Relationships between Lexical Processing Speed, Language Skills, and Autistic Traits in Children

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Abstract
Relationships between Lexical Processing Speed, Language Skills, and Autistic Traits in Children
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According to current models of spoken word recognition listeners understand speech as it unfolds over time. Eye tracking provides a non-invasive, on-line method to monitor attention, providing insight into the processing of spoken language. In the current project a spoken lexical processing assessment (LPA) confirmed current theories of spoken word recognition and investigated relationships between speed of lexical processing and intelligence, language skills and autism related traits.

Participants were thirty-five young adult university students and thirty-five children between the ages of 7 years and 11 years 11 months. Lexical processing was assessed through the LPA, which measures the latency of eye fixation to images representing target nouns and was implemented on a Tobii T60 Eye Tracker. In addition, adults were administered the Wechsler Abbreviated Scale of Intelligence (WASI), the WMI index taken from the Wechsler Adult Intelligence Scale (WAIS-IV), and selected subtests from the Comprehensive Assessment of Spoken Language (CASL). Child participants were administered the Wechsler Intelligence Scale for Children - Fourth Edition (WISC-IV), and selected CASL subtests. Adult guardians of child participants completed the Social Responsiveness Scale (SRS) as it related to the participant. It was hypothesized that since auditory input is a primary mechanism by which children encounter language and are exposed to information during
development, efficiency of lexical processing may act as a gatekeeper to the development of these skills.

Results from the Lexical Processing assessment are consistent with predictions based on the cohort model of speech perception. Relationships between lexical processing speed, working memory, intelligence and linguistic skills were not evident in young adults. However in children, who are actively developing cognitive skills, we see clear relationships between speed of lexical processing and working memory, linguistic skills including vocabulary knowledge, syntax, and non-literal language comprehension, and traits related to the autism phenotype. The results of the current project indicate promise for the use of the lexical processing assessment not only in continued processing speed and autism-related research, but also point to potential utility in terms of early identification of children at risk for difficulty with language acquisition and deficits in social interaction.
Chapter 1: Introduction

Eye tracking methodology has been used extensively to study spoken language processing, starting with a pioneering study showing that eye movements are closely time-locked to the occurrence of spoken words that refer to those objects (Cooper, 1974). Eye tracking has also been used to study the effect of word-frequency on spoken word recognition (Dahan, Magnuson, & Tanenhaus, 2001) although the methodology has not yet been used in the investigation of individual differences in language processing.

At the same time, tests of language processing that are currently in use have important limitations as a result of design, calling into question the validity of such tests. These tests of language processing are confounded by the inclusion of the measurement of skills in domains outside of language processing. For example, the Speed and Capacity of Language Processing (SCOLP) assessment is essentially a reading test, automatically confounding language processing with reading ability. Additionally, tests of processing speed, like the Coding and Symbol Search subtests of the Weschler assessments, are often confounded by motor requirements, and are sensitive to both motivation and to difficulty working under timed conditions.

Because widely used measures of information processing are limited by these confounds, the creation of a pure processing speed assessment, enabling the characterization of lexical processing speed in individuals, would be a valuable tool in the clinical setting. Processing speed can be conceptualized as a measure of
efficiency in performing basic cognitive operations and can affect performance on intelligence tests indirectly, by allowing working memory to be used more efficiently. In other words, depending on the efficiency of processing, information may be lost, affecting both success on tasks and the amount of information that can be successfully encoded. Processing speed may also affect performance on intelligence tests directly, for example, by speeding retrieval of task relevant material from long-term memory (Kail, 2000).

Research has demonstrated a positive relationship between the speed with which individuals can perform different cognitive processes and the scores they earn on various measures of intelligence (Jensen, 1998; Kail & Salthouse, 1994; Lally & Nettelbeck, 1977; Vernon, 1983). The relationship between processing speed and intelligence from one viewpoint, namely a prototypic multifactor view of intelligence (Carroll, 1993) includes processing speed, along with memory and inductive reasoning, as separate and independent factors contributing to intelligence. However, research supports the claim that processing speed is causally linked to other elements of intelligence. In this view, it’s suggested that cognitive development can be conceptualized as a cascade where age related changes in processing speed lead to changes in working memory, which in turn, lead to changes in performance on tests of fluid intelligence (Kail & Salthouse, 1994).

Support for the hypothesis that rapid processing enhances memory which, in turn, enhances reasoning was reported in a study that found that almost half of a reported age-related increase in reasoning ability was mediated by developmental changes in processing speed and working memory (Fry & Hale, 1996). Even when
age-related differences in speed, working memory, and fluid intelligence were statistically controlled, individual differences in speed had a direct effect on working memory capacity, which was a direct determinant of individual differences in inductive reasoning (Fry & Hale, 1996).

In addition to its affect on intelligence, processing speed may be related to language ability, as basic lexical processing ability is necessary for the understanding of speech. Individuals who have slowed lexical processing may be at increased risk for language difficulties. Insight into the influence of processing speed on comprehension can be found in the literature on reading speed and comprehension. Literature on the study of reading suggests that slow reading is associated with poor comprehension. Faster readers tend to have better comprehension over what is read, and tend to be more proficient readers (Carver, 1990; Pinnell, 1995). This may be accounted or by capacity of working memory, a human processing system that provides temporary storage and manipulation of the information necessary for complex cognitive tasks (Baddeley, 1992). A slower reader is likely to understand less because working memory becomes taxed in an effort to hold onto previously read material until the end of a sentence or passage. A slow reader is more likely to forget content before reaching the end of a page or even sentence, because of the burden the slow pace of reading is placing on working memory, making it impossible to integrate words and phrases into coherent representations. The phonological loop, a component of working memory, which stores and rehearses speech based information (Baddeley, 1992), may be implicated in a similar process affecting comprehension of spoken language. Namely, an individual with slowed lexical processing may not have
sufficient working memory capacity to hold on to information from the beginning of a spoken sentence until the completion of the sentence, and as a result, may fail to understand spoken language in some instances.

Here, we have designed and piloted a language based processing speed assessment, which is an ecologically valid method to determine individual differences in lexical processing. It’s commonly known that the orienting of attention is usually accompanied by a shift in eye gaze toward the object of our attention. Despite evidence, collected after extended training and in the laboratory setting, that attention can be shifted even when the eyes remain fixed (Posner, 1980), in real world environments eye gaze naturally shifts indicating the allocation of attention. Since early eye tracking research tells us that referents are fixated on in close temporal proximity to when they are heard (Cooper, 1974), an assessment measuring fixation to target after a word is presented is a natural task, appropriate even for individuals who may have difficulty understanding complex task instructions often required for less natural tasks. This assessment takes advantage of the fact that eye fixation serves as the window into the focus of one’s attention. Further, the task successfully divorces information processing measures from reading and motor ability, skills that generally confound results, especially in special populations. Performance on the task may provide insight into an individual’s language processing abilities, as lexical processing is essential language comprehension. It may also provide insight into intelligence as it’s been suggested that one of the most meaningful ways to conceptualize mental capacity is in terms of an individual’s processing speed (Kail & Salthouse, 1994).
Chapter 2: Background

2.1 Spoken Word Recognition

Marslen-Wilson (Marslen-Wilson, 1987) suggests that the process of spoken word recognition includes the three basic functions of access, selection, and integration. The access function is said to be concerned with the relationship of the incoming sensory input to the recognition process and includes the mapping of speech signals onto the representations of word-forms in the mental lexicon. The selection function discriminates word forms accessed from sensory input and selects the word-form that matches the available input best. Finally, the integration function is said to be concerned with the relationship of the recognition process to the higher-level representation of the utterance.

Current models of spoken word recognition are consistent with the idea that listeners evaluate speech as it unfolds, with speech input being compared to an activated set of lexical candidates. The cohort model of spoken word recognition (Marslen-Wilson, 1987; Marslen-Wilson & Welsh, 1978) suggests that the onset of a word activates a set of lexical candidates, or words that share the initial portion of the acoustic-phonetic input with that word. The set of candidate words sharing the initial acoustic-phonetic input comprise a cohort, and words in the cohort compete for recognition. As additional acoustic-phonetic input is received competitors that are not consistent with those speech sounds drop out of competition until only one item, the word to be recognized, remains. For example when the acoustic-phonetic input /bee/ is presented initially as a speaker pronounces the word BEAKER, cohort competitors BEAKER, BEETLE, BEET, BEAVER, BEACH, among others, compete
with each other for recognition. As the additional input /k/ is received competitors drop out and eventually, in this case, BEAKER is selected.

This model was revised, however, with the accumulation of evidence supporting the effect of word-frequency on spoken word recognition. Marslen-Wilson (1987) examined lexical decision latencies for word pairs like STREET and STREAK, where the recognition point for both words was the word-final stop-consonant. This design allowed reaction time to be measured from comparable points in the two words, namely, the release of the final stop. Comparing decision latencies for high frequency words with a mean frequency of 130 per million to low frequency words with a mean frequency of 3 per million, an advantage was found for high frequency words. In an experiment using the gating paradigm (Grosjean, 1980), where listeners hear successively larger fragments of target words and indicate, after each fragment, which word they think is being presented, an effect of frequency on spoken word recognition was confirmed. Words that participants named were categorized by frequency and it was found that subjects produced more high frequency words than low frequency words after the presentation of the first and second gate although the preference for high frequency started to disappear by the third gate (Tyler, 1984).

While the original cohort model did not consider the effect of word frequency, the revised cohort model recognizes a transient frequency effect, as there seems to be a temporary advantage for more frequent words. The revised model still assumes that all word-forms matching a given input will be accessed by that input and remain active candidates for selection while a match in the sensory input remains. At the
same time it concedes that early in the word, high frequency words will be stronger candidates than lower-frequency words. The revised model posits that elements are not simply switched on or off as sensory and contextual information accumulates leading to the eventual single candidate, but that outcome and timing of the recognition process reflects the differential levels of activation of successful and unsuccessful candidates, and the rate at which their respective activation levels are rising and falling (Marslen-Wilson, 1987).

It’s been suggested that the cohort model may not be able to explain the process of spoken word recognition when some characteristics of speech in real life conditions are considered. For example, in continuous speech, word onsets are often not clearly marked, calling into question the assumption that listeners can reliably identify the beginning speech sounds of a word (Allopenna, Magnuson, & Tanenhaus, 1998). Additionally, according to the cohort theory, lexical candidates with only a partial match to the onset of a word will never enter into the candidate set. If the cohort model is accurate, a special recovery mechanism would be required during word recognition in noisy environments, which is a typical setting for communication with speech (Allopenna, et al., 1998).

Another perspective on the process of spoken word recognition, espoused by the continuous mapping model, accounts for these criticisms of the cohort model. The continuous mapping model assumes that lexical access takes place continuously and that the initial portion of a spoken word still exerts a strong influence shortly after word onset, but also suggests that the set of activated alternatives include words that do not have the same onset but that may contain overlapping speech sounds later in
the word, as in a rhyme (Allopenna, et al., 1998). For example, BEAKER is predicted to activate SPEAKER, a rhyme, as well as BEETLE, which shares initial speech sounds. Evidence for continuous mapping comes from an eye-tracking study where eye-movements were tracked as subjects were asked to move objects. It was reported that latency and accuracy of eye movements to a target object are affected by the presence of both objects with overlapping initial phonemes, or cohort competitors, and objects that rhyme with the target (Allopenna, et al., 1998). For example, after the instruction “Pick up the candle,” eye movement to a candle is slower in the presence of CANDY and HANDLE.

2.2 Speech Perception in Noise

Although most of our understanding of spoken word recognition comes from studies conducted in noise free environments, everyday verbal communication often takes place in the presence of interfering noise. Fortunately, human speech processing systems generally enable communication in unfavorable but common listening situations such as in a noisy restaurant or at a cocktail party. Typically developing individuals with normal hearing commonly use the presence of temporal and spectral dips present in background sounds to enhance intelligibility of speech sounds (Cooke, 2006; Meddis & Hewitt, 1992; Miller & Licklider, 1950). In a process called ‘dip listening’ individuals take advantage of rapid fluctuations in level of background sounds, and ‘glimpse’ speech signal during times when the signal-to-noise ratio is relatively high (temporal dips) (Miller & Licklider, 1950). They also take advantage of the fact that spectrum of target speech is often different from background speech, leaving some frequencies of the target speech unmasked by the
competing speech and resulting in high signal-to-noise ratio in those frequencies (spectral dips) (Meddis & Hewitt, 1992).

2.3 Eye Tracking Methodology

Eye tracking methodology is widely used in the study of spoken word recognition. Eye movements are closely time-locked to the occurrence of spoken words that refer to those objects (Cooper, 1974; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). As a result, eye gaze is often considered a measure of attention. We naturally move our eyes, and focus on a particular area of a visual field, in order to see that portion of the field with fine resolution. At the same time, we divert our attention to that point and focus our concentration on the object or region of interest. It’s been suggested that if we can track a person’s eye movements, we can follow the path of that person’s attention (Duchowski, 2007).

In fact, a field of research is based on the premise that even pre-verbal children spontaneously direct their attention to events that match what they are hearing. When infants are presented with different images on each of two screens and are simultaneously presented with auditory material, the direction of their gaze gives meaningful information about their language comprehension abilities. This is the basis of the intermodal preferential looking paradigm (IPLP) (Golinkoff, 1987), which was adapted from the work of Spelke (1976), for use in assessing early language comprehension. A classic example of the paradigm comes from in an experiment using IPLP to study noun comprehension. When a picture of a boat appeared on one screen while a picture of a shoe appeared on the other, and infants heard “Where’s the shoe? Find the shoe!” infants looked more quickly and longer
toward the screen displaying the shoe than the screen displaying the boat (Golinkoff, 1987). The IPLP, which has been used extensively (Golinkoff, 1987; Hollich, et al., 2000; Meints, Plunkett, Harris, & Dimmock, 2002; Reznick, 1990) takes advantage of a response already in the repertoire of infants, visual fixation, to glean information about language comprehension during a task that even infants do naturally.

A similar, and well known, method for the study of spoken word comprehension using eye tracking is the “visual world” paradigm, where participants follow instructions to look, at, pick up, or move one of a set of objects presented in a well defined visual workspace (Tanenhaus & Spivey-Knowlton, 1996). In this paradigm, timing and pattern of fixations to potential referents in the visual display are used to draw inferences about comprehension (Tanenhaus, Magnuson, Dahan, & Chambers, 2000). Eye tracking lends itself to the study of spoken word comprehension because it offers direct, objective and quantitative observation of behavior. The estimated time required for an individual to program a saccade is 200ms (Hallett, 1986). Using this information, in addition to total latency of fixation to targets, eye-tracking provides a non-intrusive, on-line measure of how comprehension unfolds overtime, and of how it is influenced by the information provided by visual context, and enables the study of comprehension as it occurs in natural contexts (Eberhard, Spivey-Knowlton, Sedivy, & Tanenhaus, 1995).

Eye tracking technology along with the visual world paradigm is an ideal package for use in a lexical processing assessment. Since individuals naturally fixate on referents in the environment when they are mentioned, eye-tracking provides a continuous on-line measure of comprehension independent of spoken or manual
response (Cooper, 1974; Tanenhaus, et al., 1995), and enables the quantification of the latency of lexical processing. The ecological validity of the measure adds to its strength and lends itself to use in populations with developmental disorders, given the minimal need for task instructions.

2.4 Autism and the Broader Autism Phenotype

According to diagnostic criteria developed by the American Psychiatric Association, Autistic disorder is diagnosed based on abnormal or impaired development in the domains of social interaction, communication, and restricted activities and interests (2000). Diagnosis of the disorder is warranted when an individual meets DSM-IV criteria in each one of the triad of domains. However, current conceptualizations of autistic disorder subscribe to the concept of the broader autism phenotype, which purports that autism-related traits are continuously distributed in the population, independent of the diagnostic status of individuals. Research on families where one or more members have been diagnosed with the disorder point to a genetic component (Muhle, Trentacoste, & Rapin, 2004; Szatmari, Jones, Zwaigenbaum, & MacLean, 1998) and suggest that autistic disorder may represent extreme cases of deficits in social and communicative functioning that are continuously distributed in nature. In this way, the field is moving away from the conceptualization of autism as the presence or absence of diagnosis, and instead is looking at autistic symptomology as characteristics that are present to greater or lesser degrees in all people.

2.5 Language Functioning in Autism

Language deficits are often considered a hallmark of autism disorder, as many
children who receive the diagnosis have a history of delay or failure to develop spoken language. Although language deficits specifically are not a required criterion for diagnosis of autism spectrum disorders, problems with language have become central to our conceptualization of the disorder as they are often the first presenting symptoms (Kurita, 1985; Lord & Paul, 1997), and have been shown to be the most important feature for the prediction of the prognosis and developmental course of the disorder (Rutter, 1970; Venter, Lord, & Schopler, 1992).

Language functioning in autism is variable. While twenty-five percent of all children with autism never develop functional language capabilities (Klinger, Dawson, & Renner, 2002), other children diagnosed with autism have vocabulary, grammatical knowledge and articulation skills within the normal range of functioning (Lord & Paul, 1997). In a comprehensive study of language profiles in children with autism, the heterogeneity of language abilities were explored using a broad range of language measures including measures of articulation skills, receptive and expressive vocabulary, nonsense word repetition, and higher-order receptive and expressive syntax and semantics (Kjelgaard & Tager-Flusberg, 2001). This study included children between the ages of four and fourteen who represented a spectrum of IQ scores and who been diagnosed with autism. The study found a wide range of performance on each of the language measures, and identified different language subgroups based on performance on the major language measures administered. Children were placed into “normal,” “borderline,” or “impaired” language classifications dependant on whether their scores fell within normal limits, fell more than one standard deviation below the mean, or fell more than two standard
deviations below the mean. About one quarter of the sample scored within the normal range across all the tests administered and were identified as the normal subtype, another quarter were identified as borderline, and half the sample were classified as impaired (Kjelgaard & Tager-Flusberg, 2001).

Additionally, the study found a significant relationship between IQ and language abilities, indicating that IQ accounts for some of the heterogeneity found in language in children with autism. At the same time, while the majority of children classified as having normal language abilities also had IQ scores in the normal range, some children with normal language earned IQ scores consistent with mental retardation. Additionally, among those classified as impaired, children with IQ’s in the normal range and children with mental retardation were represented. This indicates that language subtypes are not fully determined by IQ (Kjelgaard & Tager-Flusberg, 2001).

2.6 Social Interest in Speech and Voice perception in Autism

The underlying cause of language deficits seen in some individuals with autism remains unknown. However, data on typically developing children suggest a link between social interaction and language learning. Specifically, language learning in typically developing infants may be enhanced by their social interest in speech, especially speech directed toward them, often called ‘motherese,’ which is characterized by higher pitch, slower tempo, and exaggerated intonation contours (Fernald, 1985; Grieser & Kuhl, 1988). Typically developing infants, given a choice, show a preference for infant directed speech compared to adult directed speech (Cooper & Aslin, 1990; Fernald, 1985; Glenn & Cunningham, 1983) and it’s been
reported that this infant directed speech is beneficial to language learners (Fernald, 1985; Fernald & Kuhl, 1987; Hirsh-Pasek, et al., 1987; Karzon, 1985; Kemler, Hirsh-Pasek, Jusczyk, & Cassidy, 1989). Specifically, infant directed speech compared to adult directed speech, has been shown to contain particularly good phonetic exemplars or sounds that are clearer, longer, and more distinct from one another (Burnham, Kitamura, & Vollmer-Conna, 2002; Kuhl, et al., 1997). An association between the clarity of a mother’s speech when she talks to her infant and that infant’s speech perception skills has also been reported (Liu, Kuhl, & Tsao, 2003).

A lack of interest in social communication, particularly speech, is well documented in autism (Baron-Cohen, Tager-Flusberg, & Cohen, 1993). Toddlers and preschool children with autism demonstrate deficits in social orienteering, such as the failure to orient in response to one’s own name (Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998; Dawson, et al., 2004; Osterling & Dawson, 1994; Osterling, Dawson, & Munson, 2002) and fail to prefer their mothers voices over a recording of many superimposed voices, unlike typically developing infants (Klin, 1991, 1992). It’s also been shown that individuals with autism are impaired in naming vocally expressed emotion (Hobson, Ouston, & Lee, 1989), and matching vocally and facially expressed emotions (Hobson, Ouston, & Lee, 1988).

Lack of preferential attention to speech and abnormal voice processing in autism has also been shown with neuroimaging. One fMRI study showed a lack of activation in voice selective regions of the superior temporal sulcus in response to vocal sounds but a normal activation pattern to non-vocal sounds in autism (Gervais, et al., 2004). Another study used event related brain potential (ERP) responses to
simple tones, complex tones and vowels to study the sensory and early attentional processing of sounds in high functioning children with autism compared to typically developing children. After hearing a series of identical sounds, the occasional presentation of a deviant sound should elicit a sensory response and an ERP index of involuntary attentional orienting, the P3a. Sensory processing and speech discrimination were comparable across groups, however in individuals with autism, involuntary orienting was affected by the nature of the stimulus, with normal response to both simple and complex tone changes, but no evidence of a P3a after vowel changes, indicating lack of involuntary attention switch (Ceponiene, et al., 2003). These results suggest that in children with autism, impairment in auditory processing of vowels occurs beyond the stage of sensory processing. Additionally, exclusive lack of P3a response to vowels suggests a speech sound specific deficit in attentional orienting.

Evidence for voice related auditory deficits affecting a listener’s ability to register an auditory change in speech stimulus, has also been described in autism. A failure to show a significant mismatch negativity (MMN) response to a change in speech syllables in an oddball sequence has been shown in children in children with autism compared to controls (Kuhl, Coffey-Corina, Padden, & Dawson, 2005). Mismatch negativity is an event related potential (ERP) component known to be elicited by an odd stimulus in a sequence of stimuli regardless of whether an individual is attending to the stimuli. Interestingly, when children with autism were divided according to whether or not they showed a preference for child directed speech, those who did show the preference exhibited a MMN resembling that of
typically developing children, while the children who preferred non-speech analog signals matched acoustically to a child directed speech sample continued to fail to show the MMN response (Kuhl, et al., 2005).

The results from these studies suggest that individuals with autism seem to show a lack of interest in speech and abnormal orienteering to socially relevant auditory information like vocal sounds. In line with this evidence, a hypothesis regarding language deficits in autism could be that a lack of interest in and attention to the human voice in some children leads to a dearth of learning opportunities, ultimately resulting in absent or deficient language acquisition.

Chapter 3: Statement Of Problem and Current Project

Eye-tracking is thought of as a measure of attention because of the fact that we focus our eyes on a portion of a visual field in order to attend to it and to examine it more closely. Additionally, we know that eye movements are closely time-locked to the occurrence of spoken words that refer to those objects (Cooper, 1974; Tanenhaus, et al., 1995), indicating that the speed at which we are able to fixate on an item will be an indication of spoken lexical information processing speed. To the best of our knowledge, individual differences in eye tracking of auditory information processing have not been studied.

The development of the Lexical Processing Assessment presented here is important because currently employed standardized language assessments require some degree of receptive and expressive language for administration. Because of this, pre-verbal children and children with language deficits, are often not successfully
screened for language difficulty early in development, when intervention services may be most crucial. Currently, young children must wait until they have developed enough language skills to be able to complete traditional language testing, or are not assessed at all if they fail to develop these required skills. With the development of the current assessment, lexical processing, a basic component of understanding spoken language, may be assessed in individuals who have not developed sophisticated receptive or expressive language.

The first aim of this project was the creation of a lexical processing assessment using eye tracking technology. Although an ideal long-term project goal is to create age norms across the lifespan, which could be utilized in clinical assessment, the focus of this dissertation project was a pilot assessment of young adults between the ages of 18 and 21, and children between the ages of 7 and 11 years 11 months. Using the Lexical Processing Assessment (LPA) lexical processing was assessed through the measurement of the latency of eye-fixation to pictures representing target nouns in three conditions including the presence of a cohort competitor, rhyme competitor, and no competition. There were also three environmental conditions including no noise, pink noise, and conversational noise.

We were interested in whether lexical processing speed, as measured by our assessment, is related to intelligence and language functioning in adults and during child development. We were also interested in whether lexical processing speed is related to presence of autistic traits in typically developing children. We hypothesize relationships between lexical processing speed and intelligence, language skills, and social skills and abilities, with slowed processing acting as the trigger for a cascade
responsible for deficits in those domains. If a relationship exists the assessment may prove useful as a screening tool for intelligence and language functioning in pre-verbal individuals and others excluded from traditional assessment due to language skills required.

Chapter 4: The Spoken Lexical Processing Assessment

4.1 Assessment Procedure

The Lexical Processing Assessment (LPA) measures the latency of eye fixation to pictures representing target nouns using eye-tracking technology. The assessment was designed and implemented on a Tobii T60 Eye Tracker. The T60 data rate is 60Hz and the device utilizes a 17” thin film transistor (TFT) screen. On each trial, four pictures representing simple nouns, each assigned to one quadrant of the Tobii T60 eye-tracking computer screen, with a fixation cross marking the center of the screen, were presented. Participants were instructed to fixate on the cross between trials, and to follow the instructions they heard through headphones. On each trial, participants heard the verbal instruction “Find the ____.” Participants followed this instruction by looking at the picture indicated. Each trial was in one of three conditions: cohort competition, rhyme competition, or no competition. Trials were also randomized to occur in three environmental background noise conditions: no noise, pink noise, and background conversation. Figure 1 provides a representation of the assessment interface. The four images comprising each trial were pre-chosen but were assigned quadrant positions randomly by the computer on each trial. The order
of trials was also randomized. The assessment consists of 90 trials, requiring each subject to perform ten trials in each of nine trial types.

4.2 Assessment Experimental Design

The Lexical Processing Assessment (LPA) was developed as a 3x3 within-subjects experimental design. The independent variables are noun competition (no-competition, cohort competition, rhyme competition) and environmental competition (no noise, pink noise, conversational noise). The dependent variable is latency of eye-fixation to target noun.

This 3x3 design is conceptualized to enable the study of three different levels of processing in each independent variable. The design incorporates 3 levels of lexical competition in order to test the listener’s resilience to different conditions that might tax the processing of speech. According to the revised cohort model, nouns that share initial cohort sounds will have overlapping activation during natural speech perception (Marslen-Wilson, 1987). The presence of a cohort competitor is the most taxing level of processing, and is expected to produce a slowdown in a saccade to target. In the rhyme condition an image representing a noun containing a speech sound that overlaps with the target in a later section of the word is included as a distractor item. This is predicted produce a milder competitor effect and associated slowdown in lexical processing. In the no-competition condition distractor items do not share initial cohort sounds or rhyming speech sounds with the target. The no-competition trials represent the purest level of the noun competition trials. The three noun competition trials are crossed with the three environmental noise conditions. This design enables us to determine whether there are interactions or additive
interference as a result of environmental distractions. Figure 2 provides a schematic of the assessment design.

4.3 Assessment Creation

**Noun selection.** In order to ensure the assessment was appropriate for use with all potential users, including very young children, care was taken in choosing nouns to be included in the measure. Words used as targets and distractors are all common nouns present in spoken English with at least the frequency of 4 occurrences per million words. This requirement was verified through the use of the Corpus of Contemporary American English (COCA) (http://www.american corpus.org/) or according to a database created from five spoken language corpora taken from a longitudinal study (Brown, 1973; Carterette & Jones, 1974; Demetras, Post, & Snow, 1986; Sachs, 1983), archived through the Child Language Data Exchange System (CHILDES) (MacWhinney, 2000). The COCA, created and maintained by Mark Davies, Professor of Corpus Linguistics at Brigham Young University, contains more than 385 million words equally divided among spoken, fiction, popular magazines, newspapers, and academic texts. The database created from CHILDES, a computerized database of transcripts from language learners, contains 1,311,864 words. Corpora making up this database can be seen in Figure 3.

**Cohort Competitor Trials.** Cohort competitor trials consist of a target noun, a cohort competitor, and two additional distractor nouns. A cohort competitor is defined as a noun beginning with the same initial phoneme and continuing to contain overlapping speech sounds with the target for between 100 and 300 ms from word onset. Distractor nouns do not rhyme with or begin with the same phoneme as either
the target or cohort competitor. All four nouns are frequency matched according to the criteria described below.

**Rhyme Competitor Trials.** Rhyme competitor trials consist of a target noun and a rhyme competitor, which rhyme with the target, and two additional distractor nouns. Distractor nouns do not rhyme with or begin with the same phoneme as either the target or rhyme competitor. All four nouns are frequency matched according to the criteria described below.

**No Competition Trials.** No competition trials consist of pictures representing the target noun and each of three distracter nouns. The distracter nouns do not rhyme or begin with the same phoneme as the target nouns. All four nouns are frequency matched according to the criteria described below.

**Frequency Matching.** On a given trial, nouns representing all four pictures were matched for frequency in spoken English. Determination of spoken English frequency was completed by lemma search and incorporated all members of the lexeme of each target word, as exposure to these similar words overlaps with frequency of exposure to the target word. We chose to limit our frequency matching to the use of spoken word frequency on the basis that young children, a portion of our target population, will not have been exposed to material in the other formats. Determination of frequency was completed using spoken English frequency data compiled in the Corpus of Contemporary American English (COCA) or the five corpora database created from CHILDES.

To determine frequency based CHILDES corpora selections, a frequency search on this database using the program CLAN (Computer Language ANalysis) (B
MacWhinney, 2000) returned the raw frequency of each token represented. Our calculation of frequency included words both when they were included as part of utterances spoken by the child and as utterances directed toward the child. This method provides a comprehensive sample of use and exposure and represents familiarity with words. Additionally, inclusion of both child and adult utterances increases the number of utterance we have to draw from. Raw frequencies were translated into frequency per million words. The COCA database provides spoken frequency in terms of frequency per million. The frequency of each word, regardless of the database of origin, in units of occurrence per million spoken words, was converted to a LOG scale. This operation transformed our data by squeezing together the larger values, stretching out the smaller values, and created a scale accounting for the unequal effect of hearing very infrequent words compared to more frequent words. Following word frequency conversion to a LOG scale, rules were implemented to create frequency-matched trials.

Because the eye tracking literature does not support a single method for matching stimuli for frequency a survey of methods used in previous research served as a guide to the development of criteria that ensures close frequency match within the limitation imposed by the practically of creating a large number of word pairs. In one study designed to examine the frequency effects of eye fixation latency, Dahan and colleagues (Dahan, et al., 2001) created cohort pairs, where one word was deemed to be High Frequency, and one was deemed to be Low Frequency. In this study frequency was determined according to Francis and Kucera (Francis, 1982). The high frequency stimuli had an average occurrence of 138 times per million (LOG
= 2.14), and the low frequency stimuli had an average occurrence of 10 times per million (LOG = 1). After a LOG transformation the difference score is 1.14, indicating this margin of difference makes word frequency sufficiently different in the view of these authors.

In another study designed to evaluate the effect of word frequency on word recognition performance, Allen et al. (Allen, Smith, Lien, Weber, & Madden, 1997) used words from four levels of word frequency, where frequency was determined by occurrence in the Kucera and Francis (Kucera, 1967) norms. Very high frequency words had an occurrence rate of 240-1,016, medium high frequency words had an occurrence rate of 151-235, low frequency words had an occurrence rate of 40-54, and very low frequency words had an occurrence rate of 1-5 (Allen, et al., 1997). Criteria for choosing these ranges were not indicated in the manuscript. We translated these ranges to LOG frequencies, and determined the difference scores for each category to get an indication of a range of LOG frequency of words considered to match according to the standards used by Allen et al. LOG Frequency ranges for very high frequency words, high frequency words, low frequency words, and very low frequency words were .63, .19, .13 and .7 respectively.

On the basis of this review, we determined a LOG frequency difference cut-off score of .6 will discriminate a frequency matched pair from a pair that differs on frequency in spoken English. This cut-off score is well below the 1.4 difference score between the averages of high and low frequency words used by Dahan et al. (Dahan, et al., 2001), and is close to the difference score representing the range for high frequency and very low frequency words according to Allen (Allen, et al., 1997). We
reason that if Allen’s medium high frequency and low frequency categories were collapsed to create three categories – high frequency, medium frequency, and low frequency, our .6 cut off, deemed to signify frequency matching, would be more strict than all three of his LOG frequency ranges .63, .78, and .7.

To create frequency matched pairs and trials, we created difference scores from candidate cohort and rhyming word pairs, and retained pairs whose difference score is .6 or below. After cohort pairs and rhyme pairs were identified, distracter nouns were added, using the same frequency rule so that the difference score between the LOG of the highest and lowest word in the four word set was no greater than the pre-determined cut-off of .6.

**Picture Stimuli Selection.** 360 pictures [4 pictures x 30 trials x 3 conditions] were selected from either Nova Development Corporation’s Art Explosion –Photo Objects 150,000, from images in the public domain obtained through the wikimedia commons database, or taken by the investigator or research assistants using a digital camera.

In order to ensure the images selected to represent target words are prototypical representations of those words, all images were rated by three individuals in a norming exercise. Volunteers viewed each picture individually on a computer screen and were asked to rate the images in response to the question “How good a representation of a ______ is this picture?” A likert scale, ranging from 1 indicating a poor representation of the noun to 5, representing an ideal prototypical image representing the noun, was used. All images included in the LPA were rated no lower than a three on the likert scale on any occasion.
In an additional measure to ensure that pictures are identifiable as the nouns they were intended to represent, the assessment introduces pictures to users by naming them. Each picture is introduced to subjects in random order prior to each trial. As each noun is presented auditorily, a box appears framing the image representing it. Eye fixation on the image is required to trigger the introduction of the next item.

**Chapter 5: Methods**

**5.1 Participants**

Thirty-five young-adult Drexel University undergraduate students were recruited from the Drexel community through the Psychology 101 research subject pool. The online research opportunity listing provided a basic description of the study, eligibility criteria, and instructions for volunteering. Eligible participants were native English speakers between the ages of 18 and 21. Exclusion criteria included the report of less than normal or corrected normal vision, or hearing impairment. Prospective participants were invited to the Developmental Lab at Drexel University, where eligibility criteria were reviewed and informed consent was completed prior to the study session.

A total of thirty-five children were recruited through partnerships with St. Cyprian, St. Gabriel, and St. Mary’s Interparochial School, three private Catholic Schools in the city of Philadelphia. Recruiting took place through letters home to parents/guardians, followed by open house or back to school night at each school where guardians were introduced to the study, given the opportunity to ask questions,
and finally, were guided through the informed consent process. As part of the informed consent process eligibility criteria were reviewed. Children who, according to guardian report, had less than normal or corrected normal vision, or hearing impairment were excluded. Children who, according to guardian report, spoke a language other than English in the home, or who acquired English as a second language, were also excluded. After guardian consent was obtained at a school meeting, school administrators scheduled study sessions for each participating child during school hours. Prior to the study session, each child completed an assent process and agreed to participate.

5.2 Measures

**Lexical Processing.** The spoken lexical processing assessment described in chapter four was administered.

**Intelligence.** The Wechsler Abbreviated Scale of Intelligence (WASI) was used to evaluate general intelligence in the young adult sample. The WASI is comprised of 4 subtests and yields three IQ scores including Verbal, Performance and Full Scale IQ (Weschler, 2002). The WASI was developed for individuals from age 6 to 89:11 years.

The Wechsler Intelligence Scale for Children - Fourth Edition (WISC-IV) was used to evaluate general intelligence in the child sample. The WISC-IV is comprised of 10 core subtests representing intellectual functioning in cognitive areas including verbal comprehension (VCI), perceptual reasoning (PRI), processing speed (PSI), and working memory (WMI), which make up a composite representing general
intellectual ability or full scale IQ (FSIQ) (Wechsler, 2003). The WISC-IV was developed for children age 6 to 16:11 years.

**Language.** Selected subtests from the Comprehensive Assessment of Spoken Language (CASL) were used to evaluate language skills in both the young adult and child samples. The CASL, a norm referenced oral language assessment, whose subtests can be administered and scored individually, was designed for individuals from ages 3 to 21 (Carrow-Woolfolk, 1999). The CASL was standardized using a nationally representative sample of 1,700 individuals between the ages of 3 and 21 years with and without disabilities. Internal reliability for the CASL subtests was reported within a range of .78 to .90 in our selected subtests, indicating high homogeneity among items in each of the tests (Carrow-Woolfolk, 1999).

CASL Subtests were selected to measure knowledge and performance in Semantic, Syntactic, and Supralinguistic language domains. Subtests were also chosen with consideration to the availability of norms in our target age populations.

Semantic language was measured with the Synonyms and Sentence Completion subtests of the CASL. The synonyms subtest assesses lexical knowledge by looking at the examinee’s ability to identify a synonym for a given word from multiple choices. In this test, the examiner reads a target word followed by four additional words. The examinee selects an answer choice that she believes is the closest, in meaning, to the target word. The sentence completion subtest, a test of semantic integration, measures the ability to retrieve and express one of a few appropriate words that complete the end of a presented sentence meaningfully, and in
a form grammatically appropriate to the stimulus sentence. The sentence completion task requires word knowledge, syntax comprehension, recall, and expression.

Syntactic aspects of language, or the knowledge and use of morphology and syntax, was measured in young adults and children with the CASL subtest Grammatical Morphemes. The Grammatical Morphemes subtest measures the knowledge of the form and meaning of grammatical morphemes and includes verb and noun modulators, prepositions, articles, possessives, pronouns and derivational suffixes. The test is structured in the form of analogies. For example, the examiner will present “bed is to beds as dress is to _____.

Linguistic competence, where sophistication beyond individual word comprehension, and use of vocabulary and syntax is required, will also be assessed. The Non-Literal Language subtest of the CASL assesses the ability to comprehend the intended meaning of utterances in cases where non-literal interpretation is required and includes cases of figurative speech, indirect requests and sarcasm. In this subtest, a sentence containing a non-literal expression is read aloud by the examiner, and the examinee is instructed to respond by explaining what is meant.

**Autistic Symptomology.** The Social Responsiveness Scale (SRS), a 65-item questionnaire, which includes items related to aspects of interpersonal behavior, communication and repetitive/stereotypic behavior that are characteristic of autism spectrum disorders, was used as a measure of autistic symptomology in the child sample. At the time of the consent to participate in the study, a parent of each child participant completed the SRS with respect to their child.
This measure was chosen for use in the current study because, in line with current research on the disorder, this instrument conceptualizes autism as a spectrum condition rather than an all-or-nothing diagnosis. The SRS provides a metric to compare a child’s behavior to established norms in order to identify where an individual falls within the entire range of behavior that exists in the general population (Constantino & Gruber, 2005). As such, the SRS offers a method of characterizing autistic traits, along a natural continuum, even in a typically developing population. The SRS, through report of a caretaker who knows the child well, assess the severity of symptoms of autism as they occur in the natural social setting and generates a single score which serves as an index of severity of social deficits (Constantino, et al., 2003).

The composition of the SRS also provides scores for five subscales based on parental responses to items belonging to five categories of behavioral observations. Social Awareness targets the child’s ability to pick up on social cues, while the Social Cognition subscale assesses a child’s ability to interpret those social cues after they have been picked up. The Social Communication subscale addresses expressive social communication displayed by the child. The Social Motivation subscale targets motivation for engagement in social-interpersonal behavior. Finally, the Autistic Mannerisms subscale includes items used to identify stereotypical behaviors or highly restricted interests characteristics that may be displayed by the child (Constantino & Gruber, 2005).

In terms of its use as valid measure of autistic symptomology, the SRS has been reported to compare favorably with the Autism Diagnostic Interview–Revised
(ADI-R), the current gold standard for the assessment of autism, with correlation coefficients greater than .64 between SRS scores and all algorithm scores for DSM-IV criterion sets generated by the ADI-R (Constantino & Davis, 2003). This relationship, along with its documented inter-rater reliability on the order of .8, makes the SRS a valid quantitative measure of autistic traits (Constantino & Davis, 2003).

5.3 Procedure

Eligible prospective young adult participants, after registering online to participate in exchange for credit in Psychology 101, were invited to the Developmental Lab at Drexel University to participate in the study. Each child was tested at her respective partnering Philadelphia Catholic School, following parental informed consent and assent procedures.

In a single study session, young adult participants were administered the Lexical Processing Assessment, WASI, WAIS-IV WMI, and selected CASL subtests. Child participants, in three separate study sessions, were administered the Lexical Processing Assessment, WISC-IV, and selected CASL subtests. A parent or guardian completed the SRS at the time of informed consent. All testing administration was conducted either by the study coordinator or a trained research assistant.

All digital LPA assessment data and standardized testing was de-identified through the exclusive use of subject number and was stored under lock and key and on a password-protected computer in our research lab at Drexel University. Only authorized personnel viewed data, for the purposes of scoring assessments and data analysis.
Chapter 6. Results: Young Adults

6.1 Description of Sample

Demographic Characteristics, Intelligence and Language Functioning. Thirty-five young adult Drexel University students participated in this study. Approximately fifty-four percent of the sample was female while approximately forty-six percent was male. Table 1 describes the results of the intelligence and language measures administered as part of the study. The summary table includes Full Scale IQ as well as Performance IQ and Verbal IQ indices, WAIS-IV Working Memory Index, a language composite calculated as the mean of administered CASL subtests, and individual CASL subtest scores.

LPA Assessment. Young adults earned a mean reaction time of 740.51 (SD = 276.05) on the Lexical Processing Assessment. When collapsed over Environmental Condition, the mean reaction time in the Cohort Condition for the levels Cohort, None, and Rhyme were 818.60 (SD = 289.66), 734.34 (SD = 270.38), and 669.27 (SD = 246.32) respectively. The mean reaction times in the Environmental Condition, when collapsed over Cohort Condition, for the levels Conversation, None, and Pink were 731.86 (SD = 249.70), 740.97 (SD = 287.21), and 748.65 (SD = 289.36) respectively. Table 2 describes the results of the Lexical Processing Assessment for all conditions. Values represent latency of fixation to target in milliseconds.

Missing Data. Of the thirty-five young adult participants in the study, three were discovered to be outside of the age range required for standardized testing norms. These three participants were not administered standardized WASI, WAIS IV, or CASL assessments. An additional two subjects were not administered the WAIS-IV
Working Memory Index due to experimenter error. All thirty-five participants participated in the lexical processing assessment. Thirty young adults (86%) completed the all study tasks.

6.2 Data Analysis

Prior to analysis, reaction time data collected on the lexical processing assessment were cleaned in order to ensure that outliers, that occurred as a result of either fixation on target prior to trial onset or clear track loss, were not included in analysis. Because research in psychophysics supports the notion that the programming of a saccade is initiated about 200 ms prior to its launch (Matin, Shao, & Boff, 1993), all data points representing target fixation in fewer than 150 milliseconds were discarded. This provides assurance that data points representing fixation latencies that were the result of saccades initiated prior to the onset of a trial are not included in analysis. Data points representing target fixation over 2500 milliseconds were also discarded, as they indicate track loss. A total of 152 out of 3150 observations or about 4.8 percent of assessment trials fell outside the 150 to 2500 milliseconds range and were discarded prior to analysis.

Two additional adjustments to data were made prior to analysis. Preliminary observation of reaction time data through a histogram revealed a positively skewed distribution. As a result, to normalize the distribution, reaction time data was submitted to a natural log transformation, which is recommended and used widely in the field of psycholinguistics (Lenzner, Kaczmirek & Lezner, 2010; Ratcliff, 1993). Additionally, in order to test the relationship between a broadly inclusive conceptualization of the language domain, a language composite variable was created.
Language composite was calculated as the mean of the scores earned on the four CASL subtests: Synonyms, Sentence Completion, Grammatical Morphemes, and Non-literal Language.

Data analysis was conducted using the open source statistical programming environment R (R Core Design Team, 2010). Analysis used linear mixed-effects modeling, and utilized restricted maximum likelihood estimation (REML; Baayen, et al., 2008), via the lme4 statistical package (Bates, 2007) within R. Preliminary model testing concluded that random effects subject ID (subject), slide ID (item), and slide order account for variance in our model, and are therefore included as random effects. We also wished to account for subject bias in speed of processing toward the four quadrants of the screen as it is well known that in western cultures the attentional trajectory flows from left to right. Research indicates that individuals focus initially on the left side of a visual field to explore objects such as artwork (Elkind & Weiss, 1967), display stronger inhibition of return when stimuli sequence are in a left to right trajectory (Spalek & Hammad, 2005), and even maintain an internal imaginary number line with smaller numbers on the left and larger numbers on the right (Dehaene, Bossini, & Giraux, 1993). To account for the effect of bias toward the left side of the screen, we also included target position as an error term in the model. As a result of significant correlations between variables of interest, analyses were not conducted in one full model. Intercorrelations for variables of interest can be seen in Table 3. Additionally, as recent research in sentence processing suggests that the risk of spurious effects in mixed-effects modeling is reduced by inclusion of interactions between fixed and random effects (Roland, 2009), this method was employed in
supplementary analyses. Mixed-effects models used in analysis can be seen in Appendix A.

**Lexical Processing.** Results show a significant effect for Cohort condition \( [b=-.11, \chi^2 (2, N=35) = 41.682, p < .001] \) while no significant effect for environmental condition \( [b=-.0009, \chi^2 (2, N=35) = 1.46, p = .48] \) was found. Figure 4 provides a graphic of cohort condition results. A significant interaction between cohort condition and environmental condition \( [b=-.1069, \chi^2 (6, N=35) =17.12, p = .009] \) was found (See Figure 5). There was no effect for gender \( [b=-.0364, \chi^2 (1, N=35) = .57, p = .45] \).

**The Relationship between Intelligence and Lexical Processing.** The relationship between Full Scale IQ and the results of the lexical processing assessment were tested in a model that included random effects described in 6.2 and the significant fixed effect, cohort, described in 6.3. On observation of data, two outliers, which were outside three standard deviations from the mean, were removed (See Figure 6). Analysis revealed no significant effect for Full Scale IQ \( [b=.0021, \chi^2 (1, N=30) = .57, p =.45] \). With inclusion of outlying variables, a significant effect was found \( [b=.0020, \chi^2 (1, N=32) = 142.59, p <.001] \). However, the relationship observed suggests the inverse of expected, namely that higher IQ is associated with slower lexical processing speed. WASI full scale IQ components, Verbal IQ and Performance IQ were also considered independently. Analysis revealed no significant effect for Verbal IQ \( [b=.0007, \chi^2 (1, N=30) = .1, p =.75] \) or Performance IQ \( [b=.0023, \chi^2 (1, N=30) = .70, p =.40] \). In an additional analysis of the full data set using a model which included the interaction between fixed and random effects, no significant effect was found for intelligence \( [b=.0020, \chi^2 (1, N=32) = .81, p =.37] \). These
consistent results indicate no relationship between intelligence and performance on the lexical processing assessment in adults.

**The Relationship between Working Memory and Lexical Processing.** The relationship between Working Memory and the results of the lexical processing assessment were tested in a model that included significant random effects described in 6.2 and the significant fixed effect, cohort, described in 6.3. On observation of data, one outlier, which was outside three standard deviations of the mean, was removed (See Figure 6). Analysis revealed no significant effect for working memory \[ b=.0009, \chi^2 (1, N=29) = .20, p =.65 \].

In an additional analysis using a model which included the interaction between fixed and random effects, no significant effect was found for working memory \[ b=.0015, \chi^2 (1, N=30) = .64, p =.43 \]. The result of this analysis, which included the full data set, is consistent with the result following the removal of the outlier. Our analyses found no relationship between working memory capacity and performance on the lexical processing assessment.

**The Relationship between Language Skills and Lexical Processing.** The relationship between Language skills and the results of the lexical processing assessment were tested in a model that included random effects described in 6.2 and the fixed effect, cohort, described in 6.3. On observation of data, one outlier, which was outside three standard deviations of the mean, was removed (See Figure 6). Analysis revealed no significant effect for language composite \[ b=.0077, \chi^2 (1, N=31) = .2.31, p =.13 \].
The relationship between unique language domains, as measured by CASL subtests, and lexical processing was also considered. Analysis revealed a significant effect for semantic integration as measured by CASL subtest Sentence Completion \([b=.0054, \chi^2 (1, N=31) = 4.11, p < .05]\). However, the relationship described by this model suggested the inverse of the expected relationship, namely that more advanced semantic integration abilities are associated with slower lexical processing speed. Analysis revealed no significant effect for semantics/vocabulary knowledge as measured by CASL subtest Synonyms \([b=.0028, \chi^2 (1, N=31) = .46, p = .5]\), syntax as measured by CASL subtest Grammatical Morphemes \([b=.0021, \chi^2 (1, N=31) = .29, p = .59]\) or supralinguistic language as measured by CASL subtest Non-literal Language \([b=.0016, \chi^2 (1, N=31) = .22, p = .64]\).

In an additional analysis using a model which included the interaction between fixed and random effects, no significant effect was found for language skills \([b=.0034, \chi^2 (1, N=32) = .76, p = .38]\). The result of this analysis, which included the full data set, is consistent with the result following the removal of the outlier.

**Chapter 7. Results: Children**

**7.1 Description of Sample**

**Demographic Characteristics, Intelligence, Language Functioning, and Autistic Symptomology.** Thirty-five elementary school children participated in this study. Approximately fifty-one percent of the sample was female while approximately forty-nine percent was male. Table 4 describes the results of
intelligence, language and autistic symptomology assessments administered as part of this study. The summary table includes Full Scale IQ as well as component IQ indices, language Composite along with individual CASL subtest scores, and SRS scores along with scores for individual SRS component scales.

**LPA Assessment.** Child participants earned a mean reaction time of 948.17 ms \((SD = 725.06)\) on the Lexical Processing Assessment. When collapsed over Environmental Condition, the mean reaction time in the Cohort Condition for the levels Cohort, None, and Rhyme were 1008.98 \((SD = 750.23)\), 896.38 \((SD = 697.59)\), and 938.97 \((SD = 722.68)\) respectively. The mean reaction times in the Environmental Condition, when collapsed over Cohort Condition, for the levels Conversation, None, and Pink were 946.29 \((SD = 756.24)\), 940.77 \((SD = 695.12)\), and 957.61 \((SD = 722.87)\) respectively. Table 5 describes the results of the Lexical Processing Assessment for all conditions. Values represent latency of fixation to target in milliseconds.

**Missing Data.** Thirty-four of thirty-five child participants (97%) completed all the study tasks. In one case the CASL subtest non-literal language was discontinued due to environmental disruption in the school setting. Analysis included all available data.

**7.2 Data Analysis**

According to the rational cited in 6.2, reaction time data collected on the lexical processing assessment in children were cleaned in order to ensure that observations that occurred as a result of either fixation to target prior to trial onset or clear track loss were not included in analysis. Data points representing target fixation
faster than 100 milliseconds and slower than 6000 milliseconds were discarded. These cut-off criteria were determined based on visual inspection of histograms and reflect the slower processing speed of children compared to adults. Using these criteria, a total of 473 out of 3150 observations or about fifteen percent of assessment trials were discarded prior to analysis. Because the design of the assessment required fixation to target prior initiation of a new trial, these discarded trials include instances of track loss, which are coded as very slow reaction times. Like the adult data, reaction time data for children were submitted to natural log transformation in order to correct a positively skewed distribution. Additionally, a language composite was calculated as the mean of the scores earned on the four CASL subtests prior to analysis.

Data analysis used linear mixed effects modeling, described in section 6.2. Consistent with model testing using young adult data, preliminary model testing concluded that subject ID (subject), slide ID (item) and target position account for variance in our model and were included in the statistical model as random effects. Model testing on the child data, unlike on the adult data, did not find an effect of slide order on performance on the lexical processing assessment. Because there was no evidence that performance changed during the course of the assessment, slide order was not included as a random effect in the model. Guided by the knowledge that age influences development in children, age was included in analyses. As expected, and consistent with the adult data, correlations among variables were found. As a result, analyses were not conducted in one full model and instead separate models were
created. Correlations for variables of interest can be seen in Tables 6 and 7. Mixed
effects models used in analyses can be viewed in Appendix B.

**Lexical Processing.** Results show a significant effect for Cohort condition
\[ b= -0.1096, \chi^2 (2, N=35) = 10.46, p = 0.005 \] while no significant effect for either the
environmental condition \[ b= -0.0037, \chi^2 (2, N=35) = 1.41, p = 0.49 \] or the interaction
between cohort condition and environmental condition \[ b= -0.1547, \chi^2 (6, N=35) = 11.24, \]
p = 0.08 was found. Figure 7 provides a graphic of reaction times in the three cohort
conditions. There was no effect for gender \[ b= -0.0939, \chi^2 (1, N=35) = 1.42, p = 0.23 \].
There was also a significant difference in reaction time in young adults and children \[ t (4163.78) = -8.11, p < 0.001 \].

**The Relationship between Intelligence and Lexical Processing.** The relationship
between Full Scale IQ and lexical processing speed was tested in a model that
included random effects described in 7.2 and the significant fixed effect, cohort,
described in 7.3. Language Composite was left out of this analysis due to its
correlation \[ r(33) = 0.69, p< 0.001 \] with Full Scale IQ (See Table 6). The results do
not show a significant effect for Full Scale IQ \[ b= -0.0039, \chi^2 (1, N=35) = 2.49, p = 0.11 \].

The relationship between stand-alone components of intelligence, as
cancelated by the Wechsler Intelligence Scale for Children–IV (WISC-IV), and
lexical processing speed were also considered. WISC-IV indices measuring verbal
comprehension (VCI), processing speed (PSI), working memory (WMI), and
perceptual reasoning (PRI) were submitted to linear mixed modeling. No significant
result for PSI \[ b= -0.0012, \chi^2 (1, N=35) = 0.14, p = 0.71 \], or PRI \[ b= -0.0042, \chi^2 (1, N=35)
= 2.96, p = 0.09 \] were found. An outlier, which was over three standard deviations
outside the mean, was removed from the VCI data (See Figure 8). No significant result for VCI was found \([b=-0.0047, \chi^2 (1, N=35) = 2.56, p = .11]\). Analysis indicates a significant result for WMI \([b=-0.0061, \chi^2 (1, N=35) = 4.17, p = .04]\) (See Figure 9).

**The Relationship between Language Skills and Lexical Processing.** The relationship between Language skills and the results of the lexical processing assessment were tested in a model that included the significant random effects described in 7.2 and the significant fixed effect, cohort, described in 7.3. The results showed a significant effect for language composite \([b=-0.0172, \chi^2 (1, N=35) = 20.05, p < .001]\) (See Figure 10).

The relationship between unique language domains, as measured by stand-alone CASL subtests, and lexical processing was also considered. Analysis of CASL subtests Synonyms \([b=-0.0078, \chi^2 (1, N=35) = 6.69, p = .009]\), Sentence Completion \([b=-0.0089, \chi^2 (1, N=35) = 17.57, p < .001]\), Grammatical Morphemes \([b=-0.0085, \chi^2 (1, N=35) = 5.84, p = .02]\) and Non-Literal Language \([b=-0.0084, \chi^2 (1, N=34) = 148.93, p < .001]\) revealed significant effects for semantics/vocabulary knowledge, semantic integration, syntax and supralinguistic language respectively (See Figures 11-14).

**The Relationship between Autistic Symptomology and Lexical Processing.** The relationship between autistic symptomology, as measured by the SRS, and the results of the lexical processing assessment were tested in a model that included the random effects described in 7.2 and the significant fixed effect, cohort, described in 7.3. The results showed a significant effect for SRS \([b=0.0089, \chi^2 (1, N=35) = 6.08, p = .02]\) (See Figure 15). The relationship between individual SRS subscales and lexical processing was also considered. Analysis of SRS subtests Social Awareness
Social Communication \( [b=0.0084, \chi^2 (1, N=35) = 8.14, p = .004] \), and Social Motivation \( [b=0.0054, \chi^2 (1, N=35) = 6.33, p = .01] \) revealed significant effects. One outlier, which was outside three standard deviations from the mean, was removed from the social cognition data (See Figure 19). On analysis, there was also a significant effect for Social Cognition \( [b=0.0117, \chi^2 (1, N=34) = 4.86, p = .004] \). There was no significant effect for Social Mannerisms \( [b=0.0024, \chi^2 (1, N=35) = 1.47, p = .23] \). The relationships between lexical processing and SRS component subscales can be seen in Figures 16-20.

An additional analysis was conducted to consider the possibility that the data points representing the children with high SRS scores may be driving the significant effect reported above. Although none of the thirty-five children in our sample were reported to have been diagnosed with an autism spectrum disorder by a parent or guardian, three children, by parental report, received SRS scores falling in the range described in the SRS manual as indicating “deficiencies in reciprocal social behavior that are clinically significant” (Constantino & Gruber, 2005). To confirm that data from these three children were not responsible for the relationship reported above, the analysis was repeated using a subset of data, which excluded the relevant three observations. Results of analysis using only the subset of children whose SRS scores suggest typical development, the significant result for SRS remained \( [b=0.0114, \chi^2 (1, N=32) = 5.20, p = .02] \) (See Figure 15). Even among children who are not likely to meet criteria for an ASD diagnosis on the basis of SRS score, those who earned higher SRS scores, indicating greater autistic symptomology, also showed slower lexical processing speed as measured by the Lexical Processing Assessment.
Chapter 8: Discussion

8.1 Review of Results and Limitations

Lexical Processing Speed. The cohort model of spoken word recognition (Marslen-Wilson, 1987; Marslen-Wilson & Welsh, 1978) describes word recognition as taking place on-line, as words unfold in time. The model holds that cohort competitors, or other words that share the initial portion of acoustic-phonetic input with a target word, are activated as lexical candidates when processed. According to the model, cohort competitors compete for recognition until additional acoustic input informs the listener that a word is no longer consistent with speech sounds in the target word. Based on the cohort models of speech perception, it was predicted that lexical processing speed would be slower in the presence of cohort competition compared to in the presence of rhyme competition or in a no competition condition. Reaction times observed in this experiment are slower than reaction times reported in the literature for both eye fixation to target and motor reaction time of hand movement, which have been reported as 222ms (SD=35) and 234 (SD=41) respectively (Bekkering, et al., 1994). The comparatively slower reaction times can me explained by our method of measurement. In this experiment reaction time was measured from the onset of the target word. At this time, in many cases, the listener does not possess enough information to initiate saccade to target. Time required for the word to unfold is included in our measurement of reaction time. Our results did confirm previous research findings of slower processing speed in the presence of cohort competition (Alloppenna, et al., 1998), in both young adults and children, consistent with expectations based on the cohort model of spoken word recognition.
The continuous mapping model of speech perception adds to the cohort model by positing that the set of activated alternatives also include those words that rhyme with a target word (Allopenna, et al., 1998). This model accounts for the fact that listeners are able to recover word meaning, even in cases where an initial speech sound is missed, therefore failing to activate the target word according to the process espoused by the cohort model. The lexical processing assessment, by including a rhyme condition, was able to test the prediction made by the continuous mapping model of speech perception, namely, that lexical processing speed would be slower in the presence of rhyme competition compared to in a no competition condition.

The results from our young adult sample indicate that lexical processing in the rhyme competition condition was significantly faster than in both the cohort competition condition and the no competition conditions. While we had predicted processing speed in the rhyme condition may be faster than the cohort condition, we had not expected that reaction time in the presence of rhyme competition would be faster than reaction time in the absence of competition. On exit interview several young adult subjects indicated that they had noticed, during the initial introduction to stimuli, which took place prior to the initiation of the trial, that some trials contained two rhyming words. A likely explanation for the decreased reaction time in rhyme trials is that adults learned that on those trials one of the rhyming words would be the target item. By narrowing the candidate target items from four down to two, even before the trial began, adults gained an unintended advantage resulting in quicker reaction times in rhyme trials. Among our child sample, a rhyme effect was not found. Interestingly, on informal exit survey, no children reported noticing that there
were rhyming items among the lexical processing trials. Overall, results from our assessment do not support previous findings (Allopenna, et al., 1998) indicating a rhyme effect in spoken word recognition. Failure to replicate this finding could be due to limitations imposed by the design of our assessment.

The lexical processing assessment was also designed to be able to consider the effects of environmental noise on lexical processing speed. This component of the assessment is important because verbal communication in natural settings often takes place in the presence of background noise. Past research has shown that the intelligibility of speech sounds is related to an articulation index, calculated as a ratio of speech and unwanted sounds received by the ear (French & Steinberg, 1947) and that the presence of temporal and spectral dips present in background sounds serve to enhance intelligibility of speech sounds (Meddis & Hewitt, 1992; Miller & Licklider, 1950). It is well known that background noise plays a role in speech recognition. In elementary school aged children, background noise has also been found to affect speech recognition and compromise academic performance in the classroom setting (Ando, Nakane, & Egawa, 1975; Crook & Langdon, 1974). In the present study, it was predicted that background noise may interfere with lexical processing. It was expected that this would be evident by slowed reaction time in the presence of background noise compared to in no noise competition conditions. However, no effect for environmental noise condition was found. This suggests that in both young adult and child populations, subjects were able to extract speech sounds from background noise without the expected cost of increased reaction time.
The lexical processing assessment was also designed to assess the potential interaction between cohort condition and environmental condition, such that the effect of noun competition on the latency of eye fixation may depend on the presence of background noise. Among adults, a significant interaction suggesting that the presence of pink noise affects latency of eye-fixation in cohort conditions differentially was found. Whereas, response time was longest in the cohort condition followed by the no competition condition, and finally the rhyme condition in those trials containing both background conversation noise and no noise, latency of eye-fixation did not follow this pattern in trials containing background pink noise. Young adult subjects display increased eye-fixation latency in pink noise compared to the other environmental background conditions in rhyme competition trials. No interaction was found in the child population.

The Relationship between Intelligence and Lexical Processing Speed. Processing speed has long been conceptualized as a component of intelligence. Theorists have agreed on a plausible relationship between processing speed and cognition and argue it is central to intellectual functioning (Colombo, 1993; Eysenck, 1987; Haith & McCarty, 1990; Kail, 1992). In fact, modern day gold standard intelligence measures, the WAIS-IV and WISC-IV, include processing speed as a component index, which combined with other indices, make up the full scale IQ score.

Processing speed is also seen as playing an even more deeply rooted role in the conceptualization of intelligence. Instead of as an independent factor, which contributes to the measure of intelligence, processing speed has been described as a causal link to performance on various other elements of intelligence (Kail, 2000). For
example, as explained by Kail (2000), a child who earned below average scores in processing speed, memory, and reasoning would have been, historically, considered to be subpar in those three domains. Considered from a more dynamic view of intelligence, it may be the case that the child has a deficit only in processing speed, which leads to poor performance in other domains of cognition. Further support for this comes from the finding that processing speed, working memory, and fluid intelligence improve with age following a similar time course, suggesting that the three abilities are related rather than independent constructs (Fry & Hale, 2000).

Based on the known relationship between processing speed, working memory, and intelligence, Fry and Hale (1996) proposed the developmental cascade model, in which they posit that during development processing speed becomes faster, leading to improvements in working memory, which, in turn, leads to better performance in reasoning and problem solving. Evidence that age related increases in processing speed were associated with improved working memory capacity, along with higher scores on tests of fluid intelligence (Fry & Hale, 1996), supported their theory and led to the conclusion that as children are able to process information more rapidly, working memory is able to function more effectively, which leads to the ability to solve problems and thus, improved performance on measures of fluid intelligence.

In the current study, we hypothesized a relationship between lexical processing speed and intelligence, in line with previous research findings on the relationship between processing speed and intelligence presented above. Specifically, we predicted that performance on the WASI and the WISC-IV, in young adults and children respectively, would predict lexical processing speed.
The results from our young adult sample showed no significant effect for the WASI full scale IQ, component measures Verbal IQ or Performance IQ, or the working memory index of the WAIS-IV. Many previous reports of the relationship between processing speed and intelligence are taken from research on children during development (Dougherty & Haith, 1997; Fry & Hale, 1996). A possible explanation for the lack of significant effects in adults is that the relationship no longer holds in individuals who have reached a developmental peak in speed of processing and a likely plateau in development of intelligence. It could be that the role of processing speed in the development of intelligence is only evident when children are developing cognitively and actively acquiring those skills that become crucial in the measurement of intelligence. Further, the four subtests making up the full scale and component WASI indices, unlike the full length Wechsler intelligence assessments do not include a measure of processing speed. This removes the expectation of a relationship between lexical processing speed and intelligence simply because the design of the assessment includes processing speed as a component, essentially defining intelligence, in part, as processing speed.

According to the developmental cascade model (Fry & Hale, 1996) we also expected a significant effect for the relationship between lexical processing speed and intelligence in children. Further support for the hypothesis comes from an established relationship between visual processing speed and intelligence during development. Dougherty (Dougherty & Haith, 1997) found that visual reaction time, measured as the time between the presentation of an image and initiation of eye movement towards the picture, at three and a half months correlates with intelligence (on the
Wechsler Preschool and Primary Scale of Intelligence-Revised) at 4 years of age. Infants with faster visual processing speed tended to have higher IQ scores as 4-year-olds.

Guided by the developmental cascade model, and with this previous research as a basis, we expected the WISC-IV full-scale IQ and component WMI, PSI, PRI, and VCI indices to predict lexical processing speed in children. However, the results fail to show a significant effect for WISC-IV full scale IQ. Analysis failed to find an effect for processing speed (PSI), perceptual reasoning (PRI) or verbal comprehension (VCI). As predicted, there was a significant effect for working memory (WMI). Working memory, as an essential element of the developmental cascade model, is the WISC-IV index expected to have the closest relationship with lexical processing speed. Lack of a significant effect for processing speed was particularly unexpected given that the two measures of processing speed, the lexical processing speed assessment and the WAIS-IV PSI, although dependent on a motor component, are purported to measure the same construct. Visual reaction time measures, like the lexical processing assessment, engage automatic and natural responses whereas manual measures of processing speed, like those included in Wechsler assessments, require more effort and are sensitive to differences in motor ability and attentional ability which affects task complexity for differing populations. In a study looking at event related potentials (ERP’s) and reaction time (RT) during cognitive tasks which varied in complexity, it was found that P300 latency to target stimuli, along with RT, increased with task demands and was inversely related to mental ability (McGarry-Roberts, Stelmack, & Campbell, 1992). The results suggest
that P300 latency and RT may influence stimulus evaluation time and the response production time associated with cognitive processing and that these may vary inversely with intelligence. The task may be experienced as more complex in young children who are actively developing attentional control, compared to adults whose attentional control system is mature and allows them to attend to the entire display field.

**The Relationship between Linguistic Competence and Lexical Processing Speed.** In the current study, a relationship between lexical processing speed and linguistic competence, as measured by the CASL assessment, was hypothesized for both adults and children. Faster and more efficient lexical processing was expected to result in increased opportunity for developing linguistic competence including the acquisition of vocabulary and grammar, and for gaining experience with higher order, non-literal language. In other words, it is expected that if an individual’s processing resources are taxed in the task of lexical processing, she may lack the resources to process beyond the basics of word identification and may fail to understand the gestalt in conversation. This may lead to compromised development of higher order language, including the ability to understand non-literal language and would be reflected by the presence of deficits in various linguistic domains.

The current study hypothesized a relationship between lexical processing speed and linguistic competence, as measured by a CASL language composite. Relationships between lexical processing speed and individual CASL subtests measuring language areas semantics/vocabulary knowledge, semantic integration, syntax and Supralinguistic language were also hypothesized. Results indicated no
relationship between language skills and performance on the lexical processing assessment in young adults. It is likely that because linguistic development in young adult university students has generally reached a plateau, the current sample performed near ceiling on the CASL. As a result, the CASL may not be an ideal measure of individual differences in this population.

In children, however, significant effects were found for the CASL language composite and each of the individual language subtests, Synonyms, Sentence Completion, Grammatical Morphemes, and Non-Literal Language. The result indicates relationships between lexical processing speed and language areas including semantics/vocabulary knowledge, semantic integration, syntax and supralinguistic language. The strongest effects were found for Sentence Completion and Non-Literal Language.

Not unexpected, given our findings showing a relationship between linguistic processing speed and language competency in children but not adults, previous research using eye tracking has shown differences in the way adults and young children handle temporary syntactic ambiguity during online sentence processing. Given an ambiguous phrase like “Put the frog on the napkin…” where the prepositional phrase could be interpreted as a modifier or as a location for putting, adults tend to resolve temporary syntactic ambiguity according to the Referential Principle of syntactic ambiguity (Crain & Steedman, 1985). In accordance with this principle, adults pursued the Modifier interpretation when visual context supported that interpretation (i.e. in a two referent context) or the Destination interpretation when visual context indicated no modifier was required to determine the referent (i.e.
in a one referent context) (Trueswell, Sekerina, Hill, & Logrip, 1999). Unlike adults, five-year-old children appear to be insensitive to the Referential Principle preferring instead the Destination interpretation of ambiguous prepositional phrases regardless of context (Trueswell, et al., 1999). The authors suggest that a likely explanation for the inability of five year olds to employ the Referential Principle is limited processing capacity, which may lead them to abandon low probability syntactic alternatives and show preference for the destination interpretation given an ambiguous sentence (Trueswell, et al., 1999).

One factor postulated to account for the relation between speed of processing and cognition, according to Salthouse’s (1996) processing speed theory of age differences in cognition, is termed the simultaneity mechanism. The simultaneity mechanism’s role in the relationship between speed of processing and quality of cognitive performance can be explained as slow processing leading to a reduction in the amount of simultaneously available information required for high level processing (Salthouse, 1996). According to the reasoning behind by the simultaneity mechanism, we would expect that faster processing speed would allow for increased information available for use during learning. This is consistent with our finding that increased lexical processing speed is associated with better performance in high level language skills. CASL subtests Sentence Completion and Nonliteral language, which assess semantic integration and understanding of non-literal language showed the strongest relationship to lexical processing speed. These subtests require abstraction and synthesis of various content available simultaneously for success.
The Relationship between Autistic Phenotype and Lexical Processing Speed.

The results of the current study support a relationship between lexical processing speed and autistic traits measured in typically developing children. Consideration of autistic symptoms in non-diagnosed individuals is consistent with the conceptualization of autism as a spectrum disorder in which autism related traits are continuously distributed in the population. Although the field is now conceptualizing autistic symptoms in terms of this broader autism phenotype, much research on autistic symptomatology comes from studies conducted on those who have been diagnosed with the disorder. Linguistic deficits have come to be known as a hallmark of the disorder, and research into the processes underlying linguistic deficits in autism is ongoing. Individuals with autism have been shown to have a deficit in the ability to process transient sequential stimuli like those encountered in spoken language.

Another hallmark of autistic disorder is deficits in social skills and abilities. Welsh has suggested that social and communication impairments in autism spectrum disorders may be the result of deficits in auditory processing that affect the ability to process and understand spoken language (Welsh, Rodrigues, Edgar, & Roberts, 2010). In the current study, we show a relationship between lexical processing speed and autistic traits as indexed by total SRS score as well as component SRS scores measuring social awareness, social communication, social motivation, and social cognition. The present results, conceptualized with consideration to the broader autism phenotype, are consistent with the findings of abnormal speech parsing and auditory processing in autism.
The current research is not the first to report a relationship between autistic traits and auditory processing in the general population. Previous research has identified a link between autistic traits in the undiagnosed general population and auditory speech perception style. Stewart and Ota (Stewart & Ota, 2008) determined that Autism Quotient scores are negatively correlated with the Ganong effect, or tendency to shift phonetic segment identification toward the perception of a real word in a listening task (ie. toward perception of gift rather that kift). In individuals with higher AQ, phonetic perception was less likely to be influenced by lexical information and is more in line with the actual acoustic difference present. This result speaks to differences in style of integration of acoustic and lexical information in phonetic processing.

8.2 Conclusions, Implications, and Future Directions

In the current project, a pure measure of processing speed, the Lexical Processing Assessment (LPA), was created using eye tracking technology. The design of the assessment is such that eye-fixation to pictures representing target words, during a visual world paradigm, are an indication of lexical information processing speed. The assessment enables the study of individual differences in linguistic processing speed and the relationship between language based processing speed and the development of other skills and abilities which are hypothesized to be affected by processing speed. Data from the lexical processing speed assessment confirm the cohort model of speech perception by showing slowed processing speed in the presence of cohort competition compared to in rhyme competition and no competition
conditions. This result establishes the Lexical Processing Assessment (LPA) as a reliable tool for the study of individual differences in processing speed.

It was hypothesized that lexical processing speed, as measured by the assessment, would be related to scores of intelligence, language functioning, and additionally, in a child population, traits related to the autistic phenotype. While these relationships were uncovered in children, results in adults were not consistent with a relationship between processing speed and intelligence scores or linguistic ability.

A few explanations for the current results are worth considering. One possible explanation is related to the peak in processing speed well documented by early adulthood. Young adults have also likely reached a plateau in the development of intelligence and language functioning by this stage of development eliminating the variability that may be required to uncover relationships. Related, the simple task demands of the LPA assessment may lack the complexity to make the task a good measure to show the link between processing speed and intelligence in young adults. To put this simply, the LPA assessment may be “too easy” for young adults, whereas developing children are taxed even in a task with relatively simple demands. The literature supports this explanation with the finding that the more complex the speeded task, the stronger the relationship between speed and intelligence (Jenson, 1988). This has been interpreted in the literature as indicating that the more demand a task places on memory and attention, the stronger the correlation between speed and general fluid intelligence (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002).

It’s been suggested that a reason that performance on complex tasks like the reading span (RSPAN), counting span (CSPAN) and operation span (OSPAN) are
related to measures of fluid intelligence is that they do not allow the participant to rely on automatized routines to perform the task (Conway et al., 2002). Instead, they rely on working memory capacity. The LPA task, by design, and in contrast, takes advantage of the natural automatic response of eye-fixation to a named object in the visual field. While the LPA assessment does likely place a small attentional and short-term memory demand on participants by nature of the need to remember the quadrant position of each item for maximum efficiency, the task is largely automatic and relies on working memory minimally if at all. In a related vein, it has been suggested in the literature that particular tasks may be good measures of particular constructs in children but not in adults and vice versa (Conway et al., 2002). The simplicity of the LPA task may result in it being a poor measure of working memory in young adults while the demands may remain high enough to tap into working memory during development. As a result, perhaps the lack of results in adults can be attributed to the fact that for adults, the LPA is a near pure processing speed measure. To be clear, it may be that for the adult population, the LPA lacks the significant working memory demand that has been suggested as the link between processing speed and fluid intelligence.

Several studies document the link between working memory and fluid intelligence (Conway et al., 2002; Engle, Tuholmki, Laughlin, & Conway, 1999; Kyllonen & Christal, 1990) This suggests that it may be the working memory component, not the pure processing speed construct that is responsible for the relationship between processing speed and intelligence in Fry’s 1996 study. In fact, Conway and colleagues (2002) point out that the processing speed tasks used in the
research conducted by Fry and Hale, which concluded a relationship between processing speed and intelligence, included measures of processing that were confounded with working memory. They argue that of the four tasks which constituted the processing speed composite in the study, two had minimal demands on working memory and two, including a visual search and an abstract matching to sample task, placed heavy demands on working memory. Because processing speed and working memory were confounded in the measures used, the result, indicating a meaningful relationship between processing speed and intelligence, may be erroneous. It is possible that working memory ability is truly responsible for the relationship observed. This possibility is supported by additional research. Conway and colleagues failed to find a relationship between processing speed and fluid intelligence when they took care to select pure processing speed tasks devoid of working memory demands (Conway et al., 2002).

Another consideration, as insight into the lack of consistent findings between lexical processing speed and intelligence across populations studied in the current project, is related to a possible distinction between developmental differences in cognitive ability and individual differences in cognitive ability. Research has shown that processing speed is an important factor underlying developmental differences in cognitive ability in childhood (Fry & Hale, 1996) and in the aging population (Salthouse, 1996). Expectations for adults have been inferred although it is possible, as suggested by Conway and colleagues (2002), that factors accounting for developmental differences in cognitive ability do not match the factors that account for individual differences in cognitive ability in young adults. The possibility exists
that processing speed is important for developmental differences in childhood but not for individual differences in adults (Conway et al., 2002).

Data from the current study does support relationships between processing speed and the development of other skills during development. We see a clear relationship between linguistic processing speed and working memory, linguistic ability, and autism-related traits in children between ages 7 and 11-years-11 months. These results are consistent with the claim made in developmental cascade model put forth by Kale and Salthouse, suggesting that increases in processing speed predict improvement in working memory (1994). Our results are also in line with expectations based on the processing-speed theory of age differences in cognition, which attributes age-related differences in cognitive functioning to a reduction of the speed of execution of cognitive operations as individuals age. Although this theory was proposed to explain cognitive decline in adults, the mechanism is thought to be relevant to the development of cognitive functioning during childhood.

The processing speed theory of adult age differences in cognition, proposed by Salthouse (1996), accounts for age-related differences in cognition in two ways, termed the limited time mechanism and the simultaneity mechanism. The limited time mechanism suggests that when speed of processing is faster there is more opportunity to accomplish a larger amount of processing, and that more processing results in higher levels of performance. In a related aspect of the theory, the simultaneity mechanism discusses the availability of information over time. It suggests that slower processing means that products of early processing may be lost to decay
before later processing is complete, resulting in lack of access to relevant information and reduced cognitive ability.

The current results are consistent with these theories inasmuch as we see evidence that faster processing of incoming linguistic information as allowing the developing child the opportunity to learn more efficiently, resulting in increased learning. We see this in all aspects of linguistic development measured using the CASL and in the development of social skills as measured by the SRS. However, according to the developmental cascade model and the processing speed theory of cognition we would expect increased processing speed to have a global effect on learning, which would extend to increased intellectual ability. Outside of working memory in isolation, the current results do not support a relationship between processing speed and either individual components of intelligence or a full scale IQ score as measured by the WASI or WISC-IV in models separating linguistic ability and intellectual functioning.

Although the current study did not include investigation into reading skill and its relationship to speed of processing, research supports a relationship between processing speed, rapid auditory naming and reading ability. It is well known that as children grow older they are able to name familiar objects more rapidly. Research shows that this increase in rapid auditory naming speed is a predictor of reading skill (Wolf, Bally & Morris 1986; Spring & Davis, 1988). Traditional interpretation of this observation is that automaticity, a function of age related experience, is the basis of the link between rapid naming and reading skill (Wolf, Bally & Morris 1986; Spring & Davis, 1988). However, (Kail & Hall, 1994) reported that it is not age, but rather
processing speed, that predicts naming time. In addition, the study showed that naming time is linked to reading recognition, which is linked to reading comprehension.

Although the current study did not consider the development of reading ability, the literature related to processing speed, rapid auditory naming and reading suggests a likely relationship between lexical processing speed and the development of reading skills. The lexical processing speed assessment developed as part of the current project may be a useful tool for further study of this relationship. Additionally, the current results, taken together with previous research, suggest that an assessment like the LPA may be of clinical utility. This type of assessment has the potential to facilitate early identification of children who have slowed lexical processing speed and who, as a result, may be at risk for reading difficulty. Identification of these children before reading problems develop may have implications for intervention.

An important result of the current project, which has implications for future research, is the finding of a relationship between processing speed and autistic symptomology in typically developing children. Backed by the results of the current study, we propose that slowed lexical processing speed, which can be measured simply as reaction time in this assessment, may be an underlying factor in autism. Our results are consistent with a theory proposed by Siegal and Blades (Siegal & Blades, 2003) which suggests auditory processing, the mechanism through which children encounter language, may act as a gatekeeper to later development. Difficulty processing and extracting linguistic information from speech likely leads to
disadvantage in the acquisition of language and in the ability to participate in conversation and associated difficulty with social skills and abilities.

The current results are consistent with the hypothesis that a deficit in auditory processing may be underlying the basis for autistic symptomology and may, in fact, be a “gatekeeper” to the development of both language and social skills. This conceptualization is consistent with an existing hypothesis proposed to explain a cause of language impairment in autism, namely a fundamental deficit in the ability to process transient sequential stimuli (Ricks & Wing, 1975; Tanguay, 1984). In a similar hypothesis, termed the time-parsing deficit hypothesis, Boucher hypothesizes that all individuals with autism spectrum disorders have impaired time-parsing of events on an extended scale, like conversational exchange, which contribute to linguistic aspects of pragmatic impairment (Boucher, 2003). She suggests that in more severe forms of the disorder impaired time-parsing on the scale of sentences, words, and morphemes may contribute to increased difficulty with semantic and syntactic development. She submits that in the most severe cases, those characterized by the absence of language development, individuals may have additional impairment in time-parsing on the level of syllables and phonemes, eliminating the capacity for language acquisition (Boucher, 2003). The results of the current research speak only to autistic traits in normally developing individuals. An important next step in the research program would be to look carefully at lexical processing in individuals diagnosed with autism. Boucher’s hypothesis could be tested through investigation of relationships between lexical processing speed and linguistic skills in a diagnosed population.
The results of the current project indicate promise for the use of the LPA assessment not only in continued autism-related research, but also points to potential utility in clinical practice. The assessment was designed deliberately for ease of use with special populations, in particular individuals with autism. It has a minimal receptive language requirement and no expressive language requirement, lending itself to use with young children and others with limited language functioning, a defining feature of autism. Another limitation of traditional assessments, in terms of their utility in assessing children with autism, is that that they assume that motivation for performance is naturally provided by social reinforcement through interactions with the examiner. This strategy works well with typically developing children. However, children with autism do not typically show preference for social events such as smiles, praise, or gestures (Rincover & Newsom, 1985), making it a challenge to motivate them during assessment.

Research on motivation in children with autism has shown that sensory reinforcers produce a higher percentage of correct responses and result in an equal number of trials before satiation when compared with edible reinforcers (Rincover & Newsom, 1985), which are another common method to motivate children with autism (Lovaas, Koegel, Simmons, & Long, 1973). The lexical processing assessment can be seen as an operant task where participants are trained to look at the target for a visual reward. Positive reinforcement through this rewarding stimulus serves to maintain the behavior. This design element eliminates the problem posed by the lack of motivation through social reinforcement observed in many children with autism. The implicit nature of the task can also be seen in the task design, which takes advantage...
of the ecological validity inherent in the task. Even without a task instruction, it is well known that eye gaze maps to visual referents related to spoken words. However, research indicates that subjects lack awareness of this natural gaze toward referents. In a recent study of eye-gaze self-monitoring only one of 14 individuals with autism and 7 of 14 typically developing individuals noticed they were controlling gaze contingent lenses (Grynszpan et al., 2011). This lack of awareness of agency related to eye gaze suggests lack of explicit eye-gaze control during visual fixation to a target on tasks like our lexical processing assessment.

In the future, following careful norming studies, an assessment like the LPA is likely to provide meaningful information to clinicians in a variety of patient populations. As a result of the careful assessment design, children with autism, who often present with the unique challenges to testing discussed above, may produce valid results using the LPA. Very young children, and others who have not developed sophisticated language, will also be testable using this assessment. Additionally, there is clinical utility for such an assessment in a rehabilitation setting as current measures of processing speed rely heavily on motor functioning. Currently, there are not reliable measures of processing speed available for use with individuals with paralysis or impaired motor functioning. As a result, processing speed measures are often left off of screening batteries for individuals with spinal cord and brain injury.
References


Table 1. *Summary Scores for Intelligence and Language Measures in Young Adults*

<table>
<thead>
<tr>
<th>Variable</th>
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<td>93-134</td>
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<td>108.90</td>
<td>12.84</td>
<td>89-139</td>
</tr>
<tr>
<td>CASL Language Composite</td>
<td>32</td>
<td>102.46</td>
<td>6.10</td>
<td>83.5-116.5</td>
</tr>
<tr>
<td>CASL Synonyms</td>
<td>32</td>
<td>103.97</td>
<td>6.83</td>
<td>87-117</td>
</tr>
<tr>
<td>CASL Sentence Completion</td>
<td>32</td>
<td>106.63</td>
<td>9.29</td>
<td>88-127</td>
</tr>
<tr>
<td>CASL Grammatical Morphemes</td>
<td>32</td>
<td>100.28</td>
<td>8.55</td>
<td>70-119</td>
</tr>
<tr>
<td>CASL Non-Literal Language</td>
<td>32</td>
<td>98.99</td>
<td>7.28</td>
<td>83-113</td>
</tr>
</tbody>
</table>

*Note: All scores are presented as Standard Scores (M = 100, SD = 15)*
Table 2. *Reaction Time Results for the Lexical Processing Assessment in Young Adults*

<table>
<thead>
<tr>
<th>Environmental Condition</th>
<th>Cohort</th>
<th>None</th>
<th>Rhyme</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SEM</td>
<td>Mean</td>
<td>SEM</td>
</tr>
<tr>
<td>Pink</td>
<td>821.45</td>
<td>18.29</td>
<td>726.63</td>
<td>14.17</td>
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<tr>
<td>None</td>
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<td>15.00</td>
<td>753.99</td>
<td>16.90</td>
</tr>
<tr>
<td>Conversation</td>
<td>805.84</td>
<td>14.26</td>
<td>722.49</td>
<td>12.89</td>
</tr>
<tr>
<td>Total</td>
<td>818.60</td>
<td>9.20</td>
<td>734.34</td>
<td>8.52</td>
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</table>

*Note: Reaction times are expressed in milliseconds*
Table 3. *Intercorrelations Between Intelligence and Language Variables in Young Adults*

<table>
<thead>
<tr>
<th>Variable</th>
<th>FSIQ</th>
<th>VIQ</th>
<th>PIQ</th>
<th>WMI</th>
<th>SYN</th>
<th>SC</th>
<th>GM</th>
<th>NL</th>
<th>LC</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSIQ</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VIQ</td>
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<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PIQ</td>
<td>0.84</td>
<td>0.48</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WMI</td>
<td>0.50</td>
<td>0.28</td>
<td>0.57</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SYN</td>
<td>0.53</td>
<td>0.48</td>
<td>0.42</td>
<td>0.24</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SC</td>
<td>0.44</td>
<td>0.41</td>
<td>0.32</td>
<td>0.46</td>
<td>0.51</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GM</td>
<td>0.45</td>
<td>0.34</td>
<td>0.43</td>
<td>0.22</td>
<td>0.58</td>
<td>0.44</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NL</td>
<td>0.30</td>
<td>0.29</td>
<td>0.21</td>
<td>0.26</td>
<td>0.61</td>
<td>0.37</td>
<td>0.15</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>LC</td>
<td>0.56</td>
<td>0.50</td>
<td>0.46</td>
<td>0.39</td>
<td>0.86</td>
<td>0.79</td>
<td>0.73</td>
<td>0.66</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Key: FSIQ=WASI Full-scale IQ; VIQ=WASI Verbal IQ; PIQ=WASI Performance IQ; WMI=WAIS-IV Working Memory Index; SYN=CASL Synonyms; SC=CASL Sentence completion; GM=CASL Grammatical morphemes; NL=CASL Nonliteral Language; LC=Language Composite.
Table 4. *Summary Scores for Intelligence, Language and Social Skills Data in Children*

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>M</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>WISC-IV Full Scale IQ</td>
<td>35</td>
<td>103.11</td>
<td>13.70</td>
<td>81-136</td>
</tr>
<tr>
<td>WISC-IV VCI</td>
<td>35</td>
<td>102.51</td>
<td>13.53</td>
<td>77-146</td>
</tr>
<tr>
<td>WISC-IV PRI</td>
<td>35</td>
<td>100.43</td>
<td>13.59</td>
<td>73-129</td>
</tr>
<tr>
<td>WISC-IV WMI</td>
<td>35</td>
<td>103.49</td>
<td>11.64</td>
<td>83-132</td>
</tr>
<tr>
<td>WISC-IV PSI</td>
<td>35</td>
<td>100.57</td>
<td>12.22</td>
<td>75-128</td>
</tr>
<tr>
<td>CASL Language Composite</td>
<td>35</td>
<td>107.56</td>
<td>9.73</td>
<td>89.75-13.67</td>
</tr>
<tr>
<td>CASL Synonyms</td>
<td>35</td>
<td>109.00</td>
<td>11.60</td>
<td>84-131</td>
</tr>
<tr>
<td>CASL Sentence Completion</td>
<td>35</td>
<td>104.51</td>
<td>14.47</td>
<td>80-141</td>
</tr>
<tr>
<td>CASL Grammatical Morphemes</td>
<td>35</td>
<td>108.23</td>
<td>10.10</td>
<td>92-131</td>
</tr>
<tr>
<td>CASL Non-Literal Language</td>
<td>34</td>
<td>107.85</td>
<td>12.26</td>
<td>83-132</td>
</tr>
<tr>
<td>SRS</td>
<td>35</td>
<td>98.76</td>
<td>15.29</td>
<td>76-140.5</td>
</tr>
<tr>
<td>SRS Social Awareness</td>
<td>35</td>
<td>97.94</td>
<td>14.83</td>
<td>74.5-134.5</td>
</tr>
<tr>
<td>SRS Social Cognition</td>
<td>35</td>
<td>97.56</td>
<td>15.45</td>
<td>80.5-149.5</td>
</tr>
<tr>
<td>SRS Social Communication</td>
<td>35</td>
<td>96.57</td>
<td>12.86</td>
<td>79-136</td>
</tr>
<tr>
<td>SRS Social Motivation</td>
<td>35</td>
<td>102.44</td>
<td>16.40</td>
<td>80.5-145</td>
</tr>
<tr>
<td>SRS Social Mannerisms</td>
<td>35</td>
<td>102.57</td>
<td>18.85</td>
<td>76-152.5</td>
</tr>
</tbody>
</table>

*Note: Data presented as Standard Scores (M = 100, SD = 15)*
Table 5. Reaction Time Results for the Lexical Processing Assessment in Children

<table>
<thead>
<tr>
<th>Environmental Cond.</th>
<th>Cohort Condition</th>
<th>Mean</th>
<th>SEM</th>
<th>Mean</th>
<th>SEM</th>
<th>Mean</th>
<th>SEM</th>
<th>Mean</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pink</td>
<td>990.64</td>
<td>43.05</td>
<td>892.00</td>
<td>38.63</td>
<td>992.13</td>
<td>44.78</td>
<td>957.61</td>
<td>24.37</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>983.34</td>
<td>39.33</td>
<td>952.91</td>
<td>44.40</td>
<td>886.27</td>
<td>36.67</td>
<td>940.77</td>
<td>23.25</td>
</tr>
<tr>
<td></td>
<td>Convo</td>
<td>1051.47</td>
<td>47.27</td>
<td>844.61</td>
<td>37.76</td>
<td>940.30</td>
<td>44.32</td>
<td>946.29</td>
<td>25.17</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1008.98</td>
<td>25.06</td>
<td>896.38</td>
<td>23.32</td>
<td>938.97</td>
<td>24.28</td>
<td>948.17</td>
<td>14.01</td>
</tr>
</tbody>
</table>

*Note: Reaction times are expressed in milliseconds*
Table 6. *Intercorrelations Between Intelligence and Language Variables in Children*

<table>
<thead>
<tr>
<th>Variable</th>
<th>FSIQ</th>
<th>VCI</th>
<th>PRI</th>
<th>WMI</th>
<th>PSI</th>
<th>LC</th>
<th>SYN</th>
<th>SC</th>
<th>GM</th>
<th>NL</th>
<th>SRS</th>
<th>AGE</th>
</tr>
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<tbody>
<tr>
<td>FSIQ</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VCI</td>
<td>0.828</td>
<td>1.000</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRI</td>
<td>0.838</td>
<td>0.686</td>
<td>1.000</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WMI</td>
<td>0.633</td>
<td>0.508</td>
<td>0.334</td>
<td>1.000</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSI</td>
<td>0.724</td>
<td>0.401</td>
<td>0.546</td>
<td>0.360</td>
<td>1.000</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LC</td>
<td>0.687</td>
<td>0.734</td>
<td>0.514</td>
<td>0.597</td>
<td>0.405</td>
<td>1.000</td>
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<td></td>
<td></td>
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</tr>
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<td>SYN</td>
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<td>0.418</td>
<td>0.411</td>
<td>0.194</td>
<td>0.250</td>
<td>0.678</td>
<td>1.000</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SC</td>
<td>0.655</td>
<td>0.741</td>
<td>0.469</td>
<td>0.559</td>
<td>0.401</td>
<td>0.889</td>
<td>0.461</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>GM</td>
<td>0.659</td>
<td>0.574</td>
<td>0.562</td>
<td>0.566</td>
<td>0.451</td>
<td>0.742</td>
<td>0.381</td>
<td>0.522</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>NL</td>
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<td>0.505</td>
<td>0.120</td>
<td>0.517</td>
<td>0.183</td>
<td>0.829</td>
<td>0.267</td>
<td>0.722</td>
<td>0.482</td>
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</tr>
<tr>
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<td>-0.114</td>
<td>0.014</td>
<td>-0.103</td>
<td>-0.018</td>
<td>-0.259</td>
<td>-0.153</td>
<td>-0.201</td>
<td>-0.326</td>
<td>-0.140</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>AGE</td>
<td>-0.065</td>
<td>0.005</td>
<td>-0.199</td>
<td>-0.221</td>
<td>-0.062</td>
<td>-0.011</td>
<td>-0.007</td>
<td>0.027</td>
<td>-0.161</td>
<td>0.121</td>
<td>0.085</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Key: FSIQ=WISC-IV Full Scale IQ; VCI=WISC-IV Verbal Comprehension Index; PRI=WISC-IV Perceptual Reasoning Index; WMI=WISC-IV Working Memory Index; PSI=WISC-IV Processing Speed Index; LC=CASL Language Composite; SYN=CASL Synonyms; SC=CASL Sentence Completion; GM=CASL Grammatical Morphemes; NL=CASL Nonliteral Language; SRS=Social Responsiveness Scale
Table 7. *Intercorrelations Between Social Responsiveness Scale Variables in Children*

<table>
<thead>
<tr>
<th>Variable</th>
<th>SRS</th>
<th>AWARE</th>
<th>COGN</th>
<th>COMM</th>
<th>MOTIV</th>
<th>MANN</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRS</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AWARE</td>
<td>0.794</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COGN</td>
<td>0.896</td>
<td>0.658</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COMM</td>
<td>0.915</td>
<td>0.702</td>
<td>0.738</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOTIV</td>
<td>0.782</td>
<td>0.667</td>
<td>0.656</td>
<td>0.604</td>
<td>1.000</td>
<td></td>
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<tr>
<td>MANN</td>
<td>0.860</td>
<td>0.503</td>
<td>0.784</td>
<td>0.793</td>
<td>0.480</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Key: SRS=Social Responsiveness Scale; AWARE= SRS Social Awareness; COGN= SRS Social Cognition; COMM= SRS Social Communication; MOTIV= SRS Social Motivation; MANN=SRS Social Mannerisms
Figure 1. Representation of Assessment Interface

Figure 1. Representation of assessment interface with no competition, cohort competition, and rhyme competition trials (left to right). Red box indicates target, black box indicates competitor.
Figure 2. *Assessment Design Schematic*

Cohort Competition

<table>
<thead>
<tr>
<th>Environmental Competition</th>
<th>None</th>
<th>Cohort</th>
<th>Rhyme</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>bride</td>
<td>shell</td>
<td>train</td>
</tr>
<tr>
<td></td>
<td>cage</td>
<td>shoe</td>
<td>rain</td>
</tr>
<tr>
<td></td>
<td>desk</td>
<td>toy</td>
<td>stick</td>
</tr>
<tr>
<td></td>
<td>moon</td>
<td>sword</td>
<td>tree</td>
</tr>
<tr>
<td>(no noise)</td>
<td>fork</td>
<td>cloud</td>
<td>box</td>
</tr>
<tr>
<td></td>
<td>earth</td>
<td>clown</td>
<td>fox</td>
</tr>
<tr>
<td></td>
<td>bike</td>
<td>nest</td>
<td>glass</td>
</tr>
<tr>
<td></td>
<td>flute</td>
<td>glue</td>
<td>sled</td>
</tr>
<tr>
<td>(pink noise)</td>
<td>nurse</td>
<td>pill</td>
<td>bear</td>
</tr>
<tr>
<td></td>
<td>soap</td>
<td>pig</td>
<td>chair</td>
</tr>
<tr>
<td></td>
<td>drum</td>
<td>skull</td>
<td>nut</td>
</tr>
<tr>
<td></td>
<td>bench</td>
<td>hat</td>
<td>ice</td>
</tr>
</tbody>
</table>

**Figure 2.** Assessment design schematic. This schematic presented with representative sample stimuli. Red text indicates target, blue text indicates cohort competitor, gold text indicates rhyme competitor, black text indicates distractor.
Figure 3. *Selection of Noun Stimuli*

<table>
<thead>
<tr>
<th>Corpus Name</th>
<th>Age Range</th>
<th>N</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown</td>
<td>Adam 2;3-4;10</td>
<td>3</td>
<td>Large longitudinal study of three children</td>
</tr>
<tr>
<td></td>
<td>Eve 1;6-2;3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sarah 2;3-5;1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carterette</td>
<td>1(^{st}) grade students</td>
<td>54</td>
<td>Speech sample taken in simple social situations (groups of three)</td>
</tr>
<tr>
<td></td>
<td>3(^{rd}) grade students</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5(^{th}) grade students</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td></td>
<td>adults</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Post</td>
<td>Lew 1;10.20 – 2;8.7</td>
<td>3</td>
<td>10 free play sessions over a 9 month period in the child’s home</td>
</tr>
<tr>
<td></td>
<td>She 1;7,18 – 2;5.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tow 1;7.5 -2;5.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sachs</td>
<td>1.1 – 5;1</td>
<td>1</td>
<td>Longitudinal naturalistic study</td>
</tr>
<tr>
<td>Suppes</td>
<td>1;11 – 3;11</td>
<td>1</td>
<td>Longitudinal study of a single child</td>
</tr>
<tr>
<td>Warren-</td>
<td>1;6 – 3;1</td>
<td>10</td>
<td>Parent-child interactions</td>
</tr>
<tr>
<td>Leubecker</td>
<td>4;6 – 6;2</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3. Selection of Noun Stimuli. This is a summary of corpora selected from the CHILDES database for use in the selection of noun stimuli.
Figure 4. *LPA Response Time in Young Adults (Cohort Competition Trials)*
Figure 5. *LPA Response Time in Young Adults*
Figure 6. *Visual Representation of Outliers in Intelligence and Language Measures*
Figure 7. LPA Response Time in Children (Cohort Competition Trials)
Figure 8. Visual Representation of Removed Outlier in Verbal Comprehension Index
Figure 9. The Relationship Between Lexical Processing Speed and Working Memory in Children
Figure 10. The Relationship Between Lexical Processing Speed and Language Composite in Children
Figure 11. The Relationship Between Lexical Processing Speed and Synonyms in Children
Figure 12. The Relationship Between Lexical Processing Speed and Sentence Completion in Children
Figure 13. The Relationship Between Lexical Processing Speed and Grammatical Morphemes in Children
Figure 14. The Relationship Between Lexical Processing Speed and Nonliteral Language in Children
Figure 15. The Relationship Between Lexical Processing Speed and Autistic Symptomology in Children
Figure 16. The Relationship Between Lexical Processing Speed and Social Awareness in Children
Figure 17. The Relationship Between Lexical Processing Speed and Social Communication in Children
Figure 18. The Relationship Between Lexical Processing Speed and Social Motivation in Children
Figure 19. Visual Representation of Removed Outlier in SRS Social Cognition
Figure 20. The Relationship Between Lexical Processing Speed and Social Cognition in Children
# Appendix A: Linear Mixed Models in Young Adults

## Full Model Random Effects in Young Adults

```
ADULTMODEL.lmer<- lmer(ResponseTime~1 +(1|Slide#) +(1+TargetPosition|subject#) +(1|Slide ORDER))
```

## Lexical Processing in Young Adults

### Cohort Condition

```
ADULTMODEL.lmer<- lmer(ResponseTime~(1|Slide#) +(1+TargetPosition|subject#) +(1|Slide ORDER))
```

### Environmental Condition

```
ADULTMODEL.lmer<- lmer(ResponseTime~(1|Slide#) +(1+TargetPosition|subject#) +(1|Slide ORDER))
```

### Interaction (Cohort*Environment)

```
ADULTMODEL.lmer<- lmer(ResponseTime~CohortCondition+(1|Slide#) +(1+TargetPosition|subject#) +(1|Slide ORDER))
```

### Lexical Processing and Intelligence in Young Adults

**Adult Model**

```r
adultModel.lmer<-lmer(RESPONSETIME~COHORTCONDITION+COHORTCONDITION*ENVIRONMENTALCONDITION+(1|SLIDE#)+(1+TARGETPOSITION|SUBJECT#)+(1|SLIDEORDER))
```

*VIQ and PIQ were tested in this model individually, replacing FSIQ*

### Supplementary Analysis

#### Lexical Processing and Intelligence in Young Adults

**Adult Model**

```r
adultModel.lmer<-lmer(RESPONSETIME~COHORTCONDITION+COHORTCONDITION*ENVIRONMENTALCONDITION+FSIQ+(1|SLIDE#)+(1+TARGETPOSITION|SUBJECT#)+(1|SLIDEORDER))+(FSIQ|SLIDE#))
```

### Lexical Processing and Working Memory in Young Adults

**Adult Model**

```r
adultModel.lmer<-lmer(RESPONSETIME~COHORTCONDITION+COHORTCONDITION*ENVIRONMENTALCONDITION+(1|SLIDE#)+(1+TARGETPOSITION|SUBJECT#)+(1|SLIDEORDER))
```

### Supplementary Analysis

#### Lexical Processing and Working Memory in Young Adults

**Adult Model**

```r
adultModel.lmer<-lmer(RESPONSETIME~WMI+COHORTCONDITION+COHORTCONDITION*ENVIRONMENTALCONDITION+(1|SLIDE#)+(1+TARGETPOSITION|SUBJECT#)+(1|SLIDEORDER)+(WMI|SLIDE#))
```
### Lexical Processing and Language Skills in Young Adults

| Model 1 | \texttt{ADULTModel.lmer<-lmer(RESPONSE\_TIME~\texttt{COHORT\_CONDITION+COHORT\_CONDITION}^* \texttt{ENVIRONMENTAL\_CONDITION+(1|SLIDE\#)+(1+TARGET\_POSITION|subject\#)+(1|SLIDE ORDER))}} |
|---------|---------------------------------------------------------------------------------------------------|
| Model 2 | \texttt{ADULTModel.lmer<-lmer(RESPONSE\_TIME~\texttt{COHORT\_CONDITION+COHORT\_CONDITION}^* \texttt{ENVIRONMENTAL\_CONDITION+LANGUAGE\_COMPOSITE+(1|SLIDE\#)+(1+TARGET\_POSITION|subject\#)+(1|SLIDE ORDER))}} |

*Synonyms, Sentence Completion, Grammatical Morphemes, and Non-literal Language were tested in this model individually, replacing Language Composite.

### Supplementary Analysis

#### Lexical Processing and Language Skills in Young Adults

| Model 1 | \texttt{ADULTModel.lmer<-lmer(RESPONSE\_TIME~\texttt{COHORT\_CONDITION+COHORT\_CONDITION}^* \texttt{ENVIRONMENTAL\_CONDITION+(1|SLIDE\#)+(1+TARGET\_POSITION|subject\#)+(1|SLIDE ORDER)+ (LANGUAGE\_COMPOSITE|SLIDE\#))}} |
|---------|---------------------------------------------------------------------------------------------------|
| Model 2 | \texttt{ADULTModel.lmer<-lmer(RESPONSE\_TIME~\texttt{COHORT\_CONDITION+COHORT\_CONDITION}^* \texttt{ENVIRONMENTAL\_CONDITION+LANGUAGE\_COMPOSITE+(1|SLIDE\#)+(1+TARGET\_POSITION|subject\#)+(1|SLIDE ORDER)+ (LANGUAGE\_COMPOSITE|SLIDE\#))}} |
Appendix B: Linear Mixed Models in Children

<table>
<thead>
<tr>
<th>Model Type</th>
<th>Model Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Full Model Random Effects in Children</strong></td>
<td>`CHILDMODEL.lmer&lt;-lm(RESPONSETIME~1+(1</td>
</tr>
</tbody>
</table>
| **Lexical Processing in Children** | **Cohort Condition**<br>`CHILDMODEL.lmer<-lmer(RESPONSETIME~AGE+(1|SLIDE#)+(1+TARGETPOSITION|SUBJECT#))`<br>`CHILDMODEL.lmer<-lmer(RESPONSETIME~AGE+COHORTCONDITION+(1|SLIDE#)+(1+TARGETPOSITION|SUBJECT#))`<br>**Environmental Condition**<br>`CHILDMODEL.lmer<-lmer(RESPONSETIME~AGE+(1|SLIDE#)+(1+TARGETPOSITION|SUBJECT#))`<br>`CHILDMODEL.lmer<-lmer(RESPONSETIME~AGE+ENVIRONMENTALCONDITION+(1|SLIDE#)+(1+TARGETPOSITION|SUBJECT#))`<br>**Interaction (Cohort*Environment)**<br>`CHILDMODEL.lmer<-lmer(RESPONSETIME~AGE+COHORTCONDITION+(1|SLIDE#)+(1+TARGETPOSITION|SUBJECT#))`<br>`CHILDMODEL.lmer<-lmer(RESPONSETIME~AGE+COHORTCONDITION+COHORTCONDITION*ENVIRONMENTALCONDITION+(1|SLIDE#)+(1+TARGETPOSITION|SUBJECT#))`<br>**Lexical Processing and Intelligence in Children**<br>`CHILDMODEL.lmer<-lmer(RESPONSETIME ~ AGE+SRS+COHORTCONDITION+(1|SLIDE#)+(1+TARGETPOSITION|SUBJECT#))`<br>`CHILDMODEL.lmer<-lmer(RESPONSETIME ~ FSIQ+AGE+SRS+COHORTCONDITION+(1|SLIDE#)+(1+TARGETPOSITION|SUBJECT#))`<br>Note: VCI, PSI, WMI, PRI were tested individually, replacing FSIQ in this model. In a separate analysis, Language Composite was added to this model.**<br>**Lexical Processing and Language Skills in Children**<br>`CHILDMODEL.lmer<-lmer(RESPONSETIME~AGE+SRS+COHORTCONDITION+(1|SLIDE#)+(1+TARGETPOSITION|SUBJECT#))`<br>`CHILDMODEL.lmer<-lmer(RESPONSETIME~LANGUAGECOMPOSITE+AGE+SRS+)`
Note: SYN, SC, GM, and NL were tested in this model individually, replacing Language Composite.

Lexical Processing and Autistic Symptomology in Children

Note: Social Awareness, Social Cognition, Social Communication, Social Motivation, and Social Mannerism were tested individually, replacing SRS in this model
Vita

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