Lexical Access in Individuals with Cerebral Palsy and Severe Speech and Physical Impairment

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LEXICAL ACCESS IN INDIVIDUALS WITH CEREBRAL PALSY AND SEVERE SPEECH AND PHYSICAL IMPAIRMENT

by

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A dissertation submitted to the Graduate Faculty in Speech-Language-Hearing Sciences in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York

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This manuscript has been read and accepted for the Graduate Faculty in Speech-Language-Hearing Sciences to satisfy the dissertation requirement for the degree of Doctor of Philosophy.

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ABSTRACT

Lexical Access in Individuals with Cerebral Palsy and Severe Speech and Physical Impairment

by

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This study examined lexical access in adolescents and adults with cerebral palsy and severe speech and physical impairment (CP/SSPI) who have limited language production due to severe dysarthria or anarthria. Deficits in language comprehension and in phonological knowledge have been well documented (Beukelman & Mirenda, 2005; Binger & Light, 2008). Although many individuals with CP/SSPI perceive segmental differences, investigations of whether impaired speech production interferes with sound awareness and language development have led to contradictory findings (Card & Dodd, 2006; Dahlgren Sandberg & Hjelmquist, 1997; Foley & Pollatsek, 1999; Vandervelden & Siegel, 1999).

The motor theory of speech perception (Liberman & Mattingly, 1985) postulated that articulatory gestures are the basis for speech perception. Similarly, subvocal rehearsal (Bishop, Byers Brown, & Robson, 1990), assumed to underlie phonological working memory and aspects lexical development, requires articulatory coding. To date, however, the impact of a severe speech production deficit on lexical activation and the organization of the mental lexicon has not been investigated. Such an investigation may reveal limitations in lexical
access that also play a role in language deficits that support or refute these views of an articulatory basis of speech perception and lexical development and access.

Investigations of spoken word recognition in children and adults using the visual world eye tracking paradigm have characterized this process as a cascading flow of information, whereby partial phonological representations activate semantic representations. This suggests a reciprocal influence between impoverished semantic and phonological representations that may explain the language impairment observed in CP/SSPI (Smith, 2001), where less efficient phonological processing might impact the ability to activate semantic associates. Thus, a weakness at one level of processing can influence another.

Moreover, children are less efficient than adults at eliminating competitors and resolving ambiguity (Huang & Snedeker, 2010; Sekerina & Brooks, 2007). If spoken word recognition is also less efficient for individuals with CP/SSPI, this may be attributed either to their speech production limitations or, more generally, to their delayed language development. The hypothesis of this study is that spoken word recognition will be severely reduced or absent in this population although individual differences in speech production and vocabulary comprehension may result in variations. The visual world eye tracking paradigm has been widely used to study activation in spoken word recognition, but has not been used with this population.

Method. Sixteen 15 to 50-year-olds with CP/SSPI participated. The experiment examined how these listeners resolve phonological or semantic competition among referents for a spoken word as it unfolds over time. In each trial, they saw four images, while listening to a spoken word as their eye movements were monitored. Each trial consisted of an auditory
target word (e.g., tire), and four pictures including a picture corresponding to the target word, a phonological competitor (e.g., TIRE), or a semantic competitor (TIE/SHIRT) and two images that were phonologically and semantically unrelated to the target. In the phonological condition, listeners typically fixate more on pictures that are phonologically related than on unrelated images. In the semantic condition, listeners typically fixate on pictures that are semantically related more than unrelated images. Fixations to the target should be greater than to the three other images. An additional semantic onset competitor condition included a picture that was semantically related to an absent phonological competitor of the target (e.g., the target is TIRE and the competitor is a picture of a SHIRT related to absent TIE).

Because there was no single appropriate control group for the subjects, eye gaze patterns were compared to published data as well as to a group of eight age-matched adults with no neurological impairment (NNI). The participants were also compared to children with typical development (6;8 to 12;4 years-of-age, \( M = 8;9, \ SD = 1.97 \)) from a previous study using the same stimuli and experimental design.

**Results.** Participants with CP/SSPI revealed significant fixations to targets and to phonological onset competitors but not to semantic relatives beyond those directed to unrelated pictures. In contrast, the adults with NNI rapidly fixated on the target picture, did not demonstrate significant fixations to phonological competitors and demonstrated marginally significant proportion of fixations to semantic relatives. Children with TD demonstrated significant phonological and semantic competition effects. None of the three groups demonstrated activation of semantic onset competitors. The time plots of gaze behavior revealed that adults did quickly fixate on phonological and semantic competitors, but then very
quickly fixated on the target, while the participants with CP/SSPI and higher PPVT-4 scores exhibited eye gaze patterns more similar to adults while those with lower scores were less efficient at resolving this competition.

**Conclusion.** Despite the presence of a severe speech impairment, individuals with CP/SSPI demonstrated phonological activation, although with less efficient processing of incoming phonological information, suggesting that theories relying on an articulatory bases of speech perception do not offer a complete explanation of lexical development and access in this population.

*Keywords: Cerebral palsy, eye tracking, lexical access, spoken word recognition*
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Adolescents and adults with cerebral palsy (CP) and severe speech and physical impairment (SSPI) who have never developed fully intelligible speech often exhibit deficits in all language domains. Limited language production and phonological impairments in this population have been well documented (Beukelman & Mirenda, 2005; Binger & Light, 2008). The question of the impact of a severe speech impairment in individuals with CP/SSPI has been central to investigations of the language deficits of this population and various theories have postulated a connection between the two.

The motor theory of speech perception (Liberman & Mattingly, 1985) postulates that articulatory gestures are the basis for speech perception. Similarly, subvocal rehearsal (Bishop et al., 1990), is assumed to underlie phonological working memory (Baddeley, 1986) and aspects of lexical development requiring articulatory coding. To date, however, the impact of a severe speech production deficit on lexical activation and the organization of the mental lexicon has not been investigated. Such an investigation may reveal limitations that also play a role in language deficits that support or refute these views of an articulatory basis of speech perception and lexical development and access.

Previous studies have focused on the ability of individuals with CP/SSPI to detect phonetic contrasts or on lexical decision tasks that have indicated that individuals with CP/SSPI have weak phonological knowledge and vocabulary levels that tend to be well below chronological age, suggesting deficits in lexical access or representation, and in the organization of the mental lexicon. Investigations of spoken word recognition in children and
adults have characterized this process as a cascading flow of information, whereby partial phonological representations activate semantic representations, so that a weakness at one level of processing can impact other levels (Huang & Snedeker, 2010). There is also a developmental trajectory in this process, as children are less efficient than adults at eliminating competitors and resolving ambiguity (Huang & Snedeker, 2010; Sekerina & Brooks, 2007).

Thus, as predicted by the motor theory or the lack of subvocal rehearsal as predicted by the theory of phonological memory (Baddeley, 1986), the hypothesis of this study is that spoken word recognition will be deficient in this population and will reflect the absence of adequate phonological representations. Understanding the relation between speech production and spoken word recognition will add to the existing theories of lexical access. If individuals who cannot speak have less efficient phonological processing and demonstrate an absence of semantic activation, this would support the view that lexical access and the organization of the mental lexicon are not independent of production. However, if individuals with CP/SSPI demonstrate lexical activation similar to adults and children who have developed fully functional speech, this would suggest that lexical organization is independent of production.

Eye tracking is now a well-established tool for studying lexical access. By examining competition across an array of referent pictures following an auditory word, the time course of spoken word recognition has been well described in adults with no neurological impairment (NNI) and children with TD (Huang & Snedeker, 2010; Yee & Sedivy, 2006). While the primary goal of this study was to investigate these processes in adolescents and adults with CP and SSPI, a secondary goal of this study was to establish the visual world eye tracking paradigm as a method of studying the language processing of individuals with severe motor
impairment. The paradigm is based on the rapid and nearly seamless integration of visual and linguistic information, allowing ongoing comprehension of spoken words to be observed by recording eye movements as a word unfolds (Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). Because this method eliminates the need for adaptations in its administration, lexical access and the time course of spoken word recognition in individuals with CP/SSPI can be directly compared with that of individuals without disabilities as well as with other clinical populations.

Although the technology underlying eye tracking in visual world paradigms is the same as the technology in many electronic communication devices that rely on controlled eye gaze, visual world paradigms examine unconscious visual attention via eye gaze while processing auditory language. The approach does not require a motor response and thus avoids the challenges of motor responses for individuals from this population.

**Lexical Deficits in Individuals with CP/SSPI**

**Speech and motor impairments.** Cerebral Palsy (CP) is a motor impairment attributed to non-progressive disturbances during brain development in the fetus or infant estimated to affect three to four individuals per 1000. The motor disorders of CP are frequently accompanied by disturbances of sensation, perception, cognition and behavior, by epilepsy and by secondary musculoskeletal problems and visual impairments. The severity of motor impairments is related to the severity of speech impairments and the likelihood of intellectual disabilities (Nordberg, Miniscalco, Lohmander, & Himmelmann, 2012; Palisano, Rosenbaum, Bartlett, & Livingston, 2007). Individuals with CP with limited speech intelligibility
(dysarthria) or those who do not produce intelligible speech (anarthria) (Redmond & Johnston, 2001; Smith, 2001) are typically classified by the Gross Motor Function Classification System (GMFCS-E&R) (Palisano et al., 2007) at Levels IV or V, the greatest severity of motor impairment, with extensive limitations in head and trunk control. They require physical assistance and extensive assistive technology that does not fully compensate for their limitations (Palisano et al., 2007). In addition, they are also typically classified by the Manual Ability Classification System (MACS) (Eliasson et al., 2006) at Levels IV or V, the greatest level of impairment of use of the hands. Appendix A lists a complete description of these classification systems.

**Expressive language deficits and augmentative and alternative communication (AAC).** In general, different modes of communication are used with different communication partners depending on the degree of intelligibility of speech of the individual with CP/SSPI, the partner’s degree of familiarity with him and a number of other factors (Blackstone & Hunt Berg, 2003). Aided communication modes consist of symbols arranged on a display that the individual indicates in some manner while the communication partner assists in interpreting the message, including speech generating devices (SGDs) where messages are spoken aloud through digitized or synthesized speech (Beukelman & Mirenda, 2005). Messages are composed by selecting the component parts (e.g., symbols, letters of the alphabet) from communication displays or that are stored in the SGD.

Different modes may be used in different environments. For example, while in school, children may use aided communication to participate in academic activities and communicate with peers and unaided modes such as pointing and vocalizing at home with their parents.
Individuals also tend to use whatever speech abilities they have. The use of AAC does not mean that speech production is not used and in fact, as a result of AAC intervention, speech production often increases (Millar, Light, & Schlosser, 2005).

While some individuals with CP/SSPI who use AAC systems are independent communicators (Blackstone & Hunt Berg, 2003) and are able to use spelling to convey messages, difficulties acquiring even basic literacy skills in learning to spell are quite common (Smith, 2001). For those who cannot spell, picture symbols or photographs (i.e., aided symbols) that represent words or phrases are often used, but the expressive lexicon is often severely constrained (Von Tetzchner & Martinsen, 1997). Expressive vocabulary is restricted to the number of symbols made available on the communication display, the ability of the individual to navigate and locate a single message from a large number of symbols, or difficulty in representing the idea to be conveyed through a graphic symbol.

In comparison with individuals who use natural speech and have access to thousands of concepts in their expressive vocabularies, those with CP/SSPI who use AAC seldom have access to more than a few hundred concepts. When there is a breakdown in communication, individuals may not be able to indicate that a word is not available, to modify semantic information or to use these strategies (Smith, 2001).

Moreover, as a result of their severe limitations in physical ability, many individuals who use AAC also require an alternative access method resulting in communication that is laborious and far slower than natural speech. It takes longer to select a graphic symbol than to articulate the corresponding word (Von Tetzchner & Martinsen, 1997). The communication rate of individuals who use aided AAC less than 15 words per minute as compared with the
natural speaking rate of 150 to 250 words per minute. As a result, conversational initiations are limited and single word utterances predominate (Smith, 1996).

**Language comprehension.** Although poor receptive vocabulary scores and limited vocabulary growth have been reported for individuals with CP/SSPI (Bishop et al., 1990; Foley & Pollatsek, 1999; Koppenhaver & Yoder, 1992; Roth & Cassatt-James, 1989; Smith, 2001), comprehension is often an overlooked component in augmented language development while the focus for this population has traditionally centered on language production (Sevick, 2006). Many individuals with CP/SSPI have Peabody Picture Vocabulary Test, Fourth Edition (PPVT-4) (Dunn & Dunn, 2007b) scores below those of peers of the same age without disabilities (Dahlgren Sandberg, Smith, & Larsson, 2010) and below that of younger children with typical language development (Smith & Blischak, 1997). The language age of those with CP and no functional speech is also below that of individuals with CP and impaired but functional speech (Foley & Pollatsek, 1999; Vandervelden & Siegel, 1999) and below that of adolescents and young adults with CP and unimpaired speech (Bishop et al., 1990).

Recent studies have examined developmental trajectories of expressive and receptive communication in CP/SSPI. Over two years, in studying a large group of children with CP with a mean age of 8;6 years, receptive communication was found to be more closely related to intellectual disability while the development of expressive communication was more closely related to type of motor disorder (Vos et al., 2014).

Increasingly, the relationship between type and severity of brain lesion on MRI and communication abilities in children with CP have been conducted. About 15% of individuals with CP have dyskinetic type of cerebral palsy including athetosis and dystonia, characterized
by severe involuntary movements and fluctuating muscle tone and deep grey matter brain lesions. White matter pathways are more likely to be affected in children with spastic CP, accounting for 70 to 80% of cases. These individuals have increased muscle tone, making movement difficult or impossible and tend to have severe cognitive impairment.

Children with CP/SSPI 18 to 36 months of age had more severe cortical and deep grey matter brain lesions and poorer overall communication skills than those with periventricular white matter lesions (Coleman, Fiori, Weir, Ware, & Boyd, 2016) as measured by the Communication and Symbolic Behavioral Scales Developmental Profile Infant-Toddler Checklist (CSBS-D)(Wetherby & Prizant, 2002).

In contrast, deficits in receptive language structure and pervasive semantic deficits of 5 to 6-year-old children with CP/SSPI as measured by the PPVT-4 (defined as a standard score <1SD and the Preschool Language Scale, 4th edition, (PLS-4) (Zimmerman, Steiner, & Pond, 2002) appear to be associated with a spastic dominant motor type of cerebral palsy. Impairments were seen across language subdomains, rather than an impairment within a specific linguistic area (Mei et al., 2015). Cognition and not severity of motor disorder (GMFCS levels) were independently associated with language impairment (Mei et al., 2015).

Similarly, those with dyskinetic type of CP had delays in sentence type comprehension that increased with sentence complexity but revealed less prominent cognitive deficits while those with spastic CP tended to have severe cognitive impairment and deficits involving language comprehension (Geytenbeek, Heim, Knol, Vermeulen, & Oostrom, 2014). Using the Computer Based instrument for Low Motor Language Testing (C-BiLLT) (Geytenbeek, Heim, Vermeulen, & Oostrom, 2010), developed to assess comprehension of spoken language of
children with CP/SSPI, the development of sentence comprehension followed the
developmental trajectory of children with TD but at a much slower rate. Up to at least 12 years of age, sentence comprehension was still developing. Thus, subtype of CP is a primary consideration in language development (Geytenbeek et al., 2014).

Age may also play an important factor in these results. Geytenbeek (et al., 2014) included 68 children ranging in age from 1;6 to 12;0 years. It is possible that in older children when myelination is complete (Coleman et al., 2016), results may differ. This supports the recommendation (Geytenbeek et al., 2014) that language development should be followed even beyond 12 years across all age groups.

**Phonological awareness.** The relationship between severe speech impairment and phonological awareness has also been extensively investigated in children, adolescents and adults with CP/SSPI (Bishop et al., 1990; Bishop & Robson, 1989b; Card & Dodd, 2006; Dahlgren Sandberg, 2001; Dahlgren Sandberg et al., 2010; Foley & Pollatsek, 1999; Peeters, Verhoeven, deMoor, & Van Balkom, 2009; Vandervelden & Siegel, 1999). Some investigators have found specific areas of difficulty for children with cerebral palsy who cannot speak, (e.g., judging written words for rhyme, segmenting syllables, phoneme manipulation) (Card & Dodd, 2006). Other studies revealed difficulties across a wider range of phonological tasks including phoneme segmentation, reading, and spelling (e.g., Vandervelden & Siegel, 1999).

Still other studies found that children with CP/SSPI perform equivalently to peers without disabilities on phonological awareness tasks yet score lower on tests of reading and writing, indicating that children with disabilities are not able to apply their phonological knowledge (Dahlgren Sandberg & Hjelmquist, 1986). Analysis of group data of a more recent
A cross-linguistic study of Irish and Swedish children with CP/SSPI suggested some common abilities and difficulties, while exploration of individual profiles highlighted the heterogeneity of the participants (Dahlgren Sandberg et al., 2010).

**Issues related to testing.** Comprehension or IQ assessment in individuals with severe motor impairment may reflect the ability to perform a motor task rather than actual comprehension or IQ (Geytenbeek et al., 2010). Although standardized tests are often used, norms cannot be applied because of the test modifications required (Dunn & Dunn, 2007b). Moreover, because tasks must be adapted to the motor abilities of these individuals in order to test various aspects of language ability, different tasks and procedures may yield different results (Geytenbeek et al., 2010; Higgenbotham & Bedrosian, 1995). Test adaptations may also change the level of difficulty of the task from its original form (Vandervelden & Siegel, 1999).

For example, if an individual with CP/SSPI is unable to point to one of four pictures on a display, the examiner may use partner assisted scanning (Burkhart, 2012) where each picture is pointed to until the individual indicates his choice. While beneficial to the examiner, the use of partner assisted scanning may add greater memory demands to the task and increase time of administration. It may also provide inadvertent cues.

The standardized language comprehension test used most frequently in past investigations has been the (PPVT-IV; Dunn & Dunn, 2007a) in its current and older versions. The test measures only spoken vocabulary comprehension and is intended to reveal an individual’s ability to indicate the referent of words out of a visual display of four pictures. The PPVT-4 can be administered with alternate response formats for individuals with motor impairment with seemingly reliable and valid results when these formats are used (Bristow &
administration of the PPVT-4 is subject to the same limitations as other tests adapted for severe motor impairment.

Several investigators have adapted paradigms that require less motor control to assess language abilities in children with CP/SSPI. Paradigms typically associated with infant development research such as *looking while listening* or *paired comparisons* have been employed but are limited in the level of language that can be assessed (Cauley, Golinkoff, Hirsh-Pasek, & Gordon, 1989). ERP paradigms for the assessment of language and cognition (Byrne, Dwyan, & Connolly, 1995) have also been attempted using the PPVT-R (Dunn & Dunn, 1981).

More recently, the C-BiLLT (Geytenbeek et al., 2010) allowed testing of language comprehension of children for whom testing had not previously been possible. This test was developed specifically to permit a child to use his preferred mode of response. Estimates of language comprehension based on results of the C-BiLLT surpassed the clinical impressions for eight children who were able to be evaluated through this instrument. Preliminary results suggested that the C-BiLLT has the potential to become a useful instrument to assess comprehension of spoken language in children with complex communication needs and cerebral palsy (Geytenbeek et al., 2010) and was subsequently used to assess spoken word comprehension (Geytenbeek et al., 2014).

The results of these studies have been difficult to compare because of population differences, differences in experimental design and procedures or methods of analysis. Age at the time of testing is particularly important because it reflects the amount of exposure to
literacy instruction. While some studies have included young school-aged children, others have focused on adolescents and adults (Binger & Light, 2008).

Control groups have also varied. Some studies used children with no motor deficits (e.g., Vandervelden & Seigel, 1999), whereas others compared individuals with cerebral palsy who could not speak to individuals who could (e.g., (Bishop et al., 1990). Because severe speech impairment is usually accompanied by severe motor impairment, comparing individuals with cerebral palsy who can and cannot speak is challenging, even if participants are matched for non-verbal IQ or years of school, since the physical impairment in those who cannot speak will be more severe.

Moreover, recent research that has demonstrated language differences based on subtype of CP may influence participant performance. As this information becomes more widely available, selection of participants will have to consider this in addition to speech impairment and other characteristics.

**Issues related to measurement of speech intelligibility.** Several communication ability scales have been developed to permit a more detailed description of severity than merely using the terms dysarthria and anarthria and to capture impairments in both speech and language. These include the Communication Function Classification System (CFCS) (Hidecker et al., 2011), the Viking Speech Scale (VSS) (Pennington, Virella, & Mjoen, 2013) and the Speech Language Profile Groups (SLPG) (Hustad, Gorton, & Lee, 2010), each using different classification systems to describe speech and language. A comparison of the three classification systems indicated consistency with regard to how well they separated children based on speech intelligibility scores (Hustad, Oakes, McFadd, & Allison, 2015).
However, the SLPG (Hustad et al., 2010) was sensitive to both speech and language impairments, classifying children as having speech motor involvement and typical language comprehension, speech motor involvement and language comprehension impairment or no speech motor involvement. Children with dysarthria and language impairment were found to be less intelligible than those with motor disorder alone (Hustad et al., 2015) indicating that speech and language both contribute to intelligibility.

Yet for individuals with the most severe speech impairment, interrater agreement may not differentiate between intelligibility. The Index of Augmented Speech Comprehensibility in Children (I-ASCC) (Dowden, 1997) assesses on a five point scale how well an individual with CP/SSSPI could be understood by an unfamiliar listener with and without contextual cues. A measure such as this that distinguishes intelligibility based on the comprehensibility of an individual’s message might prove more useful in comparing a group of individuals with each other and to correlate speech with performance on other measures.

Models of Lexical Access

Models of lexical access that describe the process of spoken word recognition can reveal lexical knowledge and shed light upon the function and structure of the mental lexicon in adolescents and adults with CP/SSPI. Investigations of spoken word recognition, which is central to speech and reading comprehension (Marslen-Wilson, 1987; Marslen-Wilson & Welsh, 1978) and related to overall language ability (McMurray, Samelson, Lee, & Tomblin, 2010) have not been conducted with this population.
Models of lexical access describe the point at which various properties of stored lexical representations in the mental lexicon become available to the rest of the language processing system (Tyler & Frauenfelder, 1987). Across all models, spoken word recognition begins with acoustic-phonetic input. Logically then, phonological processing must precede word identification and semantic processing. Activation of word candidates varies with the degree of match between the speech signal and stored lexical representations and candidate words compete for recognition simultaneously (Weber & Scharenborg, 2012).

According to the cohort model (Marslen Wilson & Tyler, 1980) words starting with the same sound or sounds become partially active as a listener hears the word. A given word is usually consistent with any one of a large number of possibilities (e.g., ham could be the start of hammer, hammock or hamburger) (Marslen Wilson & Tyler, 1980). Early in a word’s onset, when only the first 100 to 150 ms have been heard, listeners activate the set of all words compatible with this partial information. Identifying a single word begins by associating speech sounds with phonemes and then activating all lexical candidates consistent with that phonetic input. Those entries are, in turn, linked to semantic representations of meaning (Huang & Snedeker, 2010). Initial access, first of word forms and then of syntactic and semantic information associated with the word forms, is triggered from bottom-up with contextual effects only operating after phonological information has been accessed (Marslen-Wilson, 1987).

Other models, however, recognized that other factors than initial word onset influenced word recognition. For example, the importance of word frequency and neighborhood density in speed of recognition and the finding that frequent words reach the threshold for recognition
faster than infrequent words (Luce, Pisoni, & Goldfinger, 1990) makes it possible for listeners to use their knowledge of the spoken language to compensate for missing or distorted phonemes. This led to the development of the Neighborhood Activation Model (NAM; Luce & Pisoni, 1998) which predicts that the number of similar words and their word frequency affect spoken word recognition.

The visual world eye tracking paradigm had resulted in revisions to theories about the interaction of phonological and semantic information in spoken word recognition. While all theories agree that word recognition begins with phonological processing, interactive activation models such as TRACE (McClelland & Elman, 1986) posit that lexical access may not be purely sequential; analysis at one level of representation may begin before analysis at the preceding level is complete (Huang & Snedeker, 2010). The TRACE model allows for top-down influences on initial word access, such as morphology, syntax, or semantics, that may interact with basic speech perception processes to aid in speech sound recognition. TRACE was the first computationally implemented model of spoken word recognition that simulated a wide range of behavioral findings. For example, TRACE was able to simulate the results of an eye tracking study that found word candidates overlapping in onset are activated earlier than those overlapping in rhyme (Allopenna, Magnuson, & Tanenhaus, 1998; Weber & Scharenborg, 2012).

Thus, word recognition can be characterized as a flow of information whereby partial phonological information activates semantic representations with phonological and semantic processes intertwined (Huang & Snedeker, 2010). This reflects the seemingly reciprocal influence between impoverished semantic and phonological representations observed in
individuals with CP and SSPI (Smith, 2001) and may help researchers and clinicians understand the nature of lexical deficits in individuals with CP/SSPI.

**Spoken Word Recognition and Eye Tracking**

Investigations of spoken word recognition have revealed developmental differences between lexical access in children and adults as well as differences in lexical activation related to linguistic deficits in clinical populations. Eye tracking is a now well-established method to investigate spoken word recognition and has the added advantage of not requiring a motor response from participants.

The visual world eye tracking paradigm (Trueswell, 2008) has been extensively used for spoken word recognition studies (Allopenna et al., 1998; Cooper, 1974; Tanenhaus et al., 1995) based on the integration of visual and linguistic information. By recording eye movements as participants listen to verbal instructions, the temporal relation between an unfolding word and eye gaze to a referent and potential competitors reveals a great deal about how words compete for activation in the mental lexicon (Sedivy, 2010). For example, when asked to touch one of four blocks that differed in color such as “Touch the starred yellow square,” participants look at the target block an average of 250 ms after the end of the word that uniquely specified the target; after “starred” if only one of the blocks was starred, and after “square” if there were two starred yellow blocks (Tanenhaus et al., 1995).

By observing the time course of eye gaze to pictures depicting both target words and related competitors, the role of phonological, semantic and conceptual similarities in the lexical processing of adults and children has been extensively studied (Allopenna et al., 1998; Huettig
& Altmann, 2005; Sekerina & Brooks, 2007; Yee & Sedivy, 2006). For example, when presented with a four-picture display, including the target word BEAKER and a word with a matching phonological onset BEETLE, participants are more likely to fixate on the onset competitor than on the remaining images with phonologically unrelated names (Allopenna et al., 1998). This suggests competition for activation between phonologically similar entries in the lexicon.

Between 300 and 500 ms after word onset, words that are related both phonologically and semantically are activated (Yee & Sedivy, 2006). If two images are semantically related (e.g., SHIRT/TIE), the participant will look at both target and relative. As sufficient phonological information is acquired, gaze to the spoken word target will increase. Participants are more likely to fixate on an object from the same category as the object being referred to (e.g., TRUMPET/PIANO) than on an unrelated object. For example, two objects might interact in a single event (e.g., SPOON/BOWL, LOCK/KEY) or might be in a similar category such as clothing (e.g., SHIRT/TIE) and not only in associate pairs (such as CAT/MILK). Despite a lack of strong association, conceptual competition may then drive seemingly spontaneous fixations between a word and a visual object that are not associates (Huettig & Altmann, 2005) and still influence eye movements (Yee & Sedivy, 2006).

Non-depicted items that are phonologically or semantically related to the target word also influence eye movements (Yee & Sedivy, 2006). Names of absent items become active and influence lexical processing, widening the set of lexical candidates that can affect attention to include words that are not depicted (Huettig & Altmann, 2005; Yee & Sedivy, 2006).
Figure 1 illustrates a display based on an eye tracking experiment created to test this model (Yee & Sedivy, 2006). In the semantic relative example, where TIE is the target and SHIRT is the semantic relative, the pictorial representation for SHIRT becomes active enough to draw fixations. However, in the semantic onset example, in a display where TIRE, the target word, is presented along with SHIRT and two unrelated words, the listener will connect TIRE and SHIRT through the unpictured phonological competitor TIE. This will result in fixations to SHIRT being longer than to the other unrelated words visually represented in the display. Thus, eye movements reveal the connections between words beyond what is presented on the visual display along phonological and semantic characteristics. Activation of semantic representations begins long before phonological processing is complete, which in turn reveals the organization of the mental lexicon.

Figure 1. Semantic relative and semantic onset conditions.
Eye tracking investigations have revealed a developmental shift in the speed and nature of spoken word recognition in the presence of phonological and semantic competition (Huang & Snedeker, 2010; Sekerina & Brooks, 2007). Compared to adults, children look more at depicted competitors than to unrelated control items but need to hear more elements of a word before recognition, exhibit slower inhibition of competitors, and often fail to revise incorrect selections. In general, this suggests slower or less efficient processing of incoming phonological information, reduced efficiency of activation from the speech signal, or less systematic organization of the mental lexicon (Huang & Snedeker, 2010).

Thus, an analysis of eye tracking during spoken word recognition in the presence of phonological and semantic competition with individuals with CP/SSPI will allow a detailed inspection of the time course of word recognition and a comparison of phonological versus semantic activation. In addition, it will provide a comparison with two groups of individuals who have intact speech, adults with no neurological impairment and children with typical development, and the extent to which those who have a severe speech impairment differ in lexical access.

**Summary.** Eye movements can provide a rich source of data concerning underlying language mechanisms, providing a window into moment-by-moment processes underlying language comprehension. Because there is reasonable developmental continuity in the trajectory of linguistic processes, results can be compared with that of children with typical development and adults (Liberman, Schankweiler, Liberman, Fowler, & Fischer, 1977) to determine whether the speed and nature of lexical processing differ in the developmentally disabled population (Sedivy, 2010).
Theories About Lexical Deficits in CP/SSPI

The motor theory of speech perception. The motor theory of speech perception (Liberman et al., 1977), which postulates that speech is perceived by reference to how it is produced, would predict that individuals with cerebral palsy who do not speak would never have had the opportunity to acquire an articulatory code due to an inability to learn motor programs for speech output (Liberman & Mattingly, 1985). If perception is restricted by production ability, then a severe speech impairment accompanied by severe physical impairment from birth should result in weaker or inaccurate lexical representations and, in turn, weaken the overall phonological access to and the phonological organization of the mental lexicon.

Investigating the question of impaired phonological perception in adolescents and adults with CP/SSPI, the work of Bishop (et al., 1990) appeared to refute the motor theory by presenting tasks that demonstrated the ability of individuals with CP/SSPI to discriminate subtle differences in speech sounds they could not produce. However, in a same/different task using non-words, children with no speech or impaired speech performed poorly as compared to those with cerebral palsy who could speak, suggesting that the difficulty in learning new vocabulary was attributable to poor or absent subvocal rehearsal (Bishop et al., 1990).

The ability to speak enables the development of articulatory-code-based subvocal rehearsal (or covert articulation) that purportedly underlies phonological working memory (Baddeley, 1986), which in turn is proposed to underlie vocabulary development. Children with CP/SSPI perform more poorly on tasks that are said to require covert articulation. For
example, when the child is asked “Which picture is *spin* without the /s/?”, he must mentally remove the /s/ in *spin* and identify it as /pin/. Articulatory disorders that impair rehearsal in phonological working memory make this task particularly difficult. Written rhyme judgment, syllable segmentation and phoneme manipulation are said to require covert articulation (Card & Dodd, 2006), while tasks that are speech-cued (i.e., the experimenter names the pictured stimulus item) are not considered to require covert articulation and elicit better performance (Vandervelden & Siegel, 1999).

While the results of these studies suggest impaired performance in some phonological awareness tasks, a serious limitation of the subvocal rehearsal proposal is that causality between performance on particular tasks and their relationship to subvocal rehearsal can only be inferred due to methodological problems involved in its study. Subvocal rehearsal can be objectively measured through instrumentation as electromagnetic sensors that detect movements of the tongue or vocal cords or electromyography recordings that monitor subvocal rehearsal. Brain activity monitored through event-related potential and fMRI have demonstrated brain activity during subvocalization (Day & Fernyhough, 2015). More recently, wireless devices that can be placed on the throat to detect subvocalization during thought processes and allow the use of silent communication (Choi, 2013) are being developed. For the present, however, the relationship between covert and overt speech processes and the degree to which covert speech contributes to awareness of the sound structure of a language requires further investigation.

**The design of AAC vocabulary interferes with effectiveness of communication.** In general, the use of augmented communication aids the development of speech production
abilities in young children. Augmented models increase symbol comprehension and production for young children (Romski et al., 2010).

Yet the organization and design of vocabulary of an AAC device has a great impact on navigation and symbol selection and is often cited as a cause for the limited language abilities of individuals with CP/SSPI (Van Bolkom & Donker-Gimbrere, 1997). Typically, dynamic display systems are set up according to pages of vocabulary organized in a grid with symbols required for an event located together. Alternatively, the pages can be organized according to parts of speech (e.g., objects, actions, people, comments) (Drager & Light, 2006).

In typically developing children, (Wilkinson, O'Neill, & McIlvane, 2014) participants were slower to fixate on a target symbol in a grid display when distracters that did not share the same color with the target. Thus, efficient search was related to minimizing fixation to nonrelevant distracters such as color. As vulnerability to distraction can be a significant problem in individuals with CP/SSPI, minimizing the intrusion of distraction such as color may be of importance in the design of AAC displays (Wilkinson et al., 2014) where it could be expected that visual search of children with CP/SSPI might be even more effortful.

Moreover, for children and adults without disabilities, sustained attention and cognitive flexibility predicted participants’ reaction time and accuracy in symbol selection (Perrin, Robillard, & Roy-Charland, 2017). Eye scanning patterns of eye movements, accuracy and response time were measured during a visual search task in which participants were asked to locate a series of symbols on 16 cell grids. Sustained attention and cognitive flexibility were also tested. Participants had faster response times, longer fixations and more frequent fixations on symbols located in the middle of the grid. Cognitive skills predicted the individual user’s
speed and accuracy of symbol retrieval and selection. Thus, both symbol grid location and sustained attention and cognitive flexibility impacted the efficiency and effectiveness of symbol identification and selection (Perrin et al., 2017).

**The impact of severe speech and physical disability on communication development.** In children with severe physical disabilities, it is often difficult to distinguish between endogenous and experiential factors that contribute to individual differences in language development. In addition to the role of early experience, there are also biologically mediated differences (Fernald & Marchman, 2012).

Young children with severe physical disabilities experience complications resulting from impairment in sensory, motor, cognitive and social domains and unstable health with accompanying seizure disorders and feeding difficulties that may be life threatening. These complications also can profoundly disrupt production of conventional gaze, gestures and vocalization in the context of social interactions putting the child at high risk for delayed development of early signals of communication. This in turn interrupts critical teaching and learning opportunities during the first months of life (Olswang et al., 2010).

For example, vocal play between mothers and their typically developing (TD) infants offer abundant opportunities to link vocal perception with production of elementary sound features (Papousek & Papousek, 1989). In contrast, infants with CP/SSPI who are unable to maintain head and trunk postures, control arm and leg movements, manipulate objects and develop and imitate sounds are deprived of these early crucial experiences (Olswang & Pinder, 1995; Papousek & Papousek, 1989) and are less able to participate successfully in natural
communication interactions. As a result, these children are at extreme risk for delays in language acquisition (Olswang et al., 2014).

As these children mature, play activities that promote emergent literacy and language development may be unavailable to individuals with CP/SSPI because of fine and gross motor impairments and limited speech abilities (Pierce & McWilliams, 1993). Limited educational opportunities (Koppenhaver & Yoder, 1993) and restricted independent learning add to the challenges that children with CP/SSPI encounter (Bishop et al., 1990; Card & Dodd, 2006; Koppenhaver & Yoder, 1993; Peeters et al., 2009; Vandervelden & Siegel, 1999).

In typically developing 2-year-olds, using real-time measures of comprehension, the speed of word recognition and vocabulary knowledge predict cognitive and language outcomes in later childhood (Marchman & Fernald, 2008). At 18 months, speed and accuracy of real-time spoken language processing predicted subsequent vocabulary development at 2 and 3-years-of-age for both typically developing children as well as for those considered late talkers who are having difficulty in the early stages of language learning (Fernald & Marchman, 2012). Findings such as these have serious implications for young children with CP/SSPI, since the delays in learning they experience at a young age have consequences that can last a lifetime. While the increased introduction of AAC during early intervention has resulted in greater gains in both language comprehension and expression (Romski, Sevcik, Barton Hulsey, & Whitmore, 2015), the nature of intervention, the frequency, and duration remain undetermined.
**Purpose of the Study**

An investigation of the function and structure of the mental lexicon through spoken word recognition can shed light on the role of the motor theory and notions regarding subvocal rehearsal as well as difficulties in language comprehension experienced by adolescents and adults with CP/SSPI. The impact of a severe speech impairment in individuals with CP/SSPI has been central to investigations of their language deficits. Previous studies have focused on the ability of individuals with CP/SSPI to detect phonetic contrasts rather than on spoken language processing in real time. Investigations of spoken word recognition using eye tracking and the visual world paradigm can demonstrate the time course of activation for lexical information. A moment-by-moment time course analysis of visual response to spoken word recognition will reveal the process of hearing a word as it unfolds and the degree to which production and perception may be intertwined.

The current study examined the time course of phonological and semantic activation during spoken word recognition in adolescents and adults with CP/SSPI and compared their performance with results of adults with no neurological impairment and children with typical development. In particular, the goal was to determine whether individuals without spoken language activate phonological competitors at all consistent with predictions of the motor theory and proposals regarding the role of subvocal speech/rehearsal in working memory and consequently vocabulary abilities. Moreover, because this method does not require any physical response from the participants other than looking at a computer monitor and listening to spoken words, it eliminates the difficulty of individually adapting a task.
The experiment investigated (a) the time course of spoken word recognition in individuals with CP and SSPI, (b) differences in spoken word recognition between individuals with CP and SSPI and adults, and (c) the feasibility of using the eye tracking method and an experiment designed for able-bodied individuals to study spoken word recognition in individuals with CP and SSPI.

This research sought to answer three questions:

1. Are adolescents and adults with CP/SSPI sensitive to competition from phonological, semantic, and semantic onset competitors?

2. Are there individual differences in spoken word recognition between adolescents and adults with CP and SSPI correlated with speech intelligibility and other individual differences?

3. Are there similarities in lexical activation between adolescents and adults with CP and SSPI, children with typical development (TD) and adults with no neurological impairment (NNI)?

With limited production abilities and evidence of limited phonologic knowledge, as well as semantic knowledge (which is first filtered through phonology), individuals with CP and SSPI were not expected to activate the competitor’s lexical representation. In contrast, this activation was expected in adults with no neurological impairment (NNI) as well as in children with TD. Individual differences amongst the CP/SSPI participants with regards to degree of speech impairment and PPVT-4 standard scores were expected to be related to lexical access.
METHODS

Participants

Overview. There were two groups of participants in this study. These included 16 adolescents and adults with CP/SSPI ranging in age from (14;9 to 55;5 years old; $M = 23;4; SD = 12.4$; 8 men and 8 women,) and eight adults with no neurological impairment (NNI) ranging in age from 20 to 28 ($M = 25.1, SD = 1.95$) who were directly tested using the same design and procedures. Two additional participants with CP/SSPI were excluded, one because his vision was impaired and he could not calibrate the eye tracker and the other because his speech was sufficiently intelligible as to not meet the criteria of having a severe speech impairment (i.e., speech was intelligible to an unfamiliar communication partner). In addition, 12 children with TD ($M = 8.9; SD = 1.97$, range 6.8-12.4) had been previously tested for a separate study where the same experimental design was used. The results of that study were used to provide another age group with which to compare the participants with CP/SSPI.

Individuals with CP/SSPI were recruited using a flier sent to professionals who worked with these individuals (e.g., director of the program the individual attended; speech-language pathologist or teacher who worked with the individual; the local representative of the manufacturer of communication device that the participant used). Those who participated were located through professionals and speech generating device manufacturers. Participants were required to come from a household where English was the predominant language, have normal vision with or without glasses, hearing within normal limits, and the ability to answer yes and no questions so that a person unfamiliar with the individual could understand him.
All participants lived at home or in a residential facility located in New York City, upstate New York, Long Island, Philadelphia, and New Jersey.

Regardless of age, parental consent was obtained from the parents or guardian in addition to oral assent from the participant. All parents or guardians of the participants were asked to complete a questionnaire regarding medical and language background, including those participants who were above 21 years old. All parents or guardians reported that English was the dominant language at home.

Table 1

<table>
<thead>
<tr>
<th>Participant</th>
<th>Age</th>
<th>Subtype CP</th>
<th>Gross Motor</th>
<th>Manual Ability</th>
<th>Communication</th>
<th>Control of SGD</th>
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<tbody>
<tr>
<td>1</td>
<td>14;9</td>
<td>spastic</td>
<td>V</td>
<td>V</td>
<td>IV</td>
<td>eye</td>
</tr>
<tr>
<td>2</td>
<td>15;11</td>
<td>dyskinetic</td>
<td>V</td>
<td>V</td>
<td>III</td>
<td>eye</td>
</tr>
<tr>
<td>3</td>
<td>16;11</td>
<td>unknown</td>
<td>V</td>
<td>III</td>
<td>III</td>
<td>hand</td>
</tr>
<tr>
<td>4</td>
<td>17;4</td>
<td>unknown</td>
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<td>No response</td>
<td>hand</td>
</tr>
<tr>
<td>5</td>
<td>17;8</td>
<td>dyskinetic</td>
<td>V</td>
<td>IV</td>
<td>IV</td>
<td>hand</td>
</tr>
<tr>
<td>6</td>
<td>17;9</td>
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<td>IV</td>
<td>IV</td>
<td>III</td>
<td>eye</td>
</tr>
<tr>
<td>7</td>
<td>17;9</td>
<td>dyskinetic</td>
<td>IV</td>
<td>III</td>
<td>I</td>
<td>eye</td>
</tr>
<tr>
<td>8</td>
<td>18;9</td>
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<td>IV</td>
<td>IV</td>
<td>II</td>
<td>hand</td>
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<tr>
<td>9</td>
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<td>IV</td>
<td>II</td>
<td>eye</td>
</tr>
<tr>
<td>10</td>
<td>19;4</td>
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<td>IV</td>
<td>III</td>
<td>II</td>
<td>hand</td>
</tr>
<tr>
<td>11</td>
<td>22;8</td>
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<td>IV</td>
<td>III</td>
<td>III</td>
<td>No SGD</td>
</tr>
<tr>
<td>12</td>
<td>25;4</td>
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<td>V</td>
<td>V</td>
<td>I</td>
<td>hand</td>
</tr>
<tr>
<td>13</td>
<td>25;10</td>
<td>dyskinetic</td>
<td>IV</td>
<td>V</td>
<td>II</td>
<td>hand</td>
</tr>
</tbody>
</table>
Demographic data. Table 1 lists the demographic data on the participants with CP/SSPI. A description of the terms used in this table follows:

**Age.** The wide age range of these 16 participants with CP/SSPI (14;9 to 55;5 years old; \( M = 23;4; \ SD = 12.4 \)) reflected the difficulty in locating a sufficient number of individuals of similar ages. A minimum of age of 6 years had originally been established, as school-age children were the target population, but it was not known how many participants would be available and whether they would be close in age. The older age of the participants may reflect a greater willingness on their part or of their parents to have them participate.

**Subtype of CP.** Through parental questionnaire, six of the participants were reported to have dyskinetic type of cerebral palsy, three were reported to have spastic type of CP and no specific type was indicated for seven.

**Gross motor and manual ability and communication function.** With the referring professional and parent report, the Gross Motor Function Classification System- Expanded and Revised (GMFCS; Palisano et al., 2007) \( ^{a} \) Manual Ability Classification System (MACS; Eliasson, et al., 2006) \( ^{a} \) Communication Function Classification System (CFCS; Hidecker et al., 2011) \( ^{a} \) Mode of accessing Speech Generating Device

<table>
<thead>
<tr>
<th>Age</th>
<th>Subtype</th>
<th>GMFCS</th>
<th>MACS</th>
<th>CFCS</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
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<td>31;1</td>
<td>IV</td>
<td>IV</td>
<td>I</td>
<td>hand</td>
</tr>
<tr>
<td>15</td>
<td>48;9</td>
<td>unknown</td>
<td>IV</td>
<td>V</td>
<td>II</td>
</tr>
<tr>
<td>16</td>
<td>55;5</td>
<td>unknown</td>
<td>III</td>
<td>III</td>
<td>II</td>
</tr>
</tbody>
</table>

\( n = 16 \)

Note. \( ^{a} \) Age in years and months; \( ^{b} \) Subtype of CP; \( ^{c} \) Gross Motor Function Classification System-Expanded and Revised (GMFCS; Palisano et al., 2007) \( ^{d} \) Manual Ability Classification System (MACS; Eliasson, et al., 2006); \( ^{e} \) Communication Function Classification System (CFCS; Hidecker et al., 2011); \( ^{f} \) Mode of accessing Speech Generating Device.
of the participants. The Manual Ability Classification System (MACS) (Eliasson, et al., 2006) was used to assess the degree of manual impairment. A description of these Levels is listed in Appendix A.

**Communication function.** Parents assessed their children’s level of communication function using the Communication Function Classification System (CFCS) (Hidecker et al., 2011). As the authors of this classification system note, the parents tended to estimate their child’s communication ability as more effective in comparison to professionals, as all of these participants were considered to have severe dysarthria or anarthria by their speech pathologists and an SGD had been recommended for them. A description of these levels is listed in Appendix A.

**Speech generating device (SGD).** Although device use was not specifically examined, all but one of the participants with CP/SSPI used an SGD producing synthesized speech, an iPad or a laptop with special communication software. The mode of access to the SGD using eye gaze or direct selection by pointing with their hands was noted as it could be a factor that would correlate with later data analysis gained from eye tracking. Because of below-age reading skills reported by speech-language pathologists or parents, all participants had a combination of picture symbols and orthography on their device display.

**Education.** Eleven of the participants who were below 23 years old attended either a public school or special education school at the high school level. Of the five participants who were 23 years old and above, four attended a day treatment program and were no longer attending school while one lived independently.
**Adults with no neurological impairment (NNI).** The experiment was also administered to a group of eight 20 to 28-year-olds \( (M = 25.1, \ SD = 1.95) \) with NNI who were matched for average age to the group of individuals with CP/SSPI. Of the eight adults, six had a bachelor’s or master’s degree and two had a high school diploma. Confirmation of hearing within normal limits was made at the beginning of the procedure through a hearing screening administered by the examiner using a portable audiometer, the MA 25 (MAICO Diagnostics). All participants passed a hearing screening at 25dB SPL at 500, 1000, 2000 and 4000 Hz (American Speech-Language-Hearing Association, 1997). All adults reported normal vision and were tested in their homes.

**Children with typical development (TD).** A previously conducted data set from a group of 12 children with TD \( (M = 8;9, \ SD = 1.97, \ range 6;8-12;4) \) was also used as a comparison group. All children had a non-verbal IQ > 85 as measured by the Test of Nonverbal Intelligence, 4th edition (TONI-4) (Brown, Sherbenou, & Johnsen, 2010), language abilities within normal limits as measured by the Clinical Evaluation of Language Fundamentals, 5th Edition (CELF-5) (Wiig & Semel, 2013), no phonological disorders and no social/pragmatic/emotional deficits. Confirmation of hearing within normal limits was made at the beginning of the procedure through a hearing screening administered by the examiner using a portable audiometer, the MA 25 (MAICO Diagnostics). All participants passed a hearing screening at 25dB SPL at 500, 1000, 2000 and 4000 Hz (American Speech-Language-Hearing Association, 1997) and were reported to have normal vision.
Stimuli

To create the three conditions of this study, 20 pairs of stimuli that were phonological onset competitors (same onset sound) and 21 pairs of semantically related stimuli were selected in addition to pairs of unrelated images. Black and white line drawings were selected from the Cycowicz black and white image library (Cycowicz, Friedman, Rothstein, & Snodgrass, 1997). This library includes images from the Snodgrass and Vanderwart (1980) library appropriately complex for children 5 to 7-years-of-age and images that were more visually complex (Berman, Friedman, Hamberger, & Snodgrass, 1989) taken from the PPVT-R.

Seven black and white line drawings taken from clip art depicting the same words taken from clip art used in the studies by Huang & Snedeker (2010) and Yee & Sedivy (2006) were also used. These were not available in the picture libraries but necessary to create the semantic onset condition where the target must be a phonological competitor of the unpictured item. For example, if SANDALS and FEET are semantic relatives, in the semantic onset condition, SANDALS is removed from the display and replaced with SANDWICH as the target. The picture for SANDALS was taken from clip art, as it was in the Huang & Snedeker (2006) study, and not normed.

Only visually dissimilar target-related objects were selected to minimize the possibility that the participants would mistake the phonological competitor or semantically related object for the target. All images were edited so that they would be approximately the same size, visual complexity and brightness to balance the visual salience of the images in each trial. Object positions in each of the four quadrants of the display, including the positional relationship
between the target and the related object, were randomized so that each object type would be equally likely to appear in each quadrant. Object names were one to three syllables long. A full list of experimental items is given in Appendix B (Tables B1, B2 and B3).

Auditory stimuli consisting of the name of each target image were spoken by a female native speaker of American English at a 22kHz sampling rate and were normalized for amplitude in a sound attenuated booth. Recordings were reviewed by speech-language pathologists; any deviant productions were re-recorded. Auditory stimuli were delivered in sound field at 60 dB HL through the laptop speakers as measured by a mobile application, SPL Meter. Calibration with the app was first compared with calibration using a Larson Davis (Group, 2016) Model 800B Precision Integrating Type 1 Sound Level Meter, (filter off; Settings- Fast, A, Waiting) at 74 dB SPL (RMS fast) with a Cal-tone 500 Hz-3dB wav.
Figure 2 illustrates the layout of the images and their approximate size for each trial. The computer display measured 13 ½ in. x 9 in. Each of the trials consisted of four images measuring approximately 1 in., centered on a white square measuring 3 ½ in. x 3 ½ in., placed in each of the four corners of the display measuring 9 in. x 7 ¾ in. The squares were separated from each other by a green cross measuring 2 in. x 2 in. so that sufficient space for eye movements between one image to another across screen quadrants on the computer display could be recorded. The black area of the computer display extended 2 1/4 in. on either side of the white area.

As illustrated in Figure 3, in the phonological onset condition (PHONO), one of the objects in the display was a phonological onset competitor of the target. The other two objects were semantically and phonologically unrelated to any of the other objects in the display. For example, TIRE was the target, TIE was the phonological competitor, while ZEBRA and HAMBURGER were the two unrelated images. Given a display of four images, with two of them phonological onset competitors (TIE/TIRE), when the participant hears TIRE, fixations to TIE will at first increase as the word unfolds. When sufficient acoustic information regarding the target word is heard, fixations to the target TIRE will increase.

The number of overlapping phonemes at onset for the target and competitor was two or three; 13 of the pairs had two overlapping phonemes (e.g., TIE/TIRE) and seven of the words also shared a third phoneme (e.g., CAMEL/CAMERA). The words in the phonological condition were taken directly from (Snodgrass & Vanderwart, 1980) and were words that were familiar to 5-year-old children.
Figure 3. This is an example of a display in the phonological competition condition used in this experiment.

As illustrated in Figure 4, to create the semantically related (SR) condition, one of the objects (e.g., SHIRT) in the display was semantically related to the target (e.g., TIE). Two images that were unrelated phonologically and semantically were also selected (e.g., ZEBRA/HAMBURGER). Because an easily recognizable image of a semantic relative was difficult to pair with most of the targets or phonological onset competitors, only eight of the semantically related pairs consisted of targets or onset competitors from the phonological onset condition while 14 new semantically related image pairs were introduced. Given a display of four images, with two of them semantically related, (TIE/SHIRT), when the participant hears TIE, fixations to SHIRT will increase as the word unfolds. When sufficient acoustic information regarding the target word is heard, fixations to the target TIE will increase.
Figure 4. This is an example of a display used in the semantic relative condition in this experiment.

Similar to the procedure used by Yee and Sedivy (2006), in which eight of the semantically related stimuli were not associated according to published free association norms (Nelson, McEvoy, & Schreiber, 1998), six of the 21 pairs of semantically related stimuli in this study were unassociated (forward and backward), two had only forward association norms and one had only backward association norms (see Appendix D for the degree of association for semantic pairs).

The semantic onset condition (SOC) consisted of a target, and an image that was both semantically related to a word absent from the display (an unpictured word) and a phonological onset competitor of the target. Each of the targets in this condition was created by replacing the target or semantic relative in the semantically related condition with a phonological onset competitor (Yee & Sedivy, 2006). For example, as illustrated in Figure 5, the target TIRE is an onset competitor of an unpictured object tie which is semantically related to SHIRT. When sufficient acoustic information regarding the target word tire is heard, fixations to the shirt activated by the unpictured tie, will increase.
In all three conditions, two versions of each set, critical and control, were created such that images appearing as a target and a competitor (or relative) in the critical trial appeared as unrelated images in the control trial. In total there were 124 trials, half critical and half control. This ensured that the participants were not visually drawn to the two competing pictures (e.g., TIRE/TIE) even when one of them was not the spoken target and that their attention to the competitor image when they heard the onset of the target word had to be attributed to cohort or semantic competition between the two images and not due to a visual association. To the participants, however, the displays in either condition looked the same.

For example, in Figure 6, in the Phonological Critical condition, the target was TIRE. In the control condition, the display stayed the same but the target was NAIL, while the three unrelated images were TIE, TIRE and ZEBRA (Yee & Sedivy, 2006). If the participants had fixated on TIRE and TIE in the control condition, fixations to the competitor in the critical condition could not be attributed to what the participants heard.
Figure 6. Example of critical and control trials in the phonological condition.

Design

A total of 124 target words were presented auditorily to each participant, each along with four pictures. Each trial contained one of the six possible conditions of the study (phonological critical, phonological control, semantic relative critical, semantic relative control, semantic onset critical, and semantic onset control). Presentation order and location of the pictures on the display were randomized across trials.

Each trial began with a series of five red and white images presented for 400 ms each to draw visual attention of the participant to the center of the display. The picture display was presented for 500 ms without sound. The auditory target word was then presented with the picture display remaining visible for 1300 ms to give sufficient time for the participant to
examine the display and for looks and fixations to be recorded, with the next trial starting automatically. No response other than eye gaze was required from the participant. Prior to the actual experiment, there were three practice trials where participants saw a gaze replay demonstrating the eye tracking technology.

**Apparatus**

Participant’s eye gaze was recorded using a Tobii X2 60 Eye Tracker Compact Edition, a stand-alone eye tracking unit attached to a laptop (a 15.6 inch, 6 lb. Lenovo ThinkPad with a 2.4GHz quad-core i7, 8GB of RAM, 500GB 7200 RPM drive and 2GB Nvidia graphics card) with a magnetic mounting bracket which was also connected to a processing unit via a USB 2.0 connection. Gaze data were recorded and analyzed through the eye tracking unit used to record the participant’s visual responses and monitor visual attention in real time.

The Tobii eye tracker along with the Tobii studio software Version 3.2 (Tobii Technology Inc., 2012) controlled the recording of eye movements that were determined by using near infrared light and its corneal and pupillary reflections with video cameras. Gaze data was sampled at 60 Hz. System latency (i.e., the time required to capture, transfer and process data and make this available to an application during normal tracking) was < 35 ms (Tobii Technology, 2014). Auditory and visual stimuli were delivered simultaneously via E-Prime 2.0 (Psychology Software Tools, 2016) running on the laptop computer. E-Prime also recorded a gaze data file.
**Procedure**

For adolescents and adults with CP/SSPI, the entire experiment was administered in one session lasting approximately two hours and conducted in a quiet room at the participant’s home. Participants with CP/SSPI who were adults received monetary compensation. Participants who were minors received compensation directly with parental permission. Each participant with CP/SSPI was provided with a written and oral consent/assent script that described the tasks. The participant gave assent orally, by a gesture or by other movement used to indicate *yes* to participate in the study and to be audio recorded for comprehensibility testing. The method of indicating assent was noted on the assent form and witnessed by a person familiar with the participant and his/her mode of responding. For all participants with CP/SSPI, written consent was obtained from parents or guardians.

A person familiar with the participant was present during testing who could assist with positioning of the participant and describe the most reliable method the participant used for indicating *yes* during the hearing screening and for indicating pictures during administration of the PPVT-4. Other information such as the best location for the PPVT-4 test booklet to be held and confirmation of responses that were not clear to the examiner were also provided.

Confirmation of hearing within normal limits was made at the beginning of the procedure through a hearing screening administered by the examiner using a portable audiometer, the MA 25 (MAICO Diagnostics). All participants passed a hearing screening at 25dB SPL at 500, 1000, 2000 and 4000 Hz (American Speech-Language-Hearing Association, 1997).
The PPVT-4 was selected as the measure of single word vocabulary comprehension to be administered to all participants with CP/SSPI by the examiner. Since the focus of the experiment was single word recognition, it was the most appropriate available behavioral vocabulary comprehension measure. The PPVT-4 was administered by the examiner with the participants indicating the picture that the examiner named using any mode that could be accurately interpreted. For those participants who were unable to independently point to a picture, the examiner said the target word and then pointed to each picture on the test display until the participant indicated a selection (i.e., partner-assisted scanning; Burkhart, 2012).

To arrive at more finely graded ratings of speech intelligibility of the participants other than anarthria or dysarthria, the Index of Augmented Speech Comprehensibility in Children (I-ASCC) (Dowden, 1997) was then administered and responses were audio recorded for later rating of comprehensibility. This procedure measures comprehensibility of the participants with severely dysarthric speech or how well an individual’s message can be understood in a natural communicative context on a 5-point scale with 1 as most comprehensible and 5 as having speech that was not sufficient enough to make a recording. The procedures for administration of this test are described in Appendix C. Where possible, images from the experiment were used as the target word the participant was asked to name which also served to confirm that the participant could identify the image (see test words, Table C1). These ratings were used to determine whether speech comprehensibility had any relationship to performance in a spoken word recognition task (see Table C2, Judge’s Sheet).

**Eye tracking task.** The laptop was positioned on an adjustable height table that could be tilted in order for the participant’s eyes to be captured by the eye tracker. Normal home or
office background illumination was used. The participant was then positioned approximately 15 in. from the eye tracking unit measured along the axis of the eye tracking sensors (Tobii Technology, 2014). The participant was told to sit so that the sensors could detect his eyes. Visual feedback was provided from the display screen where the participant could see two white circles, one for each of his eyes, and an indicator that went from red to green to indicate that the location of the eyes could be identified.

Participants with CP/SSPI who used wheelchairs remained in their chairs, while those who were not in wheelchairs sat in a chair or other adaptive seating system that provided them with the greatest motor control. Parents and/or caregivers who accompanied the participant were asked to help position the participant during testing to limit movements that could influence gaze accuracy such as change of gaze angles and head position. Adjustments in positioning of the participant in the wheelchair or the eye tracker were sometimes necessary, as some participants found it difficult to maintain a stable position for a sustained period of time. When necessary, the head or the arms of the participant were stabilized by a caregiver or parent.

The participant was told that there would be a display of four pictures and would hear the name of one of the pictures spoken aloud; he would then look at the picture while keeping his head as steady as possible. To avoid over exposure, no pre-testing of words in the experiment was conducted.

Each participant then underwent a calibration process to ensure that the eye tracker could identify the location of both eyes. The calibration program presented a series of nine moving circles that the participant was asked to visually follow with minimal head movement.
The software alerted the examiner if there were not enough data to create an accurate calibration profile for the participant.

When calibration profiles were invalid (i.e., not enough data), participants were recalibrated to ensure the highest likelihood of obtaining valid gaze data. One participant had been eliminated from the study after three attempts at modifying positioning were not successful and the individual was unable to calibrate the eye tracker.

When calibration profiles were judged as sufficient, the examiner then started the experiment, continuously monitoring participant performance and eye movement to ensure that the participant remained in a stable position and focused on the task. Through a specially designed E-Prime script, if the Tobii X2 60 eye tracker could no longer gather sufficient gaze data because the participant shifted his gaze away from the screen, the experiment would be paused until the participant’s eyes could be located again. Once the examiner determined that both eyes of the participant were again sufficiently visible, using the visual feedback appearing on the computer monitor that showed the position of both eyes of the participant, the examiner continued the experiment by activating the space bar of the computer. However, the trial was eliminated from the analysis. The same script was also used with the adults with NNI to pause the experiment when an insufficient number of eye movements were detected. Two brief breaks were also given to maintain the participant’s attention.

For the children with TD, the experiment was administered in a sound proof booth at the Child Language Lab at the Graduate Center, CUNY using a Tobii TX 300 eye tracker (a stationary unit with a larger visual display monitor) with a 60 Hz sampling rate comparable to that used with the portable eye tracker. The children with TD selected the target picture with a
mouse; upon mouse click, the next trial appeared. The script written to pause the experiment when the eye tracker could no longer detect the participant’s eyes was not used with the children with TD.

Eye Tracking Data Analysis

The E-Prime created gaze data files with the eye tracking data for each participant which were then entered into a custom MATLAB (MathWorks, 2016) program for analysis of each gaze data sample that had been collected by the eye tracker approximately every 16 ms. Fixation duration was set in the MATLAB program of at least 50 ms of continuous looking at an image. MATLAB analyses indicated proportion of eye gaze fixations to the four pictures as well as time course information for gaze to the four pictures throughout the duration of each trial. Accuracy data were not collected for the CP/SSPI participants nor the adults with NNI as they were not required to respond with a mouse click or button press. The responses of the children with TD were analyzed for accuracy and only accurate trials were analyzed. The results were analyzed using the same MATLAB program as was used with the CP/SSPI participants and adults with NNI.

For the purpose of analyzing the data, a trial was defined as starting at target onset and ending 1300 ms after onset. Proportion of fixations data derived from the MATLAB program were then applied in statistical analyses.

A validity score from the eye tracker for both eyes for each sample was averaged by the MATLAB program; averaging across both eyes helped to prevent excluding potentially acceptable data. A validity score of 25% or greater was considered for further processing.
Validity scores of less than 25% indicated that the eye tracker had collected no data due to instrumental error or participant movement; trials composed only of samples with validity scores less than 25% or in which there were no fixations were excluded from analysis. Of the 124 trials over which eye movements were recorded continuously, any differences between target, related and unrelated images were anticipated to occur starting at 200 ms after onset of the spoken target word due to the time required for object recognition and eye movements (Sekerina & Brooks, 2007). Only fixations initiated after the onset of the target word were included in the analyses.

RESULTS

Overview

The initial analysis focused on the results of CP/SSPI group. First, the number of valid trials was determined to ensure that there were a sufficient number of trials to be analyzed. The mean proportion of fixations to the target, competitor and unrelated images were then analyzed in control and critical conditions. Subsequently, all conditions were analyzed using time course fixations, a moment by moment descriptive analysis of fixations to each of the images in the display for each condition, yielding information on the time course of spoken word recognition and how competition is resolved. An item analysis within each of the three conditions was presented followed by a participant analysis to determine if there were individual differences amongst the participants related to their PPVT-4 scores and speech comprehensibility ratings and other characteristics. Finally, to provide a comparison of lexical activation with the CP/SSPI group, two other groups were analyzed. Adults with NNI were administered the same
experiment, and children with TD participated in separate experiments. For each participant group, the mean proportion and the time course of fixations to each of the images in each condition were analyzed.

**Participants with CP/SSPI**

**PPVT-4 standard scores.** Of the 16 participants listed in Table 2, standard scores ranged from 20 to 88 ($M = 57, SD = 19.2$). A standard score of 60 or above was achieved by 50% of the participants.

**Speech intelligibility.** The I-ASCC (Index of Augmented Speech Comprehensibility in Children) was used to arrive at more finely graded ratings of speech intelligibility of the participants other than anarthria or dysarthria or that provided by the parents who completed the CFSC (Communication Function Classification System). The procedures for administration of this test are described in Appendix C.

Table 2 lists the speech comprehensibility ratings of the 16 participants. One was rated at level 1 (the examiner was able to understand conversational speech with asking for repetitions, rephrasing, asking yes and no questions, etc.), three were judged at level 2 (the examiner was able to understand the spoken names of some of the words with semantic context; participant speech was comprehensible when speaking familiar phrases such as “This is a…”), two were judged at level 3 (examiner was unable to understand spoken words even when context was known; participant was able to produce words that were differentiated from each other by initial sound, number of syllables, stress) and one was judged at level 4 (the examiner was unable to understand spoken words even when context was known; all words
produced sounded the same in terms of sounds, number of syllables, stress pattern, etc.). The remaining nine participants had speech comprehensibility judged to be at level 5 (they did not have sufficient speech to make a recording).

Invalid trials. The number of invalid trials (Table 2) for each participant was analyzed for all conditions and was an indication of how often the eye tracker was unable to detect the eyes of the participant sufficiently to analyze fixations. A large number of invalid trials resulted in fewer trials analyzed for a particular individual and for the group as a whole. For all conditions, out of a total of 1984 trials, MATLAB rejected 223 or 11% of the trials from the CP/SSPI group ($M = 13.9$, $SD = 10$, Range = 3-39). This compares with 1% of the trials rejected for the adults with NNI. For the children with TD, 7% of the trials were rejected. Thus, less gaze data analysis were available for the participants with CP/SSPI.
Table 2

*PPVT-4 Standard Scores, Speech Comprehensibility Scores and Number of Invalid Trials*

<table>
<thead>
<tr>
<th>Participant</th>
<th>Speech</th>
<th>PPVT-4</th>
<th>Invalid trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>50</td>
<td>6</td>
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<td>87</td>
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<td>88</td>
<td>15</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>35</td>
<td>14</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>64</td>
<td>11</td>
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<td>8</td>
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<td>6</td>
</tr>
<tr>
<td>16</td>
<td>3</td>
<td>37</td>
<td>3</td>
</tr>
</tbody>
</table>

\[n = 16\]

\[M = 3.9\]

\[SD = 1.4\]

\[M = 57.5\]

\[SD = 19\]

\[M = 13.9\]

\[SD = 10\]
Mean proportion of fixations to target, competitor and unrelated images. The three control conditions were analyzed separately and revealed a main effect of picture type. Three one-way ANOVAs were conducted for the three control conditions (Phonological control, Semantically Related control and Semantic Onset control) with Picture Type (Target, Competitor, Unrelated) as a factor. A statistically significant main effect of picture type was revealed for the CP/SSPI group in the Phonological control condition, $F(2, 864) = 292.411, p < .001$, the Semantically Related control condition, $F(2, 918) = 322.468, p < .001$ and the Semantic Onset control condition, $F(2, 918) = 269.770, p < .001$. Tukey’s HSD post-hoc tests revealed that for all three control conditions, CP/SSPI participants had a greater proportion of fixations to the target image, $p < .001$, compared to the three unrelated images.

In the control conditions, CP/SSPI participants did not exhibit greater fixations to the two related pictures when neither of them was the target. Comparing fixations among the three unrelated images did not reveal statistically significant effects in all three control conditions for CP/SSPI participants, Phonological, $p = .424$; Semantically related, $p = .347$; Semantic Onset, $p = .659$. Thus, fixations to the competitor image in the critical conditions were interpreted as fixations due to competition effects, rather than a confounding image feature.

Across the three critical conditions, two paired $t$-tests between unrelated image 1 and unrelated image 2 revealed no significant differences between proportion of fixations, $t(907) = -.511, p = .609$. These results suggest that the two unrelated images were equally unrelated to the target. The fixations to the two unrelated images were then averaged together for the remaining analyses.
The three critical conditions were then analyzed separately using a univariate analysis, with picture type as a factor. In the phonological condition, there was a statistically significant difference in picture type, $F(2, 885) = 265.042, p < .001$. *Tukey’s HSD* post-hoc tests revealed that fixations to the target image differed significantly from the competitor image and the competitor image differed significantly from the unrelated image, $p < .001$.

A significant effect of picture type was found in the Semantically Related critical condition, $F(2, 915) = 281.501, p < .001$ and Semantic Onset condition, $F(2, 915) = 281.598, p < .001$. In both conditions, there were significantly more fixations to the target compared to the competitor image ($p < .001$), but the mean proportions of fixations to the competitor image did not differ significantly from the unrelated images, Semantically Related, $p = .313$; Semantic Onset, $p = .954$.

**Total number of fixations in each condition.** In examining the proportion of fixations to each of the four images (Table 3), CP/SSPI participants exhibited a greater proportion of fixations to the target than to the competitor or unrelated images in all conditions. In the phonological critical condition, the proportion of fixations to the competitor was greater than the unrelated images while the proportion of fixations to the unrelated images were equal. The greatest total number of fixations were in the critical and control trials for the semantic onset condition.
Table 3

Total Number and Proportion of Fixations in Each Condition

<table>
<thead>
<tr>
<th>Critical Condition</th>
<th>Target</th>
<th>Competitor</th>
<th>Control 1</th>
<th>Control 2</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Proportion</td>
<td>Number</td>
<td>Proportion</td>
<td>Number</td>
</tr>
<tr>
<td>Phono*</td>
<td>618</td>
<td>.491</td>
<td>247</td>
<td>.1959</td>
<td>196</td>
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<tr>
<td>SR**</td>
<td>640</td>
<td>.4663</td>
<td>254</td>
<td>.1741</td>
<td>188</td>
</tr>
<tr>
<td>SOC***</td>
<td>608</td>
<td>.4950</td>
<td>227</td>
<td>.1964</td>
<td>226</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Control Condition</th>
<th>Target</th>
<th>Unrelated 1</th>
<th>Unrelated 2</th>
<th>Unrelated 3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Proportion</td>
<td>Number</td>
<td>Proportion</td>
<td>Number</td>
</tr>
<tr>
<td>Phono*</td>
<td>583</td>
<td>.4783</td>
<td>222</td>
<td>.1821</td>
<td>204</td>
</tr>
<tr>
<td>SR**</td>
<td>645</td>
<td>.4946</td>
<td>185</td>
<td>.1610</td>
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</tr>
<tr>
<td>SOC***</td>
<td>639</td>
<td>.5103</td>
<td>208</td>
<td>.1464</td>
<td>235</td>
</tr>
</tbody>
</table>

Note: * phonological ** semantically related ***semantic onset
**Time course analysis.** Time plots of the mean proportion of fixations to each image type over time, (from target onset to 1300 ms after onset) in critical trials in the phonological, semantically related, and semantic onset conditions are shown in Figure 7. These time plots reveal the relative proportion of fixations to the target, competitor, and unrelated image as the target word unfolds. The X axis is the time course from the onset of the target word divided into 180 ms sections while the Y axis is the mean proportion of fixations over time to the target, competitor and unrelated images.

![Figure 7. Time course analysis for CP/SSPI participants](image)
In the phonological condition, starting 200 ms after target onset, fixations to both the target and competitor pictures increase while fixations to the competitor are greater than to the unrelated image. By 400 ms, fixations to the target and competitor diverge with fixations to the target increasing steadily, and increase throughout the rest of the trial. However, there is still persistent activation of the competitor as compared to the target image for the remainder of the trial.

In the semantically related condition, fixations to the related image began to increase at 380 ms. There are also fixations to the related image which then decrease rapidly. At this point, fixations to the target rapidly increase, while those to the related image rapidly decrease to the level of activation of the unrelated image. In the semantic onset condition, after target onset, fixations to the target and unrelated image are approximately the same. By 380 ms, fixations to the unrelated image decrease to the level of the semantic onset competition.

**Summary.** Proportion of fixations to the target were greater than to competitor or unrelated images in all conditions indicating that the participants were able to identify the target image. Lexical competition in the phonological condition emerged by 380 ms after target onset and persisted throughout the trial although fixations to the target increased more over time. In contrast, in the semantic relative condition, during the 200 ms to 380 ms period, the activation of the semantic relative increased briefly but then decreased while fixations to the target increased. In the semantic onset condition, during the 200 ms to 380 ms period, the activation of the unrelated image increased briefly, but then decreased to the level of the semantic onset competitor.
**Item analysis.** The results of this analysis are displayed in Figure 8. For each participant and each critical trial, the mean proportion of fixations to the unrelated image was subtracted from the mean proportion of fixations to the competitor. If a participant fixated longer on the competitor in comparison to the unrelated pictures, the difference was positive. The larger the positive difference, the greater the lexical activation of the competitor. If the difference was negative, or if there was a minimal difference, lexical activation was considered weak or absent. This allowed determination of the strength of competition for each item and in each condition and if any unrelated items consistently attracted greater attention.

For example, in the phonological condition, in item 5, where the target was PEACOCK, the competitor was PEANUT and the unrelated images were AIRPLANE and ZIPPER, the difference was positive, as the participants had a greater mean proportion of fixations to the competitor at the $+0.25$ level than to the unrelated image. However, in item 6, where the target was PENCIL, the competitor was PENGUIN and the unrelated images were NECKLACE and GUITAR, the participants had a greater proportion of fixations to the unrelated images, and the difference between them was negative at the $-0.15$ level. This indicates that the phonological relationship between PENCIL and PENGUIN was not sufficiently evident. In a few instances, there was little or no difference between fixations to the competitor and unrelated image (e.g., for items 3 and 10).
In contrast to the phonological condition, the item analysis of the semantic relative condition revealed that for many of the 21 related/unrelated image pairs, there was little difference between proportion of fixations to the related and unrelated images (as in items 6, 9, 12, 15, 18, 21).
and 7) or the difference was negative (as in item 8). Only three image pairs yielded a larger difference than + 0.15 in fixations to the semantic relative as compared to the unrelated image. In the semantic relative condition, degree of association (Nelson et al., 1998) did not appear to have a positive effect on the participants’ lexical activation. Appendix D displays the degree of association between the semantically related pairs listed in the item analysis.

Of the 21 pairs of semantically related images, the participants demonstrated greater activation of the semantic relative than the unrelated images for only four image pairs. For the remaining images, there was a relatively smaller mean proportion of fixations to the semantic relative, no difference between the relative and unrelated images or greater activation of the unrelated images. For example, for item 4 (target BREAD, relative SANDWICH) and item 5 (target CLOSET, relative HANGER) there was strong activation of the relative, while for item 8 (target BIRD, relative NEST) and item 11 (target NAIL, relative HAMMER), the proportion of fixations to the unrelated images were greater than to the related image.

In the semantic onset condition, all of the semantic onset competitor pairs were based on the semantically related pairs in the semantically related condition. For example, in the semantic relative condition, EYES were the target, and GLASSES were the semantic relative. In the semantic onset condition, ICE CREAM (the onset competitor to EYES) was the target and GLASSES was the semantic relative to the unpictured image of EYES.

An item analysis of the difference in the semantic onset condition revealed smaller differences in mean proportion of fixations between the semantic onset competitor and the unrelated images. While the participants demonstrated stronger activation to some of the semantic relative pairs (item 12- target BREAD, relative SANDWICH), they did not
consistently demonstrate greater activation to semantic onset pairs based on these items (item 12 - target SANDAL, unpictured onset competitor SANDWICH, relative of competitor BREAD). The use of clip art images in the semantic onset condition might have had an effect on performance. For example, the clip art images RAIN (item 6), BEACH, (item 12) and FOUR (item 18) used as the target in the semantic onset condition and images from the Snodgrass library such as LOG (item 1) and TIRE (item 20) elicited greater mean proportion of fixations to the unrelated images.

**Individual Differences in CP/SSPI**

**Participant analysis.** The same procedure used for the item analysis was used for the participant analysis. If any individual participants demonstrated a greater mean proportion of fixations to the competitor than the unrelated images in each critical condition, this was interpreted as a demonstration of the competition effect. For each participant, the proportion of fixations to the two averaged unrelated pictures was subtracted from the proportion of fixations to the competitor. For example, in the phonological condition, where TIRE is the target and TIE is the competitor, if a participant fixated longer on the competitor TIE in comparison to the unrelated pictures (e.g., NAIL/CHAIR), the difference was considered positive. However, if the participant fixated the same amount at the unrelated picture (NAIL/CHAIR) than the competitor TIE, the difference was zero. If they fixated longer on the unrelated pictures, the difference was negative. Figure 9 shows a plot of the difference between the proportion of fixations to the competitor and the unrelated items for each participant arranged from highest to lowest PPVT-4 scores.
In each of the three critical conditions, there was a trend for a greater mean proportion of fixations to the phonological competitor for participants with lower PPVT-4 scores (e.g., participant numbers 6, 16, 9, 1, 15 and 8). Those with higher scores (e.g., participants 4, 2 and 5) had smaller differences in mean proportion of fixations to the competitor in the phonological condition but greater differences in the semantic relative or semantic onset conditions.

As shown in Figure 10, in all critical conditions there were statistically significant correlations between PPVT-4 scores and fixations to the target, PHONO, $r = .74, p = .0011$; SR, $r = .53, p = .04$; SOC, $r = .78, p < .001$. Fixations to the competitor did not reach a significant negative correlation but displayed a negative trend, PHONO, $r = -.5827, p = .05$; SR, $r = -.401, p = .1229$. 

*Figure 9. Analysis of difference between competitor and unrelated images for each of 16 participants in phonological (Phono), Semantic Relative (SR) and Semantic Onset (SO) condition in relationship to PPVT-4 standard scores*
Speech comprehensibility. There was no correlation between speech comprehensibility scores and mean proportion of fixations to the competitor or unrelated image in any condition, PHONO, $r = -.0090, p = .9737$; SR, $r = .0114, p = .9665$; SOC, $r = -.3823, p = .1439$. In examining the speech comprehensibility of participants in Figure 9, it appears that there was a range of lexical activation for those with the least comprehensible speech. For example, of the nine participants with a comprehensibility of 5 (the most severely impaired speech), four of them had a much greater proportion of fixations to the phonological competitor than the remaining five.

Of the six participants with greater speech comprehensibility (between 1 and 3), there appears to be greater variability in the mean proportion of fixations between competitor and unrelated image in each condition. For example, participants 9 and 10 both had speech comprehensibility of 2. Participant 9 had a much greater proportion of fixations to the
competitor in the phonological condition and a greater proportion of fixations to the unrelated image in the semantic relative condition. In contrast, participant 10 had a greater proportion of fixations to the unrelated image in all three conditions but the difference between competitor and unrelated image was very small.

Participant 11, however, did not fit the general pattern of findings in that speech comprehensibility may have played a role in speed of recognition of the target. This participant, with a PPVT-4 score of 63 and speech comprehensibility of 1, the highest of all participants, demonstrated a very small mean proportion of fixations to the competitor in the phonological condition and greater proportion of fixations to the unrelated images in the semantic relative and semantic onset conditions. Mean proportion of fixations to the target, in all conditions, was comparable to the participant with the highest PPVT-4 score of 88 but with much lower speech comprehensibility of 5 (see Table 4 for an example). Thus, it appears that speech production is not required for lexical activation but it does vary among participants related to language comprehension.
Table 4

Comparison of PPVT-4 Score, Speech Comprehensibility and Mean Proportion of Fixations to Target for Two Participants

<table>
<thead>
<tr>
<th>PPVT-4 SS</th>
<th>Speech Comprehensibility</th>
<th>Phonological-fixations to target</th>
<th>Semantic Relative-fixations to target</th>
<th>Semantic Onset-fixations to target</th>
</tr>
</thead>
<tbody>
<tr>
<td>88</td>
<td>5</td>
<td>.75</td>
<td>.79</td>
<td>.71</td>
</tr>
<tr>
<td>63</td>
<td>1</td>
<td>.75</td>
<td>.76</td>
<td>.68</td>
</tr>
</tbody>
</table>

Note. These two participants differed greatly in speech comprehensibility and PPVT-4 scores, but their fixations to the target in each condition were very similar.

Age. There is no significant correlation between age and mean proportion of fixations to the competitor or related images in all three conditions (PHONO: $r = 0.3382$, $p = 0.2002$; SR: $r = 0.1553$, $p = 0.5658$; SO: $r = -0.0219$, $p = 0.9359$). For example, participant 16, who was 55 years old, demonstrated the greatest difference between the competitor and the unrelated images in the phonological condition.

Invalid trials. There was no significant correlation between total number of invalid trials and proportion of fixations to the target in each condition (PHONO: $r = -0.2779$, $p = 0.2974$; SR: $r = -0.3260$, $p = 0.2178$; SOC: $r = -0.3937$, $p = 0.1314$). There was also no significant correlation between number of invalid trials and speech comprehensibility, $r = 0.0163$, $p = 0.9522$ nor between invalid trials and age $r = -0.2158$, $p = 0.4222$.

Mode of accessing Speech Generating Device (SGD). Nine of the 16 participants with CP/SSPI used their hands to operate their SGD while the remaining six used eye gaze.
Those participants who used their hands tended to have less stable positioning when seated than the participants who used eye gaze. One factor that could have affected the number of invalid trials is positioning and the participant’s ability to maintain a stable head position during the experiment. Yet there was no significant correlation, $r = 0.4055$, $p = 0.1192$, between number of invalid trials and mode of accessing the SGD.

**Examination of individual time plots.** The time plots of phonological, semantic relative and semantic onset activation for two participants are shown in Appendix E. These two participants with CP/SSPI were selected based on the participant analysis (Figure 9) and could be considered at the ends of the continuum of abilities demonstrated by the participants.

**Participant 5.** With a PPVT-4 standard score of 88, this participant is 19 years old, attends high school and lives at home. He has dyskinetic type of CP, the subtype that recent research has shown to have less severe cognitive impairment, and his speech and GMFCS scores were judged to be at Level V, the most impaired. Over the course of the experiment, he had 15 invalid trials.

**Participant 16.** With a PPVT-4 standard score of 37, this participant is 55 years old, the oldest of the participants, attends a day treatment program and lives at home. Her speech was judged to be at level 3, meaning the examiner was unable to understand spoken words even when context was known; the participant was able to produce words that were differentiated from each other by initial sound, number of syllables, or stress. Like participant 5, GMFCS Levels were also at V, the most impaired. Although the subtype of CP was not made available, this participant had only three invalid trials and did not demonstrate involuntary movements.
during the experiment, indicating that she might have spastic type of cerebral palsy where cognitive deficits are more likely.

**Summary.** While both participants recognized spoken words, patterns of lexical access varied greatly between them, perhaps reflecting their differences in subtype of CP, vocabulary comprehension, age, and education. Participant 5 demonstrated brief periods of competition earlier in the trials followed by greater fixations to the target. In the semantic relative condition, participant 5 resolved competition quickly, demonstrating a pattern more similar to that of the adults. Participant 16, however, may have had difficulty inhibiting fixations to images to which she had initially paid greater attention, which is a pattern more similar to that reported for younger children (Sekerina & Brooks, 2007). Thus, the individual time plots revealed variations as the target word unfolded that were not evident by comparing differences in proportion of fixations between competitor and unrelated images nor by the time plot of mean proportion of fixations of all participants.

**Adults Participants with No Neurological Impairment (NNI)**

**Mean proportion of fixations to target, competitor and unrelated images.** Three univariate analyses of variance were conducted analyzing the three control conditions (PHONO_C, SR_C, SOC_C) with Picture Type as a factor (Target, Competitor, Unrelated). All three control conditions revealed a main effect of picture type (PHONO_C: \( F(2, 540) = 1631.121, p < .001 \); SR_C: \( F(2, 567) = 1634.089, p < .001 \); SOC_C: \( F(2, 573) = 2776.019, p < .001 \)). *Tukey’s HSD* post-hoc tests revealed that for all three control conditions, fixations to the target were statistically significant at the .001 level, compared to the three unrelated
images, while fixations to the three remaining unrelated images were not statistically significant (PHONO_C, \( p = .199 \); SR_C, \( p = .858 \); SOC_C, \( p = .512 \)).

Thus, fixations to the competitor image in the critical conditions are interpreted as fixations drawn to the image due to priming effects, rather than a confounding feature about the image itself. The rest of the analyses focuses on analyzing the critical conditions only.

**Collapsing unrelated 1 and unrelated 2 images.** No significant differences between proportion of fixations to unrelated image 1 and unrelated image 2, \( t(907) = .358, p = .72 \). were revealed by \( t \)-tests. These results suggest that, the two unrelated images were equally unrelated to the target as demonstrated by the even proportion of fixations. There were no statistically significant differences within group comparing fixations to unrelated image 1 and unrelated image 2. The rest of the analyses conducted were done using this collapsed variable.

**Critical conditions.** There was a significant effect of picture type in the phonological condition, \( F(2, 540) = 1611.160, p < .001 \). *Tukey’s HSD* post-hoc tests revealed that this effect was driven by a significant difference between the proportion of fixations to the target compared to the competitor image, \( p < .001 \). Comparing the competitor with the unrelated image yielded no statically significant effect in the phonological condition for adult participants, \( p = .236 \).

In the semantic relative condition, a univariate analysis revealed a main effect of picture type, \( F(2, 570) = 1148.018, p < .001 \), where the target elicited significantly more fixations than the competitor image, \( p < .001 \). Though the competitor image did not differ significantly from the unrelated images, for the SR condition this effect approached significance, \( p = .071 \).
In the semantic onset condition, the analysis revealed a similar pattern with a significant effect of picture type, $F(2, 585) = 1758.069, p < .001$, and significantly more fixations to the target compared to the competitor, $p < .001$, but no significant difference between competitor and unrelated images, $p = .791$.

**Summary.** In each condition, there was a statistically significant difference between proportion of fixations to the target compared to the competitor image, $p = < .001$. Comparing the competitor with the unrelated image yielded no statistically significant effects in the phonological and semantic onset conditions, but for the semantically related condition this effect approached significance. It should be noted that the group size was quite small with consequent low statistical power and this may have affected the detection of expected differences.

**Adult NNI participant analysis.** The same procedure used for the participant analysis with the participants with CP/SSPI was used for the adults with NNI (see Figure 11). For each participant, the proportion of fixations to the two averaged unrelated pictures was subtracted from the proportion of fixations to the competitor. If any individual participants demonstrated a greater mean proportion of fixations to the competitor than the unrelated images in each critical condition, this was interpreted as a demonstration of the competitor effect.
Figure 11. Adults with NNI participant analysis in phonological (Phono), semantic relative (SR) and semantic onset (SOC) critical conditions.

Adults with NNI demonstrated far smaller differences between proportion of fixations to the competitor and unrelated images in all conditions as compared with many of the CP/SSPI participants. However, there was a trend for the adults with NNI to demonstrate differences between the competitor and unrelated images that appeared similar to those with CP/SSPI with higher PPVT-4 standard scores regardless of their speech intelligibility.

**Time course analysis.** As illustrated in Figure 12, adults with NNI fixated on all images equally and then rapidly identified the target, leaving less time to fixate on competitors. In the phonological condition, they fixated more on the target from the beginning of the trial and only for a very brief period at 400-580 ms, they fixated on the competitor. In the semantic relative condition, there was a very brief period of competition at 400-580 ms although fixations to the target were already increasing. In the semantic onset condition, they had
already increased fixations to the target by 380 ms and slightly more fixations to the unrelated images than the semantic relative of the unpictured phonological onset competitor to the target.

Figure 12. Adults with NNI- Time course analysis in phonological, semantic relative and semantic onset conditions.
Children with TD

**Control condition.** Three repeated-measures ANOVAs were conducted on the proportion of fixations to three non-target images in three conditions for control trials. There was no significant difference between proportion of fixations to the three non-target images in the control trials PHONO_C: $F(2, 22) = 2.5929, p > 0.05$; SR_C: $F(2, 22) = 3.1074, p > 0.05$; SOC_C: $F(2, 22) = 3.1187, p > 0.05$.

**Critical condition.** The mean proportion of fixations between unrelated image 1 and unrelated image 2 were calculated in each condition (PHONO, SR, SOC). No significant differences were demonstrated through $t$-tests between the proportion of fixations to unrelated image 1 and unrelated image 2 for all three conditions, $p = .181$. These results suggest that the two unrelated images were equally unrelated to the target as demonstrated by the even proportion of fixations.

Thus, fixations to the competitor image in the critical conditions are interpreted as fixations drawn to the image due to priming effects, rather than a confounding feature about the image itself. The rest of the analyses conducted were done using this collapsed variable.

**Fixations to competitor versus unrelated images.** A one-way ANOVA in the Phonological (PHONO) and Semantically Related (SR) conditions demonstrated that there were statistically significant differences among fixations to the competitor and unrelated images PHONO: $F(2,33) = 12.61, p < .001$; SR: $F(2,33) = 4.05, p < .05$. *Tukey’s* HSD post hoc test demonstrated that, fixations to the competitor are significantly higher than to the unrelated images in the PHONO $p < .05$ and the SR conditions $p = .03$. However, in the SOC
condition, there was no significant difference $F(2,33) = .35, p = .71$ among fixations to competitor and unrelated image.

**Time course analysis.** In the phonological condition, at 200 ms after target onset, children with TD demonstrated equal activation of target and competitor till 580 ms (see

*Figure 13. Children with TD- Time course analysis in phonological, semantic relative and semantic onset conditions*
Figure 13). At that point, fixations to the target rapidly increased while fixations to the competitor steadily decreased. In contrast, activation of both competitor and target persisted until about 780 ms. In the semantically related condition, at 200 ms after target onset, children with TD demonstrated greater fixations to the target. At about 380 ms, activation of the semantic relative also began to increase. Children with TD did not demonstrate activation of the phono-semantic competitor and demonstrated greater fixations to the target from onset.

Summary. A comparison of the time course of mean proportion of fixations for the competitor versus the unrelated image in each condition for the three participant groups reveals different information than that of mean proportions of fixations alone. While mean proportion of fixations over the 1300 ms of the trial may not have been significant, inspection of time plots indicates that at different points in the trials, fixations to images varied.

For example, participants with CP/SSPI demonstrated phonological competition as did children with TD, but they did not inhibit fixations to the competitor images as early in the trial. In the semantic relative condition, participants with CP/SSPI initially fixated on both the target and the competitor more than unrelated images while children with TD demonstrated greater fixations to the competitor than the unrelated images later in the time course, at 400 to 580 ms, and still greater fixations to the target. The time course of adult fixations appears to be characterized by very brief competition effects. In the semantic onset condition, all three groups demonstrated greater fixations to the target (Yee & Sedivy, 2006).

Participants with CP/SSPI demonstrated spoken word recognition with lexical competitor effects that differed from the children with TD and adults with NNI. The wide range of ages and vocabulary comprehension scores in the participants with CP/SSPI as
compared to the more homogenous adults with NNI and children with TD may have contributed to some of these differences.

**GENERAL DISCUSSION**

The study was undertaken to examine hypotheses that speech perception and phonological working memory require motor production of speech and an articulatory code. The Motor Theory predicts that individuals with CP/SSPI should be unable to perceive words and their phonological characteristics and thus, would not have a phonologically organized mental lexicon. Consequently, there should be no phonological competition in lexical access. Because the Trace theory of speech perception posits the interaction of phonological and semantic word cues, semantic competition may be similarly limited as a result. Similarly, phonological working memory (Baddeley, 1986) is thought to be critical to lexical development and representation. Subvocal rehearsal, which is critical to phonological working memory, requires an articulatory code, which is not available to individuals with CP/SSPI. Consequently, individuals with CP/SSPI who do not have the ability to speak cannot engage in subvocal rehearsal (Bishop et al., 1990), resulting in vocabulary deficits.

This research sought to answer three questions:

1. Does an inability to produce speech preclude speech perception and the establishment of a phonologically organized mental lexicon? Do adolescents and adults with CP/SSPI exhibit competition from phonological, semantic, or semantic onset competitors in lexical access?
2. Are there individual differences in spoken word recognition between adolescents and adults with CP and SSPI correlated with speech intelligibility, vocabulary comprehension, and other characteristics?

3. Are there similarities in lexical activation between adolescents and adults with CP and SSPI, children with TD and adults with no neurological impairment (NNI)?

   With limited production abilities and evidence of limited phonological knowledge, as well as semantic knowledge (which is first filtered through phonology), individuals with CP/SSPI were not expected to activate the competitor’s lexical representation. Individual differences between the CP/SSPI participants in the degree of speech impairment and PPVT-4 standard scores were expected to correlate with lexical access measures.

   A secondary goal of this study was to test the feasibility of using the visual world paradigm with the CP/SSPI population. The visual world paradigm and eye tracking may provide language testing without extensive adaptations for motoric limitations.

**Insights from Eye Tracking Results**

   The results of this study indicate that individuals with severe speech and motor impairment are able to perceive words and to resolve competition between them as the word unfolds. The ability to speak is not essential for a phonologically-based access to the lexicon and is not dependent on motor speech production.

   While the motor theory of speech perception predicts that the inability to produce speech would preclude speech perception (Liberman & Mattingly, 1985), the ability to develop spoken word recognition is dependent on information from the primary modality of audition,
along with information from a variety of information including vision and touch (Card & Dodd, 2006). Lexical access and the phonological organization of the mental lexicon do not appear to require the ability to produce speech sounds and degree of speech impairment does not have a relationship to lexical access.

The language deficits seen in individuals with CP/SSPI were reflected in their lexical activation. Phonological competition was very strong while semantic competition was much weaker for the group. Examining individual performance, those who spent more time fixating on competitors in the phonological condition also fixated more on competitors and distractors in the semantic condition. Those who quickly eliminated competitors in the phonological condition also did so in the semantic condition. Phonological and semantic activation in adults with no neurological impairment and children with typical development followed similar patterns.

This pattern supports interactive activation models of lexical access such as TRACE that proffer an intertwining of phonological and semantic processing, where any weakness in activation at one level can then impact another level (Huang & Snedeker, 2010). Word recognition can be seen as a flow of information with simultaneous phonological and semantic information activation and can explain the reciprocal influence between impoverished semantic and phonological word representations and the relations among them in individuals with CP/SSPI (Smith, 2001).

Less efficient phonological processing interfered with semantic activation, supporting the view that phonological information activates semantic representations. There was a trend for lexical access to differ according to scores on the PPVT-4. Those with higher PPVT-4
scores demonstrated less time fixating on competitors and more quickly identified the target word/picture. As PPVT-4 scores increased, phonological competition decreased, while activation of the semantic relative or semantic onset competitor increased. Those individuals who identified the target word more quickly also fixated less on other images and demonstrated smaller differences between competitor and unrelated images. As PPVT-4 scores decreased, individuals demonstrated greater difficulty in inhibiting phonological competition and in semantic organization as greater attention was allocated to competitor and unrelated images.

Individuals with CP/SSPI with vocabulary comprehension far below their chronological age may also have delays in cognitive development that impact language processing (Perrin et al., 2017), particularly in allocation of sustained attention inhibition, self-regulation, planning and modifying behavior. Cognitive abilities may explain the differences in lexical activation found between participants in this study as they also explain differences between lexical activation in adults and children.

Comparing individual differences. Because of the range of language comprehension abilities of the participants with CP/SSPI, the mean proportion of fixations in each condition and the use of one time plot to represent the group were not sufficient to reveal the differences between those with CP/SSPI. By averaging results for the group, the large effects of fixations to the phonological competitor for those with lower PPVT-4 scores and the absence of significant effects for the semantic relative overshadowed the within group differences.

A comparison of time plots for two participants with CP/SSPI, one with very high and one with very low PPVT-4 scores, revealed differences in the time course of spoken words in
relation to PPVT-4 scores and other characteristics. While both participants demonstrated that they were able to recognize spoken words, patterns of lexical access varied greatly between them as revealed by the difference between fixations to the competitor and unrelated images. A statistical analysis of these differences, coupled with the positive correlation between target fixations and PPVT-4 scores, would reveal more accurate information concerning individual differences. Moreover, an analysis of accuracy for each participant would reveal if fixations to the competitor occurred because of the competition effect or because the participant selected the competitor as the target.

** Differences in test administration between the three participant groups. ** In comparing results of the three participant groups, it is possible that proportion of fixations were weighted by the differences between the number of valid trials. The initial eye tracking analyses of the children with TD eliminated incorrectly identified targets but for the adults with NNI and participants with CP/SSPI, both correct and incorrect trials were included. There were a far greater number of valid trials for the adults with NNI than for the children. The participants with CP/SSPI had the greatest number of invalid trials but like the adults, all responses were included.

The amount of gaze data available for analyses differed across the groups. The small number of adults with NNI resulted in low statistical power and made it difficult to detect effects. It is also possible that the use of a passive (i.e., no mouse click on the target picture) paradigm with adults with NNI was sufficiently unusual as to affect their gaze behavior. The mouse click provides a natural ending to spoken word recognition. The children with TD, who

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were seen has part of another study did use a mouse click, so the eye tracking results may not be comparable.

**The semantic onset condition.** The lack of statistically significant results in the semantic onset condition for the adults with NNI, the children with TD, and individuals with CP/SSPI suggests limitations with technical aspects of the experimental task. The effects reported by Huang & Snedeker (2010) and Yee & Sedivy (2006) may be more fragile than reported and may be limited to the specific images and corresponding words selected by those investigators. This short-lived semantic onset effect occurring at 200 to 300 ms which is much shorter than the duration of the semantic relative effect. As it is directly linked to the acoustic input, it may require a different approach to measurement of fixations over time than used in this study.

**Directions for Future Research and Clinical Implications**

**The use of eye tracking for language assessment.** The outcomes of this study validate eye tracking as a consistent method of investigating language processing in real-time. In general, given the variability seen within the participants with CP/SSPI, it appears critical to investigate the specific factors that shape individual lexical performance. Further analyses could help to identity profiles of participants with CP/SSPI and their deficits and strengths, allowing more targeted intervention for communication intervention.

The use of the visual world eye tracking paradigm provided a method for language testing without extensive motor adaptations and the possibility of comparing results of adapted tasks to standardized tests. The validity of adapted test results for individuals with CP/SSPI has
long been a concern. Standard classification systems to describe motor, hand function and communication function now enable comparison of results and more comprehensive reporting of development and impairment in individuals with CP/SSPI.

The location and extent of brain lesions revealed by MRI have been related to receptive language, overall communication ability and to motor impairment in individuals with CP/SSPI (Coleman et al., 2016). Such information could also be combined with eye tracking to reveal details of language processing and their relation to observed brain lesions and subtypes of CP.

**Incorporating eye tracking research with AAC devices.** Information from eye tracking research can lead to better design of AAC communication displays. The spoken word recognition task used in this study revealed potential interference from semantically or phonologically related symbols that may occur in symbol arrays. Yee & Sedivy’s findings (2006) indicated that unpictured vocabulary items can also influence fixations. The visual world paradigm could be used to determine the best arrangement of symbols on AAAC devices. This might improve the efficiency and accuracy of communication and guide the individualization of AAC device displays using lexical/symbol activation patterns.

One challenge in using the eye tracker with individuals with severe motor impairment is to reduce the number of invalid trials and increase the amount of data available from any given task. The number of invalid trials can be minimized by further maximizing the positioning of individuals who have difficulty maintaining a stable position, minimizing involuntary movements, and decreasing the number of trials presented during any one experiment. Incorporating auditory and visual feedback based on dwell time might increase motivation and attention.
Greater focus on lexical access, language and cognition in early intervention. The intervention focus for this population has traditionally centered on language production; comprehension has been an overlooked component in augmented language development (Sevcik, 2006). A complete assessment of comprehension difficulties is essential to develop intervention strategies that are appropriate and effective for the level of the particular individual. The visual world paradigm along with other behavioral assessments can reveal differences between individuals with or without comprehension deficits, providing more detailed assessment and differential routes to intervention and may widen the scope of linguistic behaviors examined in this population.

A participant group with a smaller age range, younger participants, participants with greater speech intelligibility, and with PPVT-4 scores that are more similar across groups would provide further information. An analysis of the time course of lexical activation in a larger number of participants using PPVT-4 scores, speech intelligibility, or other characteristics as predictors would add to the findings reported here. In addition, a comparison of children with similar PPVT-4 scores would add more information concerning the role of vocabulary level in lexical access.

The language and communication rehabilitation of a child with CP/SSPI should receive as much attention as motor development. Subgroups of individuals CP who are at greater risk for language impairment need to be identified to target services early and effectively. Language and cognition assessment should take place as early as possible in young children to provide more detailed profiles of individual language strengths and weakness as a guide to intervention when an AAC system is recommended (Vos et al., 2014). Profiles of language
domains such as semantics, syntax, morphology, and pragmatics along with related cognitive abilities in relation to CP types seems critical for intervention planning (Geytenbeek et al., 2015).

Given the heterogeneous nature of CP, longitudinal research is also needed to examine the contributions of lexical access to the development and organization of the mental lexicon. Changes in lexical access with maturity and with varying approaches to early intervention can yield better treatment efficacy data. Such research would influence clinical practice in the provision of tailored AAC systems, all of which vary in their methods of access, and linguistic and cognitive requirements, and help children with CP/SSPI achieve the goal of independent communication and maximum participation in all activities.
**APPENDICES**

**Appendix A**

*Classification Systems Used to Describe Physical, Manual and Communication Abilities*

<table>
<thead>
<tr>
<th>Classification system</th>
<th>Level I</th>
<th>Level II</th>
<th>Level III</th>
<th>Level IV</th>
<th>Level V</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMFCS</td>
<td>Walks without limitations</td>
<td>Walks with limitations</td>
<td>Walks using a hand-held mobility device</td>
<td>Self-mobility with limitations; may use powered mobility</td>
<td>Transported in a manual wheelchair</td>
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<tr>
<td>MACS</td>
<td>Handles objects easily and successfully</td>
<td>Handles most objects but with somewhat reduced quality and/or speed of achievement</td>
<td>Handles objects with difficulty; needs to prepare and/or modify activities</td>
<td>Handles a limited selection of easily managed objects in adapted situations</td>
<td>Does not handle objects and has severely limited ability to perform even simple actions</td>
</tr>
<tr>
<td>CFCS</td>
<td>Sends and receives with familiar and unfamiliar partners effectively and efficiently</td>
<td>Sends and receives with familiar and unfamiliar partners but may need extra time</td>
<td>Sends and receives with familiar partners effectively, but not with unfamiliar partners</td>
<td>Inconsistently sends and/or receives even with familiar partners</td>
<td>Seldom effectively sends and receives, even with familiar partners</td>
</tr>
</tbody>
</table>

*Note.*  

* a Gross Motor Function Classification System- Expanded and Revised (GMFCS; Palisano et al., 2007).  

* b Manual Ability Classification System (MACS; Eliasson, et al., 2006).  

* c Communication Function Classification System (CFCS; Hidecker et al., 2011).
### Appendix B

Table B1

*Experimental Stimuli - Phonological Onset Condition*

<table>
<thead>
<tr>
<th>Trial</th>
<th>Target (Unrelated)</th>
<th>Competitor (Unrelated)</th>
<th>Control 1 (Target)</th>
<th>Control 2 (Unrelated)</th>
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<td>Bell</td>
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<td>Moose</td>
<td>Scale</td>
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<td>Lock</td>
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<td>------</td>
</tr>
<tr>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Lamb</td>
<td>Lamp</td>
<td>Saw</td>
<td>Basket</td>
</tr>
<tr>
<td>20</td>
<td>Bus</td>
<td>Button</td>
<td>Pen</td>
<td>Scissors</td>
</tr>
</tbody>
</table>

*Note.* In critical trials, *button* was the competitor, while *pen* and *scissors* were controls. In the control trial, participants saw the same display, but *pen* was the target, while *bus, button* and *scissors* were the unrelated control items.
Table B2

*Experimental Stimuli – Semantic Relative Condition*

<table>
<thead>
<tr>
<th>Trial</th>
<th>Target</th>
<th>Semantic relative</th>
<th>Unrelated 1</th>
<th>Unrelated 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fish</td>
<td>Hook</td>
<td>Glass</td>
<td>Dinosaur</td>
</tr>
<tr>
<td>2</td>
<td>Football</td>
<td>Helmet</td>
<td>Bottle</td>
<td>Desk</td>
</tr>
<tr>
<td>3</td>
<td>Leaves</td>
<td>Rake</td>
<td>Pig</td>
<td>Celery</td>
</tr>
<tr>
<td>4</td>
<td>Bread</td>
<td>Sandwich</td>
<td>Image</td>
<td>Shoe</td>
</tr>
<tr>
<td>5</td>
<td>Closet</td>
<td>Hanger</td>
<td>Ant</td>
<td>Pepper</td>
</tr>
<tr>
<td>6</td>
<td>Cat</td>
<td>Mouse</td>
<td>Basket</td>
<td>Straw</td>
</tr>
<tr>
<td>7</td>
<td>Shirt</td>
<td>Tie</td>
<td>Zebra</td>
<td>Hamburger</td>
</tr>
<tr>
<td>8</td>
<td>Bird</td>
<td>Nest</td>
<td>Mushroom</td>
<td>Train</td>
</tr>
<tr>
<td>9</td>
<td>Needle</td>
<td>Thread</td>
<td>Cactus</td>
<td>Turtle</td>
</tr>
<tr>
<td>10</td>
<td>Pan</td>
<td>Stove</td>
<td>Bike</td>
<td>Rope</td>
</tr>
<tr>
<td>11</td>
<td>Nail</td>
<td>Hammer</td>
<td>Duck</td>
<td>Lemon</td>
</tr>
<tr>
<td>12</td>
<td>Fork</td>
<td>Cake</td>
<td>Watch</td>
<td>Piano</td>
</tr>
<tr>
<td>13</td>
<td>Bee</td>
<td>Flower</td>
<td>Car</td>
<td>Iron</td>
</tr>
<tr>
<td>14</td>
<td>Cloud</td>
<td>Airplane</td>
<td>Turtle</td>
<td>Lips</td>
</tr>
<tr>
<td>15</td>
<td>Spoon</td>
<td>Bowl</td>
<td>Mouse</td>
<td>Ear</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>16</td>
<td>Spider</td>
<td>Web</td>
<td>Broom</td>
<td>Fence</td>
</tr>
<tr>
<td>17</td>
<td>Eyes</td>
<td>Glasses</td>
<td>Bell</td>
<td>Flag</td>
</tr>
<tr>
<td>18</td>
<td>Lamp</td>
<td>Switch</td>
<td>Frog</td>
<td>Cheese</td>
</tr>
<tr>
<td>19</td>
<td>Rooster</td>
<td>Barn</td>
<td>Toothbrush</td>
<td>Sock</td>
</tr>
<tr>
<td>20</td>
<td>Key</td>
<td>Lock</td>
<td>Feather</td>
<td>Dog</td>
</tr>
<tr>
<td>21</td>
<td>Butterfly</td>
<td>Caterpillar</td>
<td>Leg</td>
<td>Scissors</td>
</tr>
</tbody>
</table>

Note. Semantically related condition example. In critical trials, *key* was the target, *lock* was the relative while *feather* was the control item for *key* and *dog* for *lock*. In control trials, participants saw the same display, but *feather* was the target, with *key*, *lock* and *dog* as unrelated objects.
Table B3

Experimental Stimuli - Semantic Onset Competitor Condition

<table>
<thead>
<tr>
<th>Item</th>
<th>Target</th>
<th>Competitor</th>
<th>Unrelated 1</th>
<th>Unrelated 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pants (pan)</td>
<td>Stove</td>
<td>Bike</td>
<td>Rope</td>
</tr>
<tr>
<td>2</td>
<td>Clock (closet)</td>
<td>Hanger</td>
<td>Ant</td>
<td>Pepper</td>
</tr>
<tr>
<td>3</td>
<td>Helicopter(helmet)</td>
<td>Football</td>
<td>Bottle</td>
<td>Desk</td>
</tr>
<tr>
<td>4</td>
<td>Beach (bee)</td>
<td>Flower</td>
<td>Car</td>
<td>Iron</td>
</tr>
<tr>
<td>5</td>
<td>Bow (bowl)</td>
<td>Spoon</td>
<td>Mouse</td>
<td>Ear</td>
</tr>
<tr>
<td>6</td>
<td>Hamburger (hammer)</td>
<td>Nail</td>
<td>Duck</td>
<td>Lemon</td>
</tr>
<tr>
<td>7</td>
<td>Spine (spider)</td>
<td>Web</td>
<td>Broom</td>
<td>Fence</td>
</tr>
<tr>
<td>8</td>
<td>Four (fork)</td>
<td>Cake</td>
<td>Watch</td>
<td>Piano</td>
</tr>
<tr>
<td>9</td>
<td>Lamb (lamp)</td>
<td>Switch</td>
<td>Frog</td>
<td>Cheese</td>
</tr>
<tr>
<td>10</td>
<td>Logs (lock)</td>
<td>Key</td>
<td>Feather</td>
<td>Grasshopper</td>
</tr>
<tr>
<td>11</td>
<td>Rain (rake)</td>
<td>Leaves</td>
<td>Pig</td>
<td>Celery</td>
</tr>
<tr>
<td>12</td>
<td>Sandal (sandwich)</td>
<td>Bread</td>
<td>Picture</td>
<td>Ladybug</td>
</tr>
<tr>
<td>13</td>
<td>Mouth (mouse)</td>
<td>Cat</td>
<td>Basket</td>
<td>Chair</td>
</tr>
<tr>
<td>14</td>
<td>Clown (cloud)</td>
<td>Airplane</td>
<td>Turtle</td>
<td>Lips</td>
</tr>
<tr>
<td>15</td>
<td>Ice Cream (eyes)</td>
<td>Glasses</td>
<td>Bell</td>
<td>Flag</td>
</tr>
<tr>
<td>16</td>
<td>Fist (fish)</td>
<td>Hook</td>
<td>Glass</td>
<td>Dinosaur</td>
</tr>
<tr>
<td>17</td>
<td>Knee (needle)</td>
<td>Thread</td>
<td>Cactus</td>
<td>Turtle</td>
</tr>
<tr>
<td>18</td>
<td>Tire (tie)</td>
<td>Shirt</td>
<td>Zebra</td>
<td>Hamburger</td>
</tr>
<tr>
<td></td>
<td>Necklace (nest)</td>
<td>Bird</td>
<td>Mushroom</td>
<td>Train</td>
</tr>
<tr>
<td>---</td>
<td>----------------</td>
<td>------</td>
<td>----------</td>
<td>-------</td>
</tr>
<tr>
<td>20</td>
<td>Button (butterfly)</td>
<td>Caterpillar</td>
<td>Leg</td>
<td>Scissors</td>
</tr>
<tr>
<td>21</td>
<td>Four (fork)</td>
<td>Cake</td>
<td>Watch</td>
<td>Piano</td>
</tr>
</tbody>
</table>

*Note.* In critical trials, *logs* was the target, *key* was the semantically related object, *deer* and *apple* were unrelated controls. In control trials, participants saw the same display, but *deer* was the target, while *key, apple* and *logs* were unrelated controls. Unpictured onset competitors are indicated in parentheses in first column labeled Target.
Appendix C

*Speech Comprehensibility Testing based on the I-ASCC (Dowden, 1997)*

The participants were asked to name a series of 30 black and white line drawings of familiar objects that were included in this experiment plus additional action words not included. All but three of these words are also included in the master word pool of the I-ASCC (Dowden, 1997); each word is acquired by young children by the age of 30 months. By also including images used in this experiment, the participant’s recognition of the object could be verified.

The participant was shown each picture; the target word was elicited by the examiner with the least amount of cuing possible showing the picture only (e.g., “What is this?”) and was recorded for later listening by the examiner and by a judge unfamiliar with the participant but familiar with the words in the experiment.

Each of the words was assigned a context from the I-ASCC (see Appendix A, Table 1 for list of Words with Context). For example, *helicopter* was “something people ride” while *pig* was “a farm animal”. The examiner and the judge reviewed each of the recordings; they were given a list of the context for each of the recorded words (see) and asked to rate each participant on a 5-point comprehensibility scale (see Table 2, Judge’s Sheet) with 1 as most comprehensible and 5 as having speech that was not sufficient enough to make a recording.

Even with prior knowledge of the words and the context, both the examiner and the judge had great difficulty most of the words recorded by the participants. Of the five participants recorded for comprehensibility, two were judged at level 2 (i.e., the examiner was able to understand the spoken names of some of the words with semantic context; participant
speech was comprehensible when speaking familiar phrases such as “This is a…” and one at level 4 (the examiner was unable to understand spoken words even when context was known; all words produced sounded the same in terms of sounds, number of syllables, stress pattern, etc.)
<table>
<thead>
<tr>
<th>Number</th>
<th>Word</th>
<th>Context</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>four</td>
<td>Number less than 11</td>
</tr>
<tr>
<td>2</td>
<td>rain</td>
<td>Types of weather</td>
</tr>
<tr>
<td>3</td>
<td>listen</td>
<td>What you do with a book</td>
</tr>
<tr>
<td>4</td>
<td>carry</td>
<td>What you do with a book</td>
</tr>
<tr>
<td>5</td>
<td>hamburger</td>
<td>Something you eat</td>
</tr>
<tr>
<td>6</td>
<td>helicopter</td>
<td>Something people ride in</td>
</tr>
<tr>
<td>7</td>
<td>helmet</td>
<td>Something on your head</td>
</tr>
<tr>
<td>8</td>
<td>drop</td>
<td>What you do with a book</td>
</tr>
<tr>
<td>9</td>
<td>bread</td>
<td>Something you eat</td>
</tr>
<tr>
<td>10</td>
<td>ant</td>
<td>Things crawling outside</td>
</tr>
<tr>
<td>11</td>
<td>eat</td>
<td>What you do with food</td>
</tr>
<tr>
<td>12</td>
<td>table</td>
<td>Things in a room</td>
</tr>
<tr>
<td>13</td>
<td>pumpkin</td>
<td>A vegetable people eat</td>
</tr>
<tr>
<td>14</td>
<td>clock</td>
<td>Things in a room</td>
</tr>
<tr>
<td>15</td>
<td>sleep</td>
<td>Things in a room</td>
</tr>
<tr>
<td>16</td>
<td>door</td>
<td>Things in a room</td>
</tr>
<tr>
<td>17</td>
<td>eyes</td>
<td>Parts of the body</td>
</tr>
<tr>
<td>18</td>
<td>knee</td>
<td>Parts of the body</td>
</tr>
<tr>
<td>19</td>
<td>cheese</td>
<td>Something you eat</td>
</tr>
</tbody>
</table>
20 pants  Clothing
21 catch  What you do with a ball
22 pear  Fruit people eat
23 mitten  Clothing
24 sandals  Clothing
25 kick  What you do with a ball
26 car  Something you ride in
27 open  What you do with a book
28 train  Something you ride in
29 duck  A farm animal
30 pig  A farm animal
Table C2

*Speech Comprehensibility with Context – Judge’s Sheet*

Subject Number: _______          Date: _______  
Judge: __________

<table>
<thead>
<tr>
<th>Number</th>
<th>Context</th>
<th>Word</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Number less than 11</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Types of weather people talk about</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>What you see people doing with a book</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>What you see people doing with a book</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Something you eat</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Something people ride in</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Something you wear on your head</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>What you see people doing with a book</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Something you eat</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Things people see crawling outside</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>What you see people doing with food</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Things in a room</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>A vegetable people eat</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Things in a room</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Things in a room</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Things in a room</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Parts of the body</td>
<td></td>
</tr>
</tbody>
</table>
18 Parts of the body
19 Something you eat
20 Clothing
21 What you do with a ball
22 Fruit people eat
23 Clothing
24 Clothing
25 What you do with a ball
26 Something you ride in
27 What you see people doing with a book
28 Something you ride in
29 A farm animal
30 A farm animal
Table C3.

*Speech Comprehensibility Scale*

1. Examiner was able to understand conversational speech with asking for repetitions, rephrasing, asking yes and no questions, etc.

2. Examiner was able to understand the spoken names of some of the words with semantic context; participant speech was comprehensible when speaking familiar phrases such as “This is a…”

3. Examiner was unable to understand spoken words even when context was known; participant was able to produce words that were differentiated from each other by initial sound, number of syllables, stress.

4. Examiner was unable to understand spoken words even when context was known; all words participants produced sounded the same in terms of sounds, number of syllables, stress pattern, etc.

5. Participant did not have sufficient speech to make recording.
Appendix D

Degree of Association of Semantic Pairs

<table>
<thead>
<tr>
<th>Item #</th>
<th>Target</th>
<th>Relative</th>
<th>FSG*</th>
<th>BSG**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Key</td>
<td>Lock</td>
<td>0.255</td>
<td>0.406</td>
</tr>
<tr>
<td>2</td>
<td>Nail</td>
<td>Hammer</td>
<td>0.622</td>
<td>0.8</td>
</tr>
<tr>
<td>3</td>
<td>Spoon</td>
<td>Bowl</td>
<td>0.078</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>Bread</td>
<td>Sandwich</td>
<td>0.026</td>
<td>0.067</td>
</tr>
<tr>
<td>5</td>
<td>Spider</td>
<td>Web</td>
<td>0.246</td>
<td>0.845</td>
</tr>
<tr>
<td>6</td>
<td>Leaves</td>
<td>Rake</td>
<td>0.043</td>
<td>0.622</td>
</tr>
<tr>
<td>7</td>
<td>Cat</td>
<td>Mouse</td>
<td>0.256</td>
<td>0.543</td>
</tr>
<tr>
<td>8</td>
<td>Fish</td>
<td>Hook</td>
<td>0.301</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>Football</td>
<td>Helmet</td>
<td>0</td>
<td>0.124</td>
</tr>
<tr>
<td>10</td>
<td>Cloud</td>
<td>Airplane</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>11</td>
<td>Bird</td>
<td>Nest</td>
<td>0.061</td>
<td>0.681</td>
</tr>
<tr>
<td>12</td>
<td>Bee</td>
<td>Flower</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>13</td>
<td>Rooster</td>
<td>Barn</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>14</td>
<td>Lamp</td>
<td>Switch</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>15</td>
<td>Closet</td>
<td>Hanger</td>
<td>0.061</td>
<td>0.076</td>
</tr>
<tr>
<td>16</td>
<td>Pan</td>
<td>Stove</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>17</td>
<td>Needle</td>
<td>Thread</td>
<td>0.424</td>
<td>0.758</td>
</tr>
<tr>
<td>18</td>
<td>Fork</td>
<td>Cake</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>19</td>
<td>Eyes</td>
<td>Glasses</td>
<td>0.071</td>
<td>0.322</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>--------</td>
<td>-------</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>20</td>
<td>Shirt</td>
<td>Tie</td>
<td>0.103</td>
<td>0.74</td>
</tr>
<tr>
<td>21</td>
<td>Butterfly</td>
<td>Caterpillar</td>
<td>0.097</td>
<td>0.358</td>
</tr>
</tbody>
</table>

*Note.* Degree of *Forward association* (e.g., key-lock) and **Backward association** (e.g., lock-key) according to Nelson et al. (1998)
Appendix E

*Comparison of Time Plots for Two Participants with CP/SSPI #5 (PPVT-4 score 88), #16 (PPVT-4 score 37)*

**Phonological Onset Competitor (Figure E1)**

Example – target TIRE, competitor TIE, Unrelated 1 NAIL, Unrelated 2 ZEBRA

**Participant 5 with CP/SSPI.** In the phonological condition (e.g., TIRE [target], TIE [phonological onset competitor], NAIL and ZEBRA [unrelated images]), participant with CP/SSPI 5 began the trial with greater fixations to the competitor image at the onset of the trial. Between 200 and 400 ms, fixations to unrelated image 1 and to the target increased and by 400 ms, there were greater fixations to the target. During the period between 500 and at 600 ms, the participant appeared to demonstrate the cohort effect, with greater fixations to the competitor than the unrelated images. After 600 ms, fixations to the target increased while fixations to competitor and unrelated images rapidly decreased.

**Participant 16 with CP/SSPI.** This participant demonstrated the greatest fixations to the competitor image (TIE) and a very large difference between fixations to the competitor and unrelated (NAIL and ZEBRA) and target images (TIRE) throughout the trial. At one point, between 300 and 500 ms, fixations to the target exceeded those to the unrelated images, demonstrating a brief period of competition between target and competitor. After 500 ms, fixations to the competitor increased and were greater than to target and unrelated images and continued throughout the trial until 1000 ms. In this time plot, it appears that the participant did not identify the target but did demonstrate greater fixations to the competitor and the unrelated images.

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Figure E1. Comparison of time plots for phonological onset competition for participants 5 and 16 with CP/SSPI
Semantic Relative Condition (Figure E2)

Example- TIE [target], SHIRT [relative], NAIL and ZEBRA [unrelated images])

**Participant 5 with CP/SSPI.** At the beginning of the trial, there were greater fixations to the target. Between 200 to 300 ms, fixations to the relative increased, while at 300 to 400 ms, the greatest fixations were to the relative. By 500 ms, fixations to the target increased and competition was resolved.

**Participant 16 with CP/SSPI.** At the beginning of the trial, there were greater fixations to the relative. At 400 to 700 ms, there were fixations to the target, relative and unrelated images. At 700 ms, fixations to the target steadily increased, competing with unrelated images. Participant 16 correctly identified the target but did not demonstrate semantic competition.

![Figure E2](image_url). Comparison of time plots for semantic relative for participants 5 and 16 with CP/SSPI
Semantic Onset Condition (Figure E3)

Example- TIRE (target) SHIRT (relative) NAIL (unrelated 1) ZEBRA (unrelated 2)

**Participant 5.** Between 600 and 800 ms, there appears to be competition between the target and relative of the unpictured onset competitor.

**Participant 16.** Competition is between the target and unrelated images until 500 ms, when fixations to the target are greater than to other images.

*Figure E3. Comparison of time plots for semantic onset for participants 5 and 16 with CP/SSPI*
BIBLIOGRAPHY


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