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Influence of Computerized Sounding Out on Spelling Performance for Children who do and not rely on AAC

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Abstract

Purpose—Spelling is an important skill for individuals who rely on augmentative alternative communication (AAC). The purpose of this study was to investigate how computerized sounding out influenced spelling accuracy of pseudo-words. Computerized sounding out was defined as a word elongated, thus providing an opportunity for a child to hear all the sounds in the word at a slower rate.

Methods—Seven children with cerebral palsy, four who use AAC and three who do not, participated in a single subject AB design.

Results—The results of the study indicated that the use of computerized sounding out increased the phonologic accuracy of the pseudo-words produced by participants.

Conclusion—The study provides preliminary evidence for the use of computerized sounding out during spelling tasks for children with cerebral palsy who do and do not use AAC. Future directions and clinical implications are discussed.

Keywords

spelling; AAC; phonological accuracy; cerebral palsy

The ability to spell is an essential literacy skill. This is particularly true for children with complex communication needs (CCN), who are unable to meet their communication needs through natural speech and often use augmentative and alternative communication (AAC). It has been well recognized that these children may struggle to attain functional literacy skills, including spelling [1–3]. It is estimated that 70 to 90% of individuals with CCN, who use

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Declaration of Interest

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AAC, demonstrate low levels of performance in literacy learning activities, including spelling [4]. Without functional literacy, children and adults with CCN are at a considerable disadvantage, severely limiting their social, educational, employment and volunteer opportunities [5].

Relatively few studies have investigated the spelling abilities of individuals with CCN who use AAC [6, 7]. Those studies that have investigated spelling abilities in individuals who use AAC have focused on the factors that appear to be necessary for or are a prerequisite to spelling development [7–9]. One factor mentioned or explored by these studies is the ability to produce speech, and more specifically the role of subvocal or vocal articulation in becoming proficient, independent spellers. The aim of the current study was to investigate if providing computerized sounding out, or auditory providing the sound sequences of words through a digitized recording of a human voice, during spelling would increase spelling accuracy for children with CCN, in this case children with cerebral palsy, who did and did not use AAC to meet their communication needs. Rather, can children, who are unable to produce speech clearly and accurately, use an external computerized sounding out to increase their spelling accuracy?

The Role of Subvocal Articulation in Spelling Development

Subvocal articulation has been defined as mouthing speech silently [10, 11], whispering, or vocalizing speech that is barely audible to others [12], or within the brain; “hearing” and practicing the target sounds without any form of overt articulation [13]. Subvocal articulation has been hypothesized to play a significant role within the phonological loop of Baddeley and Hitch’s [14] working memory model. Numerous studies have examined the effects of recall for stimuli varying in phonology (i.e. similar phonology – cat/hat- verses different phonological forms – dog/dad) and word length for typically developing children and adults when subvocal articulation was overtly manipulated, and when subvocal articulation was suppressed verbally (i.e. repeating “the” continuously during a phonological task) [15–19]. These studies indicated that when subvocal articulation is suppressed, the ability to recall phonological information about words with increased length decreases significantly, suggesting that the ability to rehearse information using subvocal articulation, either by moving the articulators to produce overt speech or not moving the articulators for silent speech, greatly increases the ability to recall information from memory for both children and adults. Children and adults with motor speech impairments, for example those who have cerebral palsy, potentially may not be able to benefit from subvocal articulation in the same manner as typically developing children and adults because of their motor speech impairments; thus potentially making them an ideal population to examine the use of such a compensatory strategy.

Bishop and Robson [6] examined spelling skills with 24 individuals between the ages of 10–18 years with cerebral palsy who were identified as either having severe dysarthria (severely unintelligible) or anarthria (no speech) and 24 age-matched controls. All but one of the participants with cerebral palsy used AAC to communicate. Results suggested that individuals with dysarthria or anarthria did not use different processes for spelling nonwords than their age-matched peers, and that accurate spelling was achieved without the use of

subvocal articulation. Bishop and Robson concluded that the ability to subvocally articulate was not necessary for successful spelling. However, the authors based this conclusion on one individual with cerebral palsy who used an alphabet supplementation board to repair communication breakdowns. Additionally, the authors reported the collection of speech intelligibility scores, however these scores were not presented in their publication. As such, based on their study, it remains unclear how or if speech intelligibility influenced spelling abilities in children and adults with motor speech impairments.

Other studies have suggested that the ability to use subvocal articulation may be a relevant component of spelling development. Hart et al. [7] examined the types of spelling errors made by four individuals, ages 9 to 23 years of age, with CCN who used AAC. Results from their study suggested that children with CCN consistently made more spelling errors than spelling-age-matched typical peers. Significant to this study was the observation that the spelling-age-matched typical peers were noted to overtly practice, or by definition, subvocally practice, the sounds of target words during the spelling activities (e.g. the child would overtly say the sounds /b/ /o/ /t/ when spelling “boat”); however the participants with CCN were not observed to do so. Hart et al. concluded that overt subvocal articulation could play a critical role in the development of spelling and that the children they tested with CCN may have shown less proficient spelling because they lacked the ability to overtly articulate, or subvocally articulate, the sounds in the targeted words.

In a related study, Larsson and Dahlgren Sandberg [20] drew a similar conclusion with respect to the ability to subvocally articulate when examining memory skills in children with CCN. In their study, Larsson and Dahlgren Sandberg compared the memory ability of 15 children with CCN to memory abilities of typically developing children. Results revealed that children with CCN had decreased memory skills compared to typically developing peers. The researchers concluded that the lack of articulatory ability of children with CCN significantly affected the subvocal rehearsal process and in turn reduced their memory skills.

Peeters et al. [8] reported on a longitudinal study examining factors related to early reading and spelling success for 52 children with cerebral palsy. Unlike previous studies Peeters et al. measured single word speech intelligibility. The study concluded that in relation to other early literacy predictors, speech production accuracy is the most important predictor of early reading and spelling success for children with cerebral palsy; thus, the better an individual’s speech intelligibility, the better their early reading and spelling abilities.

On balance, these studies demonstrate that the importance of subvocal articulation on spelling tasks has yet to be specifically determined. Although multiple studies have examined the spelling abilities of individuals with CCN, their participants were a heterogeneous group and speech intelligibility, though reportedly measured, was not fully described. This study was designed to determine whether the use of computerized sounding out during spelling would increase spelling accuracy for pseudo-words for children with cerebral palsy who did and did not use AAC.

Computerized Sounding Out Effects on Spelling Tasks for Children with Cerebral Palsy

If it is assumed that speech production is the most important factor in spelling development, as proposed by Peeters et al. [8], it might be hypothesized that those individuals with poorer speech intelligibility will not be able to effectively use subvocal articulation because of either their lack of coordinated speech movements or time constraints due to slow speech limiting the co-articulation of sounds. Additionally, if one assumes that voice output positively affects subvocal articulation by repeating the letter names for the AAC user, as suggested by the speech feedback during spelling tasks with children with autism or cerebral palsy [21, 22], then it might be presumed that the use of a computerized sounding out of sounds, or auditory providing the sound sequences of words through a digitized recording of a human voice, would increase spelling abilities for children with cerebral palsy with moderate to severe dysarthria who use AAC.

Based on past and current literature, it was hypothesized that there would be a relationship between speech intelligibility, subvocal articulation abilities, and spelling performance in those with CCN regardless of whether or not they use AAC. By providing speech sound information through computerized sounding out to children with cerebral palsy who have decreased speech intelligibility it was predicted that they would improve their spelling abilities. More specifically, computerized sounding out would increase their correct production of the consonants and vowels associated with target pseudo-words. However, if no relation was found, the results of the study would call into question the suggestion that speech production and overt subvocal articulation are necessary for accurate spelling.

Research Questions and Hypotheses

The purpose of this study was to determine the influence of computerized sounding out on spelling accuracy of target pseudo-words during spelling tasks completed by school age-children with mild to severe dysarthria of speech related to a diagnosis of cerebral palsy. These children did and did not use AAC to meet their communication needs. The research question addressed in this study was:

Research Question: Does a computerized sounding out of pseudo-words (i.e. providing an auditory model of the sound sequences within the target pseudo-word) increase accuracy of the phonological spelling elements – sounds of the target – in the pseudo-words spelled by children who have dysarthria related to cerebral palsy and who may or may not use AAC to communicate?

It was hypothesized that computerized sounding out would increase the accuracy of the pseudo-word spelling for children with cerebral palsy who do or do not use AAC. If no difference is found among children, this finding would illustrate that children with severe dysarthria who use AAC have access to intact orthographic representations of phonological sequences when those sequences are elongated to help alleviate phonological working memory demands [7, 20].

Methods

An AB single subject experimental research design was used involving four children who relied on AAC and three children who did not from various locations in the USA over the course of eight months. The independent variables were (a) a spelling generation task without computerized sounding out (i.e. Baseline), and (b) a spelling generation task with the computerized sounding out (i.e. Intervention). The dependent variables were (a) correctly spelled pseudo-words at the whole word level, and (b) percentage of correctly used phonology (i.e. sounds in the pseudo-words).

Participants

Initially eight children (three females, five males) with cerebral palsy who did and did not rely on AAC were recruited to participate. One child was excluded from the study due to an unstable performance during the Baseline Condition. The remaining seven children (two females, five males) completed the study. The participants ranged in age from 5 years, 8 months to 11 years, 3 months ($M = 7.9$ years of age). Standard American English was spoken within each participant's home. Participant demographics are summarized in Table 1. The inclusion criteria for participants included: (a) normal to corrected vision, (b) normal hearing [23], and (c) grade-level academic participation, with assignment lengths adjusted as needed with or without paraprofessional support as reported by parents and verified through school records.

Measures

To document 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) [24], 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. Marantz¹). 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 first author, or (b) the first author 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 recorder¹. 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 [25, 26].

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) [27], form A, was administered to each participant. Consistent with the testing procedures in the TWS-4 manual, the investigator 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

¹Marantz CM311A digital recorder, Marantz America, LLC, 100 Corporate Drive, Mahwah, NJ 07430-2041

typical writing method for writing activities (e.g. pencil and paper, typing on a laptop). The first author 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) [28] 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. Scores are contained in Table 2.

Experimental Stimuli

The experimental stimuli included 12 lists of 10 consonant-vowel-consonant (CVC) pseudo-words matched on phonotactic probability (i.e. the frequency with which a particular phoneme or phoneme sequence occurs in a language) [29, 39]. Pseudo-words were used to control for each participant's previous spelling experiences. Six lists of whole (unsegmented) pseudo-words were created for the Baseline and Return-to-Baseline Conditions. The remaining 6 lists of pseudo-words were recorded as both whole words and words segmented into phonemes and used during the Intervention Condition, when computerized sounding out was present.

The first author recorded the pseudo-words in a standard single-walled isolated sound booth using a digital recorder¹ with an adult Crown headset microphone². Pseudo-words were edited using Adobe Audition³. All pseudo-words were normalized to 80 dB, with 3 milliseconds of silence added to the beginning and ending 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—During the Intervention Condition participants were provided with the computerized sounding out presented auditorily through external speakers attached to the research laptop computer. Computerized sounding out provides a digitized voice presentation of the segmented sounds or sounding out for each target pseudo-word, for example if the target pseudo-word was *nooth* the computerized sounding out was /n/ /u/ /θ/. Participants were instructed to listen to the computerized sounding out twice, but they were given the opportunity to listen to the sound segmentations up to six times, if they chose to do so.

The computerized sounding out (i.e. individual speech sounds) was recorded in the same manner as the whole pseudo-words. Following the recording, the sounds were edited using Adobe Audition³. All sounds were normalized to 80 dB, with 3 milliseconds of silence added to the beginning and ending of each sound sequence. The duration of the sounds ranged from 0.35 seconds to 0.98 seconds ($M = 0.65$).

²Crown CM311A headset microphone, Crown Audio, Inc., P. O. Box 88807, Chicago, IL 60695-1807

³Adobe Audition, www.adobe.com/products/audition.html, San Jose, CA

Spelling generation task—Each participant was instructed to spell target pseudo-words as if they were completing a spelling test at school. The pseudo-words were presented individually through external speakers attached to the research laptop by the first author. Four participants used AAC devices to generate their response to the target pseudo-words and three participants used paper and pencil to write their answers.

Reliability of Measures

A graduate student in speech-language pathology served as the second judge. Twenty percent of the spelling responses across participants were transcribed and re-scored using video and audio recordings for each participant. Reliability between the first judge (i.e. first author) and second judge for 20% of all sessions across participants was 98.8%.

Procedures

This study involved two conditions: Baseline and Intervention. Participants were seen either at their home or a location of their parents' choice (i.e. five children were seen at home, one child was seen at a therapy centre, and one child in a daycare setting); however regardless of the setting the participants were seen by the first author in a quiet room without distractions. Each participant was seated at a table with the research computer and attached speakers in front of her or him. During each session, the first author instructed each participant that they would be hearing pseudo-words or alien words, but they were to use their preferred method of spelling to spell the pseudo-words like a real English word or words they would see in a book. Following the spelling of each of the pseudo-words the first author would read back what the child had spelled and then present the next pseudo-word. The verbal presentation of what the child had spelled was completed to ensure that the first author had transcribed the spelling of each target pseudo-word correctly, as well as to verify with each participant that he or she was ready for the presentation of the next pseudo-word. Verbal feedback on accuracy was not provided. The first author did provide statements intermittently encouraging the participant to continue to 'spell their best' and 'let's try another one'.

Baseline condition—During each Baseline session, lasting 30 minutes in length, a pseudo-word list consisting of 10 words was administered to each participant. A stable Baseline Condition was defined as a minimum of 3 sessions with a slope at or near 0 based on whole pseudo-word spelling accuracy (i.e. none of the pseudo-words presented were spelled correctly when examined at the 'whole' word level) [31]. The Intervention Condition was not implemented until a stable Baseline was attained.

Intervention condition—The Intervention Condition consisted of approximately five, 30 minute sessions over a two-week period. During each intervention session the participants were told that they would be spelling a list of 10 pseudo-words. They were instructed, as with the Baseline sessions, that they would be hearing pseudo-words or alien words and they were to spell the pseudo-words like real English words or words they would see in a book. Unlike the Baseline Condition however, after each target pseudo-words was presented the participants would then hear the computerized sounding out. Participants heard the computerized sounding out at least twice, however they could choose to listen to it up to 6 times.

Data Analyses

Each participant's spellings were analyzed for percentage of correctly used phonology (i.e. sounds in the pseudo-words). Correct representation of the target sound within each pseudo-word received a score of '1' and incorrect or missing sounds within each pseudo-word received a score of '0'. The percentage of correctly used phonology was calculated by examining the sounds generated by each participant for the target pseudo-words for each list divided by the total number of available sounds for each list.

Results

For all participants the percentage of correctly used phonology for both consonants and vowels increased from the Baseline Condition (i.e. computerized sounding out was absent) to the Intervention Condition (i.e. computerized sounding out was present). Results for seven participant's spellings are visually displayed and discussed individually in the following section.

Sam* was 8 years of age and had just finished first grade. He relied on a Dynavox VTM⁴ with direct selection to communicate. He primarily accessed iconic symbols to communicate, but was transitioning toward spelling messages with word prediction. Sam received speech-language therapy, physical therapy, and occupational therapy weekly through his school district. His speech intelligibility for words on the I-ASCC was 6% and for the HINT sentences was 10.2%.

Sam increased his percent correct consonants for phonology from Baseline to Intervention Condition (Figure 1). Sam's vowel percent correct increased during the Intervention Condition to roughly 50%; however he continued to make errors specific to short and long vowel sounds.

Ethan was 11 years, 3 months of age and was in the fourth grade. He had a diagnosis of cerebral palsy, used an Eco- 14 5 with direct selection to communicate, and a motorized wheelchair to move around. Ethan was fully included within his regular-education classroom with paraprofessional assistance. He received speech-language therapy, physical therapy, occupational therapy, and technology support weekly through his school district. Ethan used both iconic symbols and spelling, and was beginning to rely more on word prediction to assist his spelling of ideas for spontaneous communication. Ethan's speech intelligibility for words on the I-ASCC was 3%, and for the HINT sentences was 4.7%.

Ethan increased his percent correct for consonants for phonology for the target pseudo-words from the Baseline to Intervention Condition when computerized sounding out was provided (Figure 2). Vowels were observed to vary with a slight increase during Intervention sessions 1, 4, and 5.

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

⁴Dynavox V, DynaVox Mayer-Johnson, 2100 Wharton Street, Suite 400, Pittsburgh, PA 15203

Hank was 8 years, 10 months of age and was in the third grade. He had a diagnosis of cerebral palsy, used a Vantage Lite^{TM6} with direct selection to communicate, and used a motorized wheelchair. Hank was included within his classroom with the assistance of a paraprofessional half of the school day. He received special educational services to address concerns in language arts during the other half of his school day. Hank received speech-language therapy, physical therapy, and occupational therapy support through his school district. Hank's speech intelligibility for words on the I-ASCC was 3%, and his intelligibility on the HINT sentences was 7.6%.

Hank demonstrated only a change in phonology percent correct for vowels in the pseudo-words from the Baseline to Intervention Condition when computerized sounding out was provided (Figure 3). Percent correct for consonants during the Intervention Condition was observed to decrease from the Baseline Condition.

Zack was 7 years, 4 months and in the first grade at the time of the study. He had a diagnosis of cerebral palsy, used a Dynavox V^{TM5} with direct selection to communicate, and used a motorized wheelchair. Zack was included the majority of the day within his general-education classroom, specifically 5 hours, with paraprofessional assistance. He received special educational services for 2 hours each day. Additionally, Zack received speech-language therapy, physical therapy, and occupational therapy support through his school district. Zack used a combination of iconic symbols and spelling, relying on word prediction. Zack's speech intelligibility for words on the I-ASCC was 0%, and his intelligibility on the HINT sentences was 0%.

Zack increased his percent correct consonants for phonology from Baseline to Intervention Condition (Figure 4). Zack's vowel percent correct increased during the Intervention Condition during only 2 sessions (i.e., Intervention Session 3 and Intervention Session 5); otherwise he did not generate the correct vowel sound for the target pseudo-words.

Mallory was 6 years, 2 months and in kindergarten. She has a diagnosis of cerebral palsy and used her natural speech to communicate. Her mother reported that Mallory was home-schooled. She received speech therapy and occupational therapy through the local school system. Her speech intelligibility for words on the I-ASCC was 80%, and her intelligibility on the HINT sentences was 96.4%.

Phonologically, Mallory's percent correct for both consonants and vowels increased from Baseline to the Intervention Condition (Figure 5). Consonants were produced with greater accuracy than vowels during the Intervention sessions.

Sheri was 8 years, 7 months old and in the third grade. She had a diagnosis of cerebral palsy and used speech to communicate, and a wheelchair or crutches to assist her in moving around school and/or home. Sheri was fully included within her general-education classroom, with paraprofessional assistance. She received speech therapy, occupational

⁶Vantage Lite, Prentke Romich Company (PRC) World Headquarters, 1022 Heyl Road, Wooster, OH 44691

⁵Eco-14, Prentke Romich Company (PRC) World Headquarters, 1022 Heyl Road, Wooster, OH 44691

therapy, and physical therapy through the school. Sheri's speech intelligibility for words on the I-ASCC was 86%, and her intelligibility on the HINT sentences was 97.1%.

Sheri's phonology percent correct for consonants and vowels increased from the Baseline to Intervention Condition (Figure 6).

David was 5 years, 8 months and in kindergarten at the time of the study. He has a diagnosis of cerebral palsy and used speech to communicate. David was fully included in his general-education classroom. David received physical therapy and occupational therapy through the school, but had been dismissed from speech therapy at the beginning of the school year. His speech intelligibility for words on the I-ASCC was 84%, and his intelligibility on the HINT sentences was 99.3%.

David's phonology percent correct for consonants remained high from the Baseline to Intervention Condition (Figure 7). His phonology percent correct for vowels did show a slight increase from Baseline to the Intervention Condition.

Discussion

The purpose of this study was to better understand the influence of computerized sounding out (i.e. an auditory compensation) on spelling for children with motor speech impairments related to cerebral palsy, who do and do not rely on AAC. Seven children ranging in age from 5 years 8 months to 11 years 3 months demonstrated that the computerized sounding out improved spelling production.

Computerized Sounding Out Effects on Spelling Tasks for Children with Cerebral Palsy

It was hypothesized that computerized sounding out would increase the accuracy of pseudo-word spelling for children with cerebral palsy who do or do not use AAC. However, it was predicted that if no difference was found among children, the finding would illustrate that children with severe dysarthria who use AAC have access to intact orthographic representations of phonological sequences when those sequences are elongated to help alleviate phonological working memory demands [7, 20]. A review of the results revealed that by acoustically providing sound information through computerized sounding out all the children with cerebral palsy, including those who have decreased speech intelligibility, were able to obtain higher spelling scores both at the pseudo-word level and on the pseudo-word elements for phonology.

Regardless of the severity of speech intelligibility all of the children were able to listen to and apply the computerized sounding out to improve their phonologic accuracy at the element level. Thus, the findings of the present study substantiated that the use of a computerized sounding out was beneficial for most children in increasing spelling accuracy and could be successfully used by children ranging in age, receptive vocabulary abilities, and speech intelligibility. As with previous studies that have investigated providing letter names during spelling activities [21, 22], the current study demonstrates that providing letter sounds is an effective strategy to increase the spelling of pseudo-words.

Clinical Implications

The first clinical implication is that the use of a computerized sounding out of words to assist in spelling should be considered with a wide range of children varying in language and speech intelligibility abilities. Similar studies [21, 22, 32–34] have found that children who do and do not use AAC are successful at using computerized programs to assist with independent reading and spelling practice.

Secondly, the use of the computerized sounding out was successfully employed across a wide range of ages. Children ranged in age from 5 years, 8 months to 11 years, 3 months, and they all showed success in using the computerized sounding out to spell pseudo-words. All the children commented that they felt their spelling was better when they had access to the computerized sounding out then when they did not.

Limitations and Future Directions

This study contributes to the literature by providing initial data on one strategy that may increase successful, accurate spelling for children with cerebral palsy who use and who do not use AAC. However, there are several limitations to the current study that should be considered. Due to the small number of children with a single subject design it is not feasible to generalize these results across the population of children with CCN or cerebral palsy. Future research should include expanding the number of children to allow for better understanding on how the use of computerized sounding out impacts the spelling accuracy of children with cerebral palsy who do and do not use AAC.

A second limitation of the current study is the wide variability within the children's speech intelligibility. Those children who used AAC had severe dysarthria and considerably low speech intelligibility abilities (i.e. ranging from 0 to 10.2% on single words and sentences). The children who did not use AAC had higher speech intelligibility, between 80 to 90% at the single word and sentence levels. Future research should identify children with speech intelligibility in the middle of the range, 30 to 70%. Examining a wider range of speech intelligibility will provide a better understanding of how computerized sounding out influences spelling accuracy for children who have relatively low to moderate speech intelligibility.

The final limitation addresses the issue that the children within this study also had a wide range of receptive vocabulary abilities. Weak vocabulary scores have been associated with poor phonological skills and ultimately poor literacy skills for children who use AAC and children who do not use AAC [35–40]. However, it is unclear how vocabulary impacts one's spelling development, and ultimately the use of computerized sounding out. Adding more children with low and high vocabulary abilities would assist in understanding how these differences affect the use of computerized sounding out on pseudo- and real-word spelling. Future studies should consider examining the effects of computerized sounding out on spelling tasks for other populations with and without vocabulary and overall language concerns to better understand the role and relationship of vocabulary and language to spelling development.

Conclusion

In conclusion, this study provides preliminary evidence for the use of a computerized sounding out during spelling tasks for children with cerebral palsy who do and do not use AAC. Seven of the seven children were successful in increasing their production of phonologic elements when spelling pseudo-words when provided the computerized sounding out regardless of their ability to produce clear speech. Future research is required to determine how language and reading abilities affect the use of computerized sounding out with children who have a range of speech intelligibility abilities. With enhanced spelling abilities, and overall literacy skills, children who do and do not require AAC due to the severity of their speech impairment will be better prepared to participate in advanced education, social, and employment opportunities.

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Appendix A

Nonword Spelling Lists

Baseline Spelling Lists		
	Nonword Pronunciation	Spellings
List 1	/wɒt/	waught
		wought
		waut
	/wʊk/	wook
		zail
		zale
	/zel/	zeil
		voll
		deeze
	/dɪz/	dease
		deize
		deese
	/dʒev/	jev
		toke
		toak
	/tok/	tolk
		tuke
		bood
	/gʌrb/	bould
		gibe

Baseline Spelling Lists

	Nonword Pronunciation	Spellings
List 2	/zel/	zail
		zale
		zeil
		zoll
	/zɔl/	sate
		sait
		seight
		saight
	/set/	sete
		seat
		fick
		yeeze
	/yiz/	yease
		yeize
		yese
		yieze
	/yeese/	yeese
		yive
		poon
		pune
	/pewn/	pewn
		kem
	/kɛm/	toose
		tuce
		tuise
		tuse
	/tɪʃ/	tish
List 3	/doot/	doot
		dute
		duit
		dewt
	/doute/	doute
		dutie
		bep
		roop
	/roup/	roup
		roupe
		ruke
		zought
	/ruk/	ruke
		zought

Baseline Spelling Lists	
Nonword Pronunciation	Spellings
	zaught
	zaut
/wʊk/	wook
/hɪf/	hief
	heef
	heaf
/hɑɪf/	hife
/gɪv/	geave
	geeve
	geve
/bɑɪv/	bive
List 4	
	vight
/vɑɪt/	vite
	veight
/væp/	vap
/kʊm/	koom
	kume
	komb
	keum
/tɛm/	tem
/bʊd/	bood
	bould
/gob/	gobe
/tɛn/	tain
	tane
	tein
/tʃɛn/	chen
/tik/	teak
	teek
	tique
	teik
	tic
	tiek
/tɛp/	tep
List 5	
	zool
/zʊl/	zuel
	zule
	zoul

Baseline Spelling Lists

Nonword Pronunciation	Spellings
/vɪl/	vull
/ɡɪn/	geen
	gean
	gene
/ɡɪŋ/	ging
/pʊn/	poon
	pune
	pewn
/pɛm/	pem
/vɛt/	vate
	vait
	veight
	vaight
	vete
	veat
/vætʃ/	vatch
/hɛn/	hain
	hane
	hein
/yæn/	yan

Intervention Spelling Lists

	Nonword Pronunciation	Spellings	Sounds for Computerized Sounding Out
List 1	/ten/	tain	
		tane	/t/ /e/ /n/
		tein	
	/tɛm/	tem	/t/ /ɛ/ /m/
		ped	/p/ /ɛ/ /d/
		pead	
	/pæb/	paid	
		pab	/p/ /æ/ /b/
		geet	/g/ /i/ /t/
	/git/	geat	
		guite	
		buke	/b/ /u/ /k/
	/buk/	zoke	/z/ /o/ /k/
		zoak	
		zolk	
	/zɛp/	zep	/z/ /ɛ/ /p/

Intervention Spelling Lists

	Nonword Pronunciation	Spellings	Sounds for Computerized Sounding Out
List 2	/bul/	bool	/b/ /u/ /l/
		buel	
		bule	
		boul	
	/gal/	goll	/g/ /ɑ/ /l/
	/pon/	pone	/p/ /o/ /n/
		pown	
		poan	
	/pem/	pem	/p/ /ɛ/ /m/
	/kud/	kude	/k/ /u/ /d/
		kood	
		kewd	
		keud	
	/keb/	kabe	/k/ /e/ /b/
	/guz/	guse	/g/ /u/ /z/
		gooze	
guise			
gose			
goose			
/buʒ/	bouge	/b/ /u/ /ʒ/	
/vis/	vease	/v/ /i/ /s/	
	viece		
	veace		
	veese		
/vɪʃ/	vish	/v/ /ɪ/ /ʃ/	
/tus/	toose	/t/ /u/ /s/	
	tuce		
	tuice		
	tuse		
/tɪʃ/	tish	/t/ /ɪ/ /ʃ/	
List 3	/vik/	veak	/v/ /i/ /k/
		veek	
		vique	
		veik	
		vic	
	/vuk/	viek	
		vuke	/v/ /u/ /k/
	/lɪtʃ/	litch	/l/ /ɪ/ /tʃ/
		lich	
		liche	
/rætʃ/	ratch	/r/ /æ/ /tʃ/	

Intervention Spelling Lists

	Nonword Pronunciation	Spellings	Sounds for Computerized Sounding Out
List 4	/wɒl/	wole woll woal wowl woul	/w/ /o/ /l/
	/yɒl/	yoll	/y/ /ɒ/ /l/
	/tʊd/	tood tould	/t/ /ʊ/ /d/
	/tʃædʒ/	chadge	/tʃ/ /æ/ /dʒ/
	/pɪm/	peam peem peme	/p/ /i/ /m/
	/tɛm/	tem	/t/ /ɛ/ /m/
	/pɛd/	ped pead paid	/p/ /ɛ/ /d/
	/kæɡ/	kag	/k/ /æ/ /ɡ/
	/bæf/	balf baff baph baugh	/b/ /æ/ /f/
	/bɪʃ/	bish	/b/ /ɪ/ /ʃ/
List 5	/zɔt/	zought zaught zaut	/z/ /ɔ/ /t/
	/zætʃ/	zatch	/z/ /æ/ /tʃ/
	/vɪz/	veeze vease veize vese vieze veese	/v/ /ɪ/ /z/
	/vaɪv/	vive	/v/ /aɪ/ /v/
	/sus/	soose suce suice suse	/s/ /u/ /s/
	/sɪʃ/	sish	/s/ /ɪ/ /ʃ/
	/set/	sate sait seight	/s/ /e/ /t/

Intervention Spelling Lists		
Nonword Pronunciation	Spellings	Sounds for Computerized Sounding Out
	saight	
	sete	
	seat	
/sætʃ/	satch	/s/ /æ/ /tʃ/
/sum/	soom	/s/ /u/ /m/
	sume	
	somb	
	seum	
	som	
/ʃɛn/	shen	/ʃ/ /ɛ/ /n/
/vʊd/	vood	/v/ /ʊ/ /d/
	vould	
/vub/	vube	/v/ /u/ /b/
/dit/	deat	/d/ /i/ /t/
	deet	
	duite	
/gɛp/	gep	/g/ /ɛ/ /p/
/hif/	hief	/h/ /i/ /f/
	heef	
	heaf	
/wof/	woaf	/w/ /o/ /f/

Figure 1.
Sam's percentage correct phonology

Figure 2.
Ethan's percentage correct phonology

Figure 3.
Hank's percentage correct phonology

Figure 4.
Zack's percentage correct phonology

Figure 5.
Mallory's percentage correct phonology

Figure 6.
Sheri's percentage correct phonology

Figure 7.
David's percentage correct phonology

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	1 st (end of)	Dynavox V™
Ethan	11;3	4 th	Eco-14
Hank	8;10	3 rd	Vantage Lite™
Zack	7;4	1 st	Dynavox V™
Mallory	6;2	kindergarten	Speech
Sheri	8;7	3 rd	Speech
David	5;8	kindergarten	Speech

Note.

* All names were changed for participant confidentiality.

Table 2
Participant Scores on Standardized Testing & Intelligibility Scores at the Word and Sentence Levels (N = 7)

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%
Ethan	5	67*	171	108	3%	4.7%
Hank	2	73	108	80	3%	7.6%
Zack	0	<77	58	64	0%	0%
Mallory	1	82	111	107	80%	96.4%
Sheri	6	78*	93	74	86%	97.1%
David	1	82	115	116	84%	99.3%

Note.

SS = Standardized Score;

* indicates at or above a first grade equivalency level