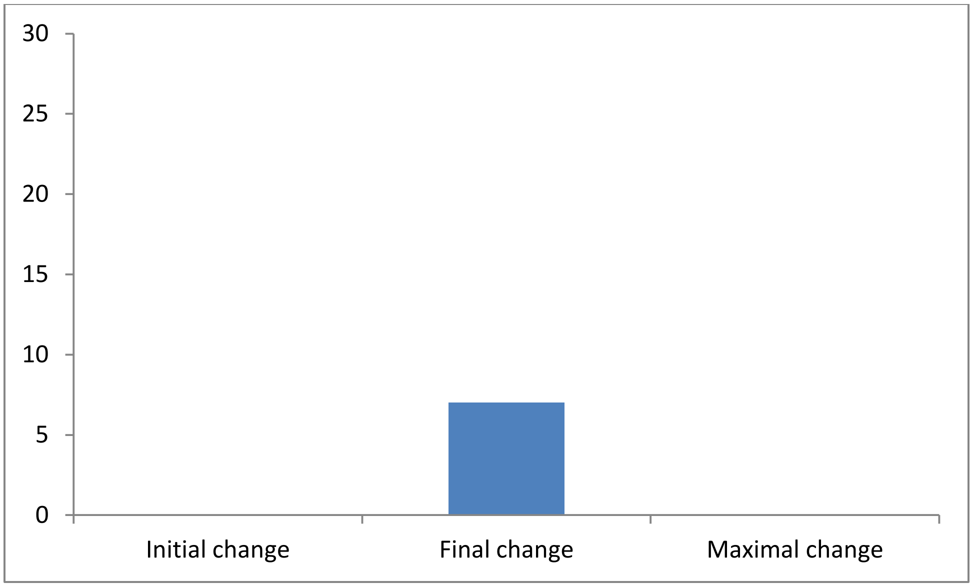
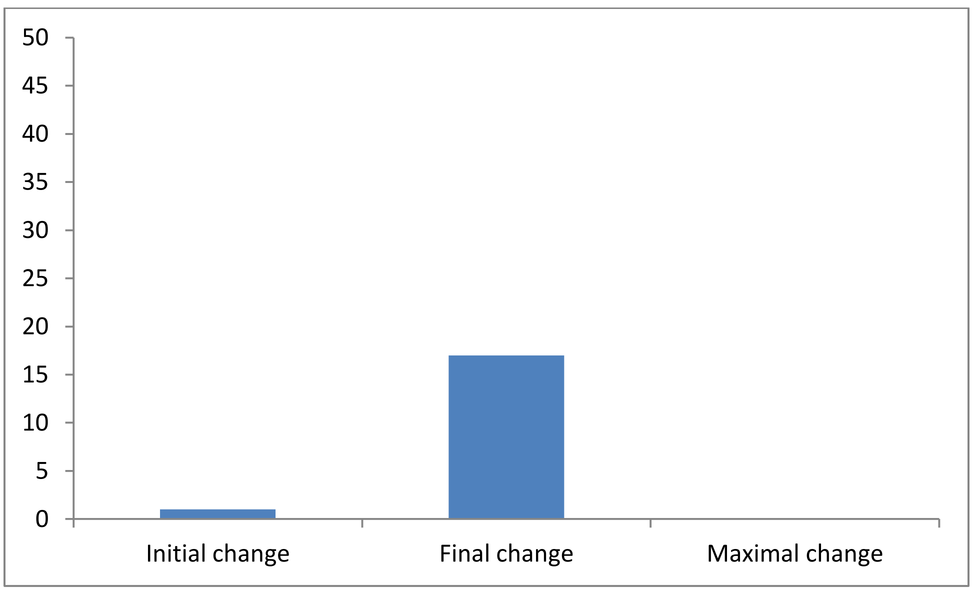


Figure 8. *Number of each error type made during Intervention condition by Hank.*



Figures 9 and 10 illustrate Sam's error types from Baseline to Intervention. Sam was observed to make errors at all three levels: initial, final, and maximally different. When examining the difference in errors from Baseline to Intervention, there are no significant changes in error type when computerized sounding out was present compared to when it was not.

Figure 9. *Number of each error type made during Baseline condition by Sam*.

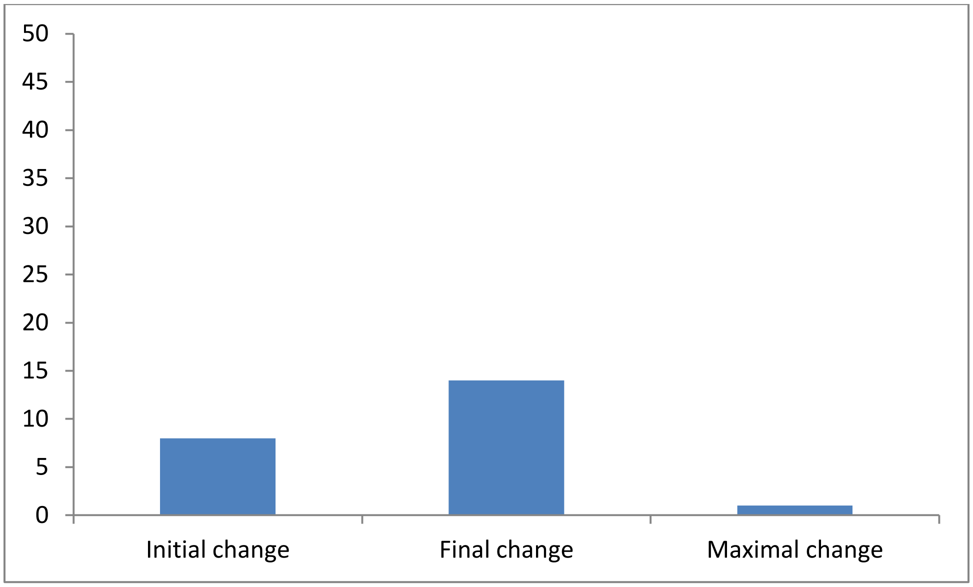
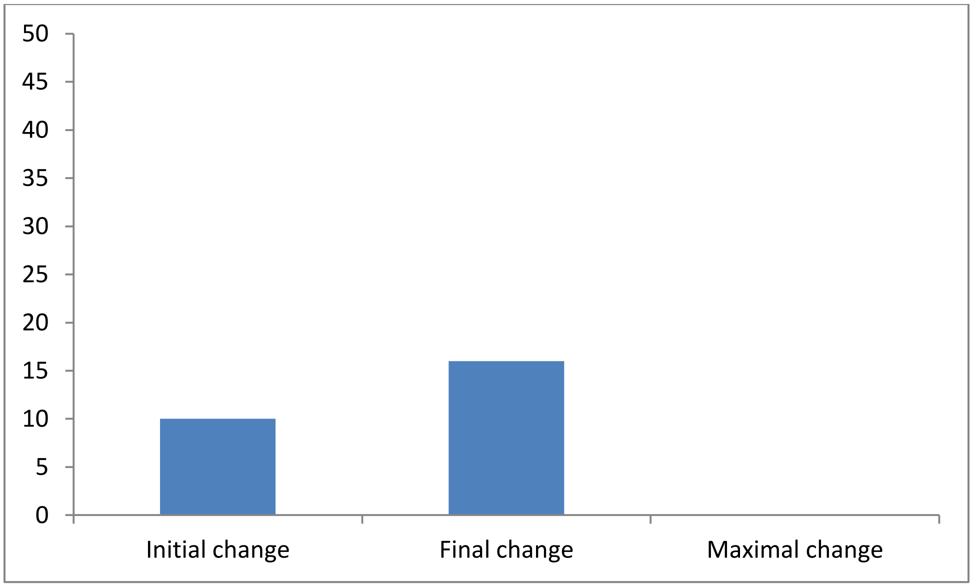


Figure 10. *Number of each error type made during Intervention condition by Sam*.



Figures 11 and 12 illustrate the number of Sheri's error types from Baseline to Intervention. Similarly to Sam, Sheri was observed to make errors at all three error levels: initial, final, and maximally different. When examining the difference in errors from Baseline to Intervention, Sheri demonstrates a decrease in both initial and final change errors after moving to

Intervention.

Figure 11. *Number of each error type made during Baseline condition by Sheri*.

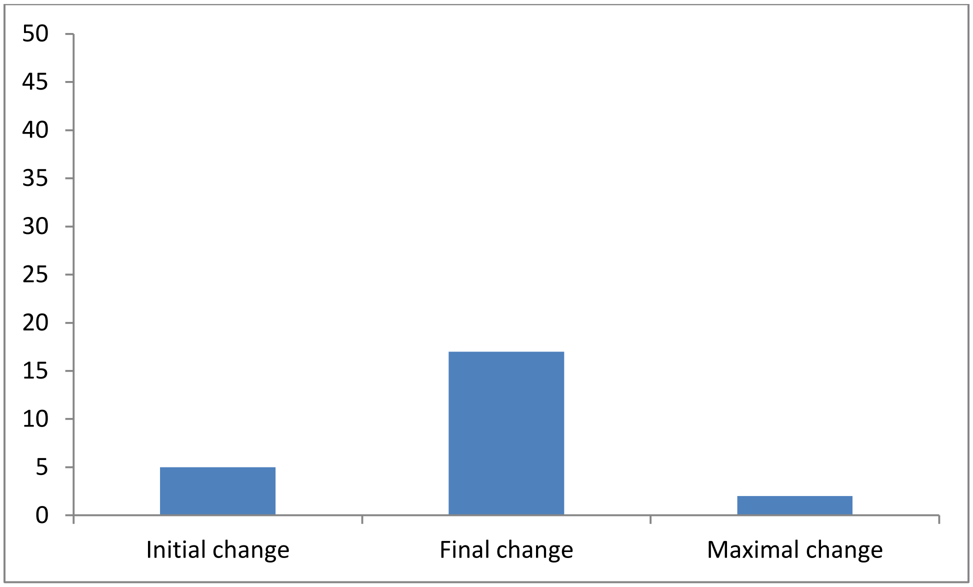
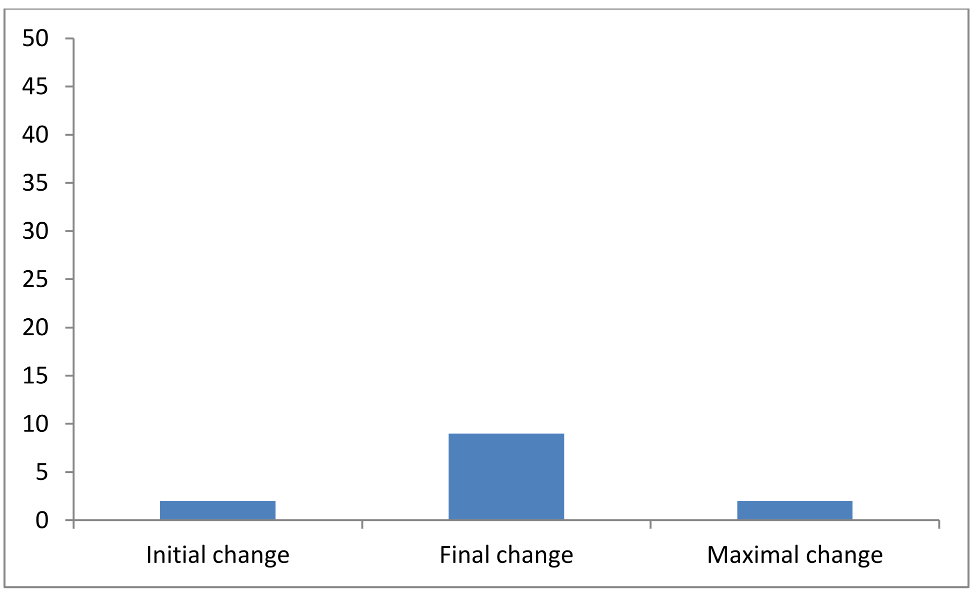


Figure 12. *Number of each error type made during Intervention condition by Sheri*.



Discussion

It was hypothesized pseudo-words with higher phonotactic and orthotactic probabilities would be more accurately identified than words with lower phonotactic and orthotactic probabilities. The results of the present study demonstrated that the words with high and low phonotactic and orthographic probability were identified at the same rate across the participants. Additionally the results suggest that regardless of the probability the pseudo-words were identified at a lower rate than expected. It could be hypothesized that the errors exhibited by the three children may be related to decreased phonological awareness skills, lower working memory skills, decreased speech intelligibility, or a combination of these factors. Furthermore, it was hypothesized that computerized sounding out would increase the overall accuracy of pseudo-word identified by the participants. Results from the study indicated that computerized sounding out was not beneficial to the participants, as their overall word recognition of pseudo-words did not increase. This may suggest that the participants were not segmenting the sounds in the words to begin with, so hearing the word sounded out by phonemes did not help. Participants appeared to be using some knowledge of letter-to-sound correspondence. However, with the high frequency of final change errors in all participants, it appears that they may be recognizing the initial phoneme from the auditory stimulus but not listening to all the sounds within the pseudo-words. If they see the pseudo-words as whole chunks instead of a combination of phonemes, they may not see a difference between the target and a pseudo-word with a final change error because the first sounds are the same.

Also, the role of intelligibility in the literacy skills of this population remains unclear. Research has suggested that speech production is a significant precursor to word decoding skills in individuals with cerebral palsy (Dahlgren Sandberg & Hjelmquist, 1997; Peeters et al., 2009). While Sheri, the participant with the highest intelligibility scores, identified 63% of words correctly overall, Hank, who had the lowest intelligibility scores, identified 68.75% of words correctly overall. Therefore, intelligibility may play a role in word decoding, but it is not the only determining factor.

Limitations of the Present Study and Future Directions

However, nothing can be stated with much certainty due to the limitations of this study. Only three participants were investigated. To achieve more significant results, further research should consider using a larger sample size of participants.

This study is a post hoc analysis of data. Thus information on each participant's phonological awareness, working memory, and word decoding skills was not available. Future studies should consider adding measures to examine how phonological awareness, working memory, and word decoding skills influence pseudo-word recognition of high and low phonotactic and orthographic probability as well as computerized sounding out.
Additionally, research has suggested that speech production is a key factor in literacy skill development (Peeters et al., 2009); future research should be continued to investigate this factor. In order to explore better the role of subvocal rehearsal as well as computerized sounding out in subsequent studies, the sample should not only be larger, but it also should have a heterogeneous assortment of intelligibility levels across participants. Therefore, intelligibility levels can be analyzed with respect to decoding skills.

Conclusion

There are many factors that play a role in literacy development. In populations that use AAC devices to communicate literacy development is incredibly important. It remains unclear exactly how phonotactic and orthotactic probabilities influence word learning. The role of subvocal rehearsal and computerized sounding also remain unclear. However, new questions and ideas for future investigation have been provided.

Footnote

[*] Names of participants have been changes for confidentiality purposes. All names provided are pseudo-names created for the purpose of the manuscript.

[1] Vantage Lite

Prentke Romich Company (PRC) World Headquarters

1022 Heyl Road

Wooster, OH 44691

[2] Dynavox V

DynaVox Mayer-Johnson

2100 Wharton Street

Suite 400

Pittsburgh, PA 15203

[3] Marantz CM311A digital recorder

Marantz America, LLC

100 Corporate Drive

Mahwah, NJ 07430-2041

[4] Crown CM311A headset microphone

Crown Audio, Inc.

P. O. Box 88807

Chicago, IL 60695-1807

[5] Adobe Audition

www.adobe.come/products/audition.html

San Jose, CA

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Appendix A

Nonword identification lists

Baseline Identification Lists

	Pronunciation	Target written word	Foils	Orthography: consistent or inconsistent
List 1	/wɔt/	waut	pim	inconsistent
			yaut	
			waup	
	/w ʊk/	wook	wooch	consistent
			san	
			yook	
	/zel/	zail	boad	inconsistent
			thail	
			zair	
	/ bʊd/	bould	boug	inconsistent
			dould	
			mave	
	/ dʒɛv/	jev	buke	consistent
			jez	
			wev	
	/ gɑɪb/	gibe	gige	consistent
			louth	
			dibe	
	/ vɑl/	voll	zoll	consistent
			vor	
			chife	
	/ tok/	toak	toach	inconsistent
			fazz	
			koak	
	/ diz/	deize	nop	inconsistent
			beize	
			deive	
	/ tuk/	tuke	tupe	consistent
			wadge	
			chuke	

List 2	/ jɑɪv/	yive	buke	consistent
			yize	
			wive	

	/ pun/	poon	koon	inconsistent
			vide	
			poom	
	/ zɑl/	zoll	tholl	consistent
			zor	
			yik	
	/ fɪk/	fick	shick	consistent
			hob	
			fip	
	/ zol/	zole	thole	inconsistent
			zore	
			teep	
	/ kɛm/	kem	keng	consistent
			loof	
			chem	
	/ set/	sait	saich	inconsistent
			thait	
			mooze	
	/ tɪʃ/	tish	chish	consistent
			lotch	
			tis	
	/ jiz/	yeeze	yeethe	inconsistent
			heeze	
			boap	
	/ tus/	tuce	heach	inconsistent
			kuce	
			tushe	

List 3	/ bɑɪv/	bive	bithe	consistent
			zush	
			jive	
	/ hif/	hief	hiesh	inconsistent
			wief	
			boun	
	/ giv/	geve	yool	inconsistent
			geze	
			jeve	
	/ bɛp/	bep	hoaf	consistent
			dep	
			bek	
	/ ruk/	ruke	rupe	consistent
			luke	

			bab	
	/ rup/	roup	rouch	inconsistent
			loup	
			famb	
	/ dut /	doot	mave	inconsistent
			douch	
			goot	
	/ hɑɪf/	hife	yife	consistent
			gobe	
			hise	
	/ zɔt/	zaut	piff	inconsistent
			vaut	
			zaup	
	/ wʊk/	wook	woop	consistent
			fafe	
			yook	

List 4	/ bʊd/	bould	boug	inconsistent
			vazz	
			dould	
	/ væp/	vap	thap	consistent
			vach	
			touge	
	/ tʃɛn/	chen	chem	consistent
			fook	
			ken	
	/ ten/	tain	moop	inconsistent
			kain	
			taing	
	/ vɑɪt/	vite	thite	inconsistent
			wumb	
			vike	
	/ tɛp/	tep	libe	consistent
			kep	
			tech	
	/ tik/	teak	teap	inconsistent
			keak	
			nowl	
	/ kum/	koom	koon	inconsistent
			seaf	
			poom	
	/ tɛm/	tem	shodge	consistent

			kem	
			tang	
	/ gob/	gobe	goge	consistent
			bobe	
			han	

List 5	/ jæn/	yan	yam	consistent
			wan	
			joof	
	/ vætʃ/	vatch	vap	consistent
			goaf	
			zatch	
	/ pun/	poon	poom	inconsistent
			wape	
			koon	
	/zul /	zool	zoor	inconsistent
			dith	
			vool	
	/ vet/	vate	boose	inconsistent
			zate	
			vape	
	/gin /	geen	hoss	inconsistent
			geen	
			jeen	
	/ hen/	haim	poad	inconsistent
			haim	
			yain	
	/pɛm /	pem	peng	consistent
			vash	
			tem	
	/ gɪŋ/	ging	jing	consistent
			gim	
			rouch	
	/ vʊl/	vull	kag	consistent
			zull	
			vur	

Intervention Identification Lists

List 1	/ buk/	buke	guke	consistent
			hadge	
			bupe	

	/pɛd /	ped	peb	inconsistent
			ched	
			wole	
	/ ten/	tein	zock	inconsistent
			teing	
			kein	
	/bul /	bool	zad	inconsistent
			gool	
			boor	
	/ zok/	zoke	voke	inconsistent
			zote	
			geel	
	/git /	geat	geap	inconsistent
			zosh	
			deat	
	/ zɛp/	zep	vep	consistent
			pouge	
			zet	
	/tɛm /	tem	teng	consistent
			roaf	
			pem	
	/ pæb/	pab	pag	consistent
			chab	
			shive	
	/ gɑl/	goll	zick	consistent
			gorr	
			joll	

List 2	/buʒ /	bouge	fadge	consistent
			bouve	
			douge	
	/vɪʃ /	vish	vith	consistent
			zish	
			chook	
	/ sɑɪl/	sile	shile	inconsistent
			sire	
			boap	
	/sɑl /	soll	foll	consistent
			lig	
			sorr	
	/vis /	veace	nawk	inconsistent
			zeace	

			veafe	
	/ guz/	gooze	goove	inconsistent
			litch	
			dooze	
	/kud /	kude	tude	inconsistent
			heaf	
			kube	
	/ keb/	kabe	bouse	consistent
			tabe	
			kage	
	/pon /	poan	choan	inconsistent
			poang	
			salf	
	/ pɛm/	pem	peng	consistent
			kem	
			foaf	

List 3	/vik /	veak	veet	inconsistent
			theek	
			bown	
	/jɑl /	yoll	yorr	consistent
			holl	
			heem	
	/ vuk/	vuke	kab	consistent
			zuke	
			vupe	
	/lɪtʃ /	liche	riche	inconsistent
			lipe	
			koothe	
	/ tud/	tood	heem	inconsistent
			toob	
			pood	
	/tʃædʒ /	chadge	tadge	consistent
			chade	
			voof	
	/ rætʃ/	ratch	rak	consistent
			jush	
			latch	
	/pim /	peam	mooth	inconsistent
			keam	
			pean	
	/wol /	woul	youl	inconsistent

			wour	
			dace	
	/tɛm /	tem	pem	consistent
			foss	
			teng	

List 4	/ zætʃ/	zatch	zatk	consistent
			poaf	
			vatch	
	/ zɔt/	zaught	maff	inconsistent
			vaught	
			zauch	
	/viz /	veize	theize	inconsistent
			fock	
			veive	
	/bɪʃ /	bish	gish	consistent
			bith	
			zube	
	/vɑɪv /	vive	gatch	consistent
			vize	
			thive	
	/bæf /	baff	bash	inconsistent
			moak	
			jaff	
	/ sus/	suse	shuse	inconsistent
			mebb	
			sushe	
	/ kæg/	kag	houch	consistent
			kad	
			pag	
	/sɪʃ /	sish	sith	consistent
			louch	
			thish	
	/pɛd /	ped	peb	inconsistent
			ched	
			kawn	

List 5	/ wof/	woaf	woash	consistent
			kabe	
			foah	
	/ vʊd/	vood	deech	inconsistent
			voob	

			zood	
	/hif /	heaf	yeaf	inconsistent
			heas	
			faud	
	/ʃɛn /	shen	fen	consistent
			shem	
			wath	
	/ gɛp/	gep	gek	consistent
			libe	
			bep	
	/ sum/	soom	soong	inconsistent
			foom	
			yait	
	/ dit/	deet	tosh	inconsistent
			geet	
			deek	
	/sætʃ /	satch	sak	consistent
			toaf	
			fatch	
	/vub /	vube	ching	consistent
			vude	
			zube	
	/ set/	sate	sape	inconsistent
			bove	
			thate	