# AUDITORY SELECTIVE ATTENTION AND LANGUAGE PROCESSING IN CHILDREN WITH AND WITHOUT SPECIFIC LANGUAGE IMPAIRMENT

By

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Abstract

AUDITORY SELECTIVE ATTENTION AND LANGUAGE PROCESSING IN CHILDREN WITH AND WITHOUT SPECIFIC LANGUAGE IMPAIRMENT

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There is a growing consensus that children with specific language impairment (SLI) have impairments in basic cognitive functions that underlie linguistic performance deficits. One such function is attention and its control. Selective attention involves the cognitive control of attention directed towards a relevant stimulus and a simultaneous inhibition of attention towards irrelevant stimuli.

In this study, a novel paradigm was used to gain information about the way children with typical language development (TLD) and with SLI attend to and process linguistic stimuli. Participants listened to words through headphones and were instructed to attend to the words in one ear while ignoring the words in the other ear. They were simultaneously presented with pictures and asked to make a lexical (same/different) decision. The pictures either matched the attended word, the unattended word, or were unrelated. A baseline condition utilized the cross-modal decision task in the absence of distracters. The groups performed with similar accuracy. Analysis of reaction time (RT) revealed main effects for Group and Condition. Analysis of patterns of performance within groups indicated that increasing levels of interference resulted in slower RTs for the TLD group. These data suggest that subjects with TLD actively inhibited competing stimuli in the unattended channel and selected the relevant stimuli efficiently. Subjects with SLI performed with a different pattern; they did not process competing stimuli differently from non-competing stimuli in the unattended channel. These results suggest that subjects with SLI had difficulty inhibiting distractors of all types. Analysis of supplemental task performance revealed deficits in the SLI group on tasks of verbal working memory and visuo-spatial executive function, but no group differences in basic dichotic listening skills. Correlations between experimental task performance, language scores, nonverbal intelligence scores, and supplemental task scores were examined. Moderate correlations between performance on the auditory selective attention task and the working memory task, as well as on the nonverbal intelligence measure, suggested that a common construct contributed to performance on these measures. However, regression analyses revealed that these factors did not adequately account for the variance in experimental RTs, suggesting that additional, unidentified factors were also at play.

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# Chapter 1: Introduction

Children with specific language impairment have deficits in cognitive control processes known as *executive functions* (Gillam, Montgomery, & Gillam, 2008; Hick, Botting, & Conti-Ramsden, 2005; Im-Bolter, Johnson & Pascual-Leone, 2006; Marton, 2008; Spaulding, 2010; van Daal, Verhoeven, & van Balkom, 2009). Attention is a critical component of many information and language processing models (Cowan, Elliott, Saults, Morey, Mattox, & Hismajatullina, et al., 2005; Posner, 1995), and co-morbid deficits in attention are often observed in children with SLI (Cantwell & Baker, 1991; Cohen, Vallance, Barwick, Im, Menna, Horodezky, & Isaacson, 2000; Snowling, Bishop, Stothard, Chipcase, & Kaplan, 2006). In children with SLI, limitations in working memory have been well established (Ellis-Weismer, Evans, & Hesketh, 1999; Gathercole & Baddeley, 1990; Montgomery, 2000, 2002; Marton & Schwartz, 2003). However, the precise influence of selective attention on language development and language processing has not yet been investigated as thoroughly in the literature. Limitations in sustained and selective attention have been identified in preschoolers with SLI (Spaulding, Plante & Vance, 2008; Spaulding, 2010). However more research is needed to determine the nature of the attention difficulties and how they might impact language processing throughout childhood. The current study investigates auditory selective attention abilities in school-aged children with and without specific language impairment.

Models of Working Memory and Selective Attention

Selective attention is an active process, whereby an individual chooses a stimulus to be processed more fully, while suppressing all other irrelevant stimuli (Gomes, Motholm, Christodoulou, Ritter, & Cowan, 2000). Other executive functions that influence language processing include organization and planning, maintaining and shifting set, inhibitory control, and working memory. Working memory, in particular, has been established as a critical mediator in language processing (Baddeley, 1986, 1996; Montgomery, 2000b, 2002b). Models of working memory typically involve some aspect of attention control, although the architecture of the relationship differs by model. For example, Baddeley (1986) suggests that information stored in working memory is regulated by the "central executive" component. In contrast, Kane & Engle (Engle, 2002; Kane & Engle, 2003) have proposed a model whereby working memory is mediated by executive attention, or attention control. Specifically, they suggest that working memory is made up of two components: short term memory and controlled attention; and further, that the attention component actually drives the predictive value of working memory capacity. Engle (2002) showed that working memory capacity predicted performance on tasks that measure executive control of attention, including Stroop, antisaccade, and dichotic listening tasks. Most recently, Engle (2010) conceptualized working memory as having both domain-specific aspects (e.g., the phonological loop and auditory, visual, or spatial stores) as well as the domain-general aspect of *attention control*, which allows an individual to keep relevant stimuli in active memory and to suppress interferences from competing stimuli.

Given that working memory deficits have been well established in children with SLI, in Engle's view, deficits in attention control would be closely related, and might also be implicated in the language limitations in this population. This view has not been directly addressed in the literature to date. Although the current study will not attempt to account for a broad model of working memory and executive function in SLI, Engle's view of attention control will serve as a basis for examining selective attention and interpreting the results of an experimental task.

Models of selective attention must account for a proposed selection mechanism, with debate as to whether excitatory, inhibitory, or both types of mechanisms are responsible for stimulus selection. Models that focus on excitatory processes are sometimes called spotlight models of attention; attention is directed toward some feature of incoming stimuli. Stimuli that fall within the scope of the spotlight are amplified and selected for further processing. Such models (e.g., Broadbent, 1982) do not address the role of inhibition or suppression of irrelevant stimuli. In contrast, most modern models of selective attention support a dual-process mechanism, in which both excitatory and inhibitory processing are required for selection (e.g., Houghton & Tipper, 1994; Melara, Rao & Tong, 2002). In this case, not only are relevant stimuli amplified by excitatory processes, but irrelevant stimuli are actively suppressed by an inhibitory mechanism. This dual mechanism improves the efficiency of selection by reducing interference from competing stimuli. A critical question to be addressed in clinical populations is whether difficulties in selective attention are reflective of limitations in signal enhancement (e.g., attending to the relevant stimulus), inhibitory control (e.g., suppression of irrelevant stimuli), or both.

Measuring Selective Attention

Auditory selective attention can be measured behaviorally and electrophysiologically with varying stimuli, presentation modes, and response modes. In some studies, linguistic stimuli (e.g., speech sounds) have been used. For example, some investigators (e.g., Melara et al., 2002; Shafer, Morr, Datta, Kurtzburg, & Schwartz, 2005; Shafer, Ponton, Datta, Morr, & Schwartz, 2007; Szymanski, Lund, & Woods, 1999) have examined ERPs to vowel, consonant-vowel (CV) or vowel-consonant-vowel (VCV) stimuli in attended and unattended conditions. Others have incorporated higher-level linguistic stimuli such as words, sentences, and paragraphs (e.g., Vorobyev et al., 2004; Stevens, Sanders, & Neville, 2006). Behavioral measures such as accuracy and reaction time in response to target stimuli are often recorded and analyzed. Additional behavioral methods include shadowing, in which a subject must repeat what he or she hears in one ear while ignoring any stimuli being presented to the other ear; and selective monitoring, where the subject must listen for and respond to a target stimulus while ignoring all irrelevant stimuli (Gomes et al., 2000).

Most classic studies of auditory selective attention (e.g., Hansen & Hillyard, 1980), as well as more recent studies (e.g., Francis & Nusbaum, 2002; Melara et al., 2002), have included only adults as subjects, and only a few studies have attempted to link auditory selective attention abilities with language processing. In a series of experiments designed to measure lexical processing without attention, Dupoux, Kouider, and Mehler (2003) presented target words and primes dichotically (e.g., target words to the right channel, identical primes to the left channel) and manipulated the characteristics of the prime to control for attention allocation or for the processing of unattended stimuli with attention switches. Subjects were instructed to attend to one channel and to make a lexical decision about the stimulus (word/nonword). Primes, presented in the opposite channel, were either the same word (repetition) or unrelated to the target. Timing of prime presentation relative to the target was manipulated, and the authors found that priming occurred only when the subjects switched their attention to the "unattended" channel (e.g., when the prime occurred before the target), but not when it was truly ignored. In these controlled conditions, listeners used auditory selection to choose the appropriate linguistic stimulus for processing and to suppress irrelevant stimuli. As of yet, there is no information on the development of these abilities in children.

A small number of studies have investigated target detection in attended and unattended conditions developmentally (e.g., Bartgis, Lilly & Thomas, 2003; Gomes, Duff, Barnhardt, Barrett, & Ritter, 2007; Jerger, Pearson & Spence, 1999). Bartgis and colleagues (2003) identified a linear progression in the ability to allocate attention selectively to the appropriate channel from five to nine years of age. In their study, electrophysiological responses showed that five-year olds processed both standard and deviant (target) stimuli similarly, whereas seven- and nine-year olds processed the target stimuli to a greater extent than they did the standard or "irrelevant" stimuli. Therefore, the older children appeared to be more effective in their ability to select the target stimulus for processing. Gomes et al. (2007) utilized a similar methodology to assess auditory selective attention in nine and 12 year old children, as well as in adults. Results suggested that in typically developing children and adolescents, improvements are consistent with primary developments in speed and efficiency of processing, as opposed to target- or distracter-specific processing.

In a few cases, dichotic listening (DL) tasks have been employed to examine the relationship between attention and language processing (Asbjornsen & Hugdahl, 1995; Dupoux et al., 2003; Niemi, Gunderson, Leppäsaari, & Hugdahl, 2003). Historically, DL experiments have been used to identify a right-ear advantage that is thought to reflect left-hemisphere lateralization for language processing in the brains of normal individuals (Kimura, 1967). In the 1990's, the focus of many dichotic listening studies shifted to explore the relationship between processes such as arousal and attention and DL performance in adults and children (Asbjornsen, Hugdahl, & Bryden, 1992; Obrzut, 1995; Obrzut, Horgesheimer, & Boliek, 1999). The magnitude of the right ear effect in adults can be modulated by selective attention, either by verbally instructing the participant to attend to one ear over the other (also known as a *directed* or *forced attention* condition), or by presenting cuing tones to the attended channel. Children can overcome the right ear advantage when presented with cuing tones to the left ear, but only at short stimulus-onset-asynchronies (SOAs.) That is, if the stimulus is presented long enough after the cue tone, the right ear effect re-emerges (Obrzut et al., 1999). Studies that have manipulated attention variables in combination with traditional DL procedures in clinical populations have had varying results. Asbjornsen et al. (2003) found that a combination of DL procedures along with tests of executive function were successful in identifying more than 90% of children with reading disabilities in their sample. Children with SLI have exhibited a weaker right-ear advantage when compared with TLD subjects (Cohen, Riccio, & Hynd, 1999), and difficulty overcoming the right-ear advantage in forced-left conditions (Niemi et al., 2003). The latter difficulty is thought to be indicative of an underlying impairment in cognitive control of attention, particularly in the ability to inhibit a prepotent or automatic response.

Fewer studies have examined auditory selective attention abilities in clinical populations. Some investigators have assessed attention skills using subtests of published materials such as the *Test of Everyday Attention* (*TEA;* Robertson, Ward, Ridgeway, & Nimmo-Smith, 1994) or the *Test of Everyday Attention for Children (TEA-Ch;* Manly et al., 1998) (e.g., Bishop & Norbury, 2005; Sterr, 2004). These tests are composed of tasks that measure several subcomponents of attention, including visual selective attention, attention switching, auditory-verbal working memory, and sustained attention. For example, a test battery that had been normed on adults revealed deficits in auditory tasks relative to visual tasks in children with SLI (Noterdaeme, Amorosa, Mildenberger, Sitter, & Minow, 2001).

Other investigators have used experimental tasks to identify attention impairments in children with dyslexia (Facoetti, Lorusso, Paganoni, Cattaneo, Galli, Umilta, & Mascetti, 2003) and with autism (Ciesielski, Courchesne, & Elmasian, 1990). In the latter study, children with autism did not exhibit the attention-related ERP responses seen in their typically developing peers. Likewise, children with dyslexia exhibited impairments in auditory and visual attention attributable to limited facilitation and inhibition effects. The authors concluded that impairments in facilitation and inhibition required for selection might explain phonological processing impairments in dyslexia (Facoetti et al., 2003). Given the significant co-morbidity of SLI and dyslexia diagnoses (Snowling, Bishop, & Stothard, 2000), it is possible that deficits in auditory attention could also contribute to limitations in phonological and lexical processing in children with SLI. Studies aimed at identifying attention deficits in children with SLI are described further below.

Processing Limitations and Patterns of Impairment in Children with SLI

A range of deficits, including language-specific areas (e.g., morphosyntax) and hypothesized underlying deficits (e.g., auditory processing), has been investigated in children with SLI. However, the etiology of these deficits continues to be controversial. They have been attributed to a specific deficit in linguistic knowledge (e.g., *The Extended Optional Infinitive Account,* Rice & Wexler, 1995; Rice, Wexler, & Cleave, 1995), limitations in general processing capacity (e.g., *Generalized Slowing Hypothesis,* Kail, 1994), and limitations in more specific types of processing such as in phonological working memory (Gathercole & Baddeley, 1990) or auditory temporal processing (Leonard, 1998; Tallal & Piercy, 1973a, 1973b, 1974, 1975). Although impairments in specific areas such as morphoysyntactic, phonological, or auditory processing might be explained by the domain-specific theories noted above, it appears likely that a generally limited processing capacity and generally slower processing speed contributes to the heterogeneous nature and range of impairments in children with SLI. Kail and colleagues (Kail, 1994; Leonard et al., 2007; Miller, Kail, Leonard, & Tomblin, 2001; Miller et al., 2006) have consistently shown that children with SLI demonstrate slower reaction times on motor, cognitive, and linguistic tasks. Slow RTs were also shown to be stable over time in children with SLI (Miller et al., 2006). Response times are thought to provide a measure of global processing speed; slower RTs in children with SLI appear to be indicative of a general processing limitation that affects all levels of language function. However, other studies have identified limitations to this hypothesis (Windsor & Hwang, 1999; Windsor, Milbrath, Carney, & Rakowski, 2001), in that not all children with SLI demonstrate slowing, and that by utilizing different statistical methods of analysis, the slowing appears to be more process-specific rather than generalized.

Patterns of impairment in children with SLI have also been examined. Some investigators suggested that language development in children with SLI is primarily *delayed*; that is, development generally follows the same sequence as in typical language development, at a slower rate (e.g., Curtiss, Katz, & Tallal, 1992). Language development in children with SLI can also be described as *deviant*, or developing in ways that are different from their typically-language developing peers. Deviant patterns may be characterized by plateaus in development, where mastery of particular skills is never achieved; by profile differences in which a child demonstrates different degrees of delay across language domains or modalities; or by abnormal error frequencies, in which children with SLI display error types found in typical development, but with greater frequency (Leonard, 1998). A related possibility may be that children with SLI utilize different underlying mechanisms to perform the same tasks as their TLD peers (Marton, 2009). The question of patterns of delay or deviance is important to keep in mind as we consider the development of executive function skills in children with SLI.

## Attention Deficits in SLI

In addition to generalized limitations in processing, performance deficits of children with SLI on linguistic tasks have often been attributed to limited attention (e.g., Bishop, Carlyon, Deeks, & Bishop, 1999; Helzer, Champlin, & Gillam, 1996). There is a high co-morbidity of SLI and ADHD diagnoses (Cantwell & Baker, 1991; Snowling et al., 2006) and differentiating between effects of the two disorders can be a challenge for clinicians and researchers alike. Redmond, Thompson and Goldstein (in press) recently discussed the importance of identifying measures that would accurately diagnose and differentiate between these groups. They developed psycholinguistic profiles for SLI, TLD, and ADHD participants; using measures such as the Test of Early Grammatical Impairment (TEGI: Rice & Wexler, 2001), the nonword repetition task (NWR: Dollaghan & Campbell, 1998), the sentence recall task (SR: Redmond, 2005), and the Test of Narrative Language (TNL: Gillam & Pearson, 2004). They found that although all four measures resulted in strong diagnostic accuracy, the strongest predictors of language status were the TEGI and the SR. A slight reduction of effect size was identified when differentiating SLI from ADHD, even though their samples were relatively distinct; children with co-morbid deficits were excluded from the study.

Using Engle's (2002, 2010) theory of working memory and attention control as a guide, we might assume that children with SLI, who have known impairments in working memory and information processing, would have associated deficits in executive control of attention. Whether these deficits are reflective of problems selecting the relevant stimulus for processing or inhibiting the irrelevant stimuli is up for debate. Stevens and colleagues (2006, 2008) have presented neurophysiological evidence that attentional enhancement is limited in children with SLI, and is also amenable to treatment. On the other hand, Spaulding (2010) has suggested that suppression of both irrelevant and competing information is impaired in children with SLI. Deficits on tasks that require higher level processing involving working memory or lexical access could also be attributed to an impaired inhibitory mechanism in children with SLI (Ellis Weismer, Evans, & Hesketh, 1999; Matron, Kelmenson, & Pinkhasova, 2007; Seiger-Gardner & Schwartz, 2008). Performance deficits in auditory processing of stimuli with low phonetic substance or brief temporal cues (e.g., Leonard, MacGregor, & Allen, 1992; Tallal & Stark, 1981) could be related to underlying deficits in auditory selective attention. For example, Shafer et al. (2005) found that children with SLI had difficulty discriminating vowels of brief duration, and suggested that attention could play a role in their deficits. Although many authors have suggested implications of attention limitations on task performance, relatively few studies have *directly* investigated the links between selective attention and language processing in this population.

Despite differences in opinion regarding the specific mechanism of attention that may be impaired, there is a growing body of evidence supporting the presence of attention deficits in children with SLI. Many authors have studied sustained selective attention using a Continuous Performance Test, in either auditory (Hanson & Montgomery, 2002) or visual (Finneran, Francis, & Leonard, 2009) form. In addition to standard speech perception and auditory processing tasks, Hanson & Montgomery (2002) administered the *Auditory Continuous Performance Test* (Keith, 1994) to measure children's ability to maintain selective attention. Children listened to an 11-minute audiotape consisting of 600 monosyllabic words, and their task was to monitor the word list and respond (by raising a finger) when they heard a target word. No group differences (SLI versus TLD) emerged in accuracy (hits) on the *ACPT* task. Thus, the authors concluded that sustained selective attention was not a contributing factor to the poor performance of the SLI group on the auditory processing tasks. However, the *ACPT* task confounds sustained and selective attention. In fact, Armstrong (1997) found that the auditory form of the *Continuous Performance Test* (Mirsky & Cardon, 1962) did not clearly discriminate sustained from selective attention. Therefore, this task did not isolate the attentional mechanisms potentially impaired in children with SLI. Additionally, by measuring only accuracy, there is no way to know whether the SLI group took longer to process and select the appropriate stimulus. More recently, Finneran et al. (2009) identified reduced sustained attention using the visual form of the Continuous Performance Task in 4-6 year old children with SLI. These findings suggest that attention deficits in SLI may extend beyond the auditory domain, contrary to previous findings (e.g., Noterdaeme et al., 2002). Spaulding, Plante, & Vance (2008) investigated sustained selective attention skills in preschoolers under varying attentional load conditions and in both visual and auditory modalities. They found that the participants with SLI performed more poorly than their TLD peers in conditions of high attentional load (using degraded stimuli) in the auditory modality. SLI subjects performed similarly on the visual tasks, regardless of attentional load. The authors concluded that separate attentional capacities might be responsible for processing auditory and visual information.

Neurophysiological indices of attention have also been used to examine allocation of attention and the effect of attention on speech processing in children with SLI (Shafer et al., 2007; Stevens, Sanders, and Neville, 2006). Shafer et al. (2007) examined attention allocation to speech processing in passive versus attended conditions in 8-10 year old children with and without SLI. The results of this study suggested that children with SLI might have limited attentional resources and/or difficulties allocating attention to speech processing. These findings are noteworthy, particularly given the implication that limitations in auditory attention may impact early speech perception (as per Juczyk, 1994) as well as later language learning and processing. However, the methodology of this study, which involved ERP recordings to standard speech sounds of varying duration (short versus long vowel sounds), limits its application to more general theories of linguistic processing in children with SLI. Using a very different paradigm, Stevens et al. (2006) examined auditory selective attention in 3-8 year old children with and without SLI. They found that compared to children with TLD, children with SLI did not exhibit early attentional modulation to probe stimuli embedded in attended narratives (measured as an amplification in an ERP response 100ms post stimulus). There were no differences between groups on ERP responses to unattended stimuli. These results indicate that the deficit in selective attention in the SLI group could be pinpointed specifically at the level of signal enhancement, or selection of the relevant/attended stimulus.

Results of these neurophysiological investigations are promising, but still far from clear in terms of explaining language processing differences in children with SLI. Recent behavioral studies focusing on *sustained* selective attention have provided compelling results, particularly in preschoolers (Finneran et al., 2009; Spaulding, Plante, & Vance, 2008). However, there continues to be a need for research involving older school-aged children for whom intact attention and executive function skills are critical to continued development in an academic environment.

Research Questions

Several questions remain: How does a child's ability to attend selectively to auditory stimuli affect language processing? Specifically, do children with SLI exhibit deficits in selective attention that can be related directly to their language deficits? If so, is the deficit reflective of problems activating and selecting relevant stimuli, inhibiting irrelevant stimuli, or both? Underlying impairments in auditory selective attention could account for specific deficits observed in children with language impairments, such as limitations in auditory temporal processing, lexical access, morphosyntactic acquisition, or syntactic processing. Furthermore, if auditory selective attention is required for speech perception from infancy (Jusczyk, 1994), limitations in auditory selective attention could be a contributing factor in the perceptual deficits and in the late emergence of language in children with SLI. Most importantly, if a deficit in the cognitive control of attention is identified in children with SLI, it may be amenable to intervention.

Before these questions can be addressed, it is necessary to identify a task that will isolate selective attention abilities from sustained attention and working memory. It is also important to utilize a task that can be directly related to language processing as opposed to one that involves pure tone or simple speech sound stimuli and then requires correlation to a language deficit. The aim of the current study was to systematically investigate the contribution of auditory selective attention to lexical processing in 9-12 year old children with SLI, using a paradigm that manipulated attention within a dichotic listening task. Increasing interference was presented in the form of competing stimuli in the "to-be-ignored" channel. Increases in reaction time and/or decreases in accuracy could be reflective of limitations in selection, inhibition, or both. Specifically, in children with typical language development, the expectation was that inhibition of words in the unattended channel would be reflected as an increase in reaction time as compared to baseline, and overall accuracy of lexical processing will not be affected. This finding could account for the ability in children with typical language development to select and process relevant auditory stimuli (e.g., primary speaker's utterances) while suppressing and limiting processing of unrelated or interfering stimuli (e.g., background conversation). Patterns of reaction time and accuracy in the SLI group were expected to differ from TLD peers. There are at least three ways in which performance might have differed, with varying theoretical significance. If reaction times were disproportionately increased, or if accuracy was significantly decreased in conditions designed to increase demands on suppression mechanisms, SLI children would be demonstrating deficits in inhibitory control. This pattern would be in concordance with recent investigations identifying inefficient inhibitory mechanisms in children with SLI (Marton et al., 2007; Spaulding, 2010). Additionally, this pattern of results would suggest deviant selective attention skills in children with SLI, skills that differ both quantitatively (e.g., speed/accuracy) and qualitatively (pattern of performance across conditions). If, however, the SLI group demonstrated slower reaction times or decreased accuracy than the TLD group on experimental conditions (relative to baseline), but no difference in the pattern of performance between groups, we would conclude that children with SLI demonstrate a delayed profile of attention modulation compared to TLD peers. In this scenario, performance would be more likely attributable to overall difficulties in activation or selection, as opposed to a specific deficit in the inhibitory mechanism. Finally, if response times in all conditions (including baseline) were increased compared to TLD, results would support a generalized slowing hypothesis for language processing, regardless of the manipulation of attention.

# Chapter 2: Methodology

## Participants

Thirty school-aged participants took part in the study, ranging in age from 9;1 (years;months) to 12;2 (*M* =10;9, *SD* = 10.5 months). Half the participants (*n*=15) were language impaired (SLI), and the other half (*n*=15) had typical language development (TLD) and served as age-matched controls. Children between the ages of 9-12 years were targeted, given that in typically developing children, auditory selective attention abilities undergo the most significant changes between the ages of five and seven, with some continuing development through age 9 (Bartgis et al., 2003). The average age of participants in each group was statistically similar; the mean age in the TLD group was 10;10 and the mean age of SLI participants was 10;8 ($F$ (1,28) = 0.216, $p$=.646). The groups were similar in terms of gender as well, the TLD group included 10 males and 5 females, and the SLI group was made up of 11 males, 4 females. All participants were monolingual speakers of English.

All participants were given a set of standardized assessments to determine eligibility to participate in the study, including *Test of Nonverbal Intelligence*, 3$^{rd}$ Edition (*TONI-3*; Brown, Sherbenou, & Johnsen, 1997), and either the *Clinical Evaluation of Language Fundamentals, 3$^{rd}$ Edition (CELF-3,* Semel, Wiig, & Secord, 1996) or *4$^{th}$ Edition (CELF-4,* Semel, Wiig, & Secord, 2004), depending on the date of initial intake. Parents filled out a case history form, a socioeconomic status (SES) questionnaire (adapted from Hollingshead, 1975), and the *Conners' Rating Scales-Revised* (Conners, 1997), a screening measure for Attention Deficit/Hyperactivity Disorder (ADHD). All participants passed a binaural hearing screening (500, 1000, 2000, and 4000 Hz at 20 dB). Handedness was determined using the Edinburgh Handedness survey (Oldfield, 1971).

SLI Group

Children with SLI scored within one standard deviation of the mean on the *TONI-3* (*M* = 101.3, *SD* = 12.8). SLI subjects obtained a Total Language Score more than 1.25 *SD* below the mean on the *CELF-3* or *CELF-4* (*M* = 81.1, *SD* =11.6*).* Two participants failed to meet this particular criterion, but were included in the study due to either a) Receptive or Expressive Composite scores that fell more than 1.25 below the mean, or b) a diagnosis by a certified Speech-Language Pathologist and current enrollment in speech-language therapy. Children were excluded from the study if they presented with or had a history of frank motor, neurological, or social-emotional impairment. Children with a documented diagnosis of ADHD were also excluded. Parents of 13 of the 15 children in the SLI group filled out the Conners' Rating Scale to further screen for attention difficulties. According to the manual, scores greater than 65 on the ADHD Index are considered grounds for further exploration or assessment. Eight of these 13 children received scores higher than 65 (*M* = 70, *SD* = 12.7). Given this high percentage of participants, and the common co-occurrence of attention and language impairments in school-aged children (Cantwell & Baker, 1991; Snowling et al., 2006), we decided not to exclude these participants, but rather to consider these scores in our later statistical analyses. Fourteen of the 15 participants in the SLI group were right-handed.

Control Group

Children with TLD also scored within one standard deviation of the mean on the *TONI-3* (*M* = 113.5, *SD* = 14.4). Their Total Language scores on the *CELF-3* or *CELF-4* were within the average range (*M* = 112.0, *SD* =8.2*).* TLD subjects had no history of speech, language, learning, motor, neurological, or social-emotional impairments, as per parent report. Parents of seven of the 15 children in the TLD group filled out the Conners' Rating Scale. None scored above 65 (*M* = 47.4, *SD* = 7.1), and none of the 15 subjects had a documented diagnosis of ADHD. Twelve of 15 participants in the TLD group were right-handed. See Table 1.

Table 1. Participant Characteristics

| ***Participant*** | ***Gender*** | ***Age (Y;M)*** | ***SES*** | ***TONI-3*** | ***CELF-3/4 REC*** | ***CELF-3/4 EXP*** | ***CELF-3/4 TOT*** | ***CRS-R*** |
|---|---|---|---|---|---|---|---|---|
| TLD01 | M | 10;8 | UM | 95 | 120 | 104 | 104 | |
| TLD02 | M | 11;1 | UM | 99 | 112 | 116 | 114 | |
| TLD03 | F | 10;2 | UM | 98 | 99 | 101 | 102 | |
| TLD04 | M | 10;6 | UM | 115 | 104 | 100 | 102 | |
| TLD05 | F | 10;6 | U | 104 | 119 | 128 | 123 | 58 |
| TLD06 | M | 10;0 | U | 121 | 101 | 108 | 108 | |
| TLD07 | M | 10;3 | U | 105 | 113 | 101 | 106 | 57 |
| TLD08 | M | 11;6 | UM | 122 | 99 | 110 | 102 | |
| TLD09 | M | 10;9 | UM | 95 | 105 | 118 | 111 | |
| TLD10 | F | 11;9 | M | 142 | 99 | 122 | 114 | |
| TLD11 | F | 11;1 | UM | 97 | 102 | 112 | 109 | 42 |
| TLD12 | F | 12;1 | U | 117 | 109 | 124 | 118 | 42 |
| TLD13 | M | 9;1 | UM | 118 | 105 | 128 | 120 | 42 |
| TLD14 | M | 11;1 | UM | 133 | 116 | 132 | 126 | 45 |
| TLD15 | M | 11;4 | UM | 111 | 122 | 121 | 122 | 46 |
| ***M*** | | **10;10** | | **111.47** | **108.33** | **115.00** | **112.07** | **47.43** |
| ***SD*** | | **9.7 M** | | **14.32** | **8.14** | **10.77** | **8.24** | **7.07** |
| SLI01 | M | 10;6 | L | 135 | 83 | 96 | 88 | 49 |
| SLI02 | F | 11;9 | UM | 98 | 86 | 75 | 81 | 73 |
| SLI03 | M | 9;1 | M | 95 | 85 | 75 | 75 | |
| SLI04 | M | 10;3 | UM | 118 | 88 | 83 | 82 | |
| SLI05 | M | 10;2 | M | 98 | 76 | 71 | 69 | 87 |
| SLI06 | M | 9;6 | UM | 91 | 94 | 92 | 93 | 84 |
| SLI07 | M | 12;2 | UM | 100 | 93 | 73 | 82 | 76 |
| SLI08 | M | 12;2 | UM | 85 | 90 | 80 | 82 | 80 |
| SLI09 | F | 10;0 | M | 87 | 82 | 106 | 98 | 84 |
| SLI10 | M | 12;1 | L | 95 | 61 | 52 | 52 | 68 |
| SLI11 | M | 11;0 | L | 108 | 79 | 101 | 90 | 62 |
| SLI12 | F | 10;7 | U | 98 | 76 | 95 | 85 | 49 |
| SLI13 | M | 9;1 | UM | 95 | 83 | 63 | 70 | 64 |
| SLI14 | F | 10;6 | U | 104 | 79 | 77 | 76 | 74 |
| SLI15 | M | 10;1 | UM | 112 | 96 | 83 | 93 | 60 |
| ***M*** | | **10;8** | | **101.27** | **83.40** | **81.47** | **81.07** | **70.00** |
| ***SD*** | | **11.4 M** | | **12.85** | **8.82** | **14.61** | **11.63** | **12.68** |

Note: SES = Socioeconomic status; L = lower, M = middle, UM = upper-middle, U = upper. *TONI-3 = Test of Nonverbal Intelligence, 3rd Edition; CELF-3/4 = Clinical Evaluation of Language Fundamentals, 3rd or 4th Edition; CRS-R = Conners' Rating Scale, Revised.*

**Stimuli**

All auditory stimuli were monosyllabic words of high familiarity based on Cycowicz, Friedman, Rothstein, & Snodgrass (1997). Stimuli were recorded by a female speaker in a soundproof booth and were analyzed using *Cool Edit Pro* software. Each token was recorded multiple times and the best exemplar of each token was chosen (e.g., no sound clipping, no changes in fundamental frequency, steady formant structure). All tokens were normalized for peak RMS amplitude. The audio files were cut and pasted into two-channel audio files, with one word in the right channel and another word in the left. Word pairs were constructed such that the words were not phonologically or semantically related. Word-association norms were consulted to ensure that there was no semantic relationship between the words (Nelson, McEvoy & Schreiber, 1998). Word pairs were matched and edited such that the onset and offset of the words occurred simultaneously. Word pairs ranged in duration from 410-650 ms. The two-channel auditory stimuli were imported into *E-Prime* (Psychology Software Tools, Inc., 2003) as individual .wav files and trial lists were created for each condition. See Appendix A for a complete listing of word pairs. Auditory stimuli were presented to the participants through headphones at 70 dB SPL.

Visual stimuli were black and white line drawings from Snodgrass & Vanderwart (1980), all of which have been determined to be highly familiar items for children (Cycowicz et al., 1997). The line drawings were presented on a 17-inch PC computer screen at a distance of approximately 18 inches from the subject. Subjects first participated in a pre-test naming task to ensure that they recognized the pictures and utilized the appropriate label. Although previous experience with these stimuli in experiments involving children with SLI in this age range suggested that they are highly familiar (Seiger-Gardner & Schwartz, 2008); any picture that was not correctly named during the pre-test was excluded from later analysis.

## **Design**

Trial lists were constructed such that five conditions (*baseline same, baseline different, attend, ignore,* and *unrelated)* occurred within each of two main trial blocks (right ear attend, left ear attend). Thirty stimuli (word/picture pairs) were created for each condition, resulting in 150 trials per ear. Thirty additional filler stimuli were presented in each trial block to balance the number of *same* and *different* responses, for a total of 180 trials per ear. For each ear, subjects were first presented with the baseline conditions (60 trials), followed by the experimental conditions (three blocks of 40 trials each). Within each of the experimental blocks, stimuli in the three experimental conditions and the filler trials were randomly presented. The order of presentation of trial blocks (right ear attend followed by left, or vice versa) was counterbalanced across participants (within each group, 7 participants received the right ear block first and 8 participants received the left ear block first).

### Conditions

As noted above, five conditions were included in this study (see Figure 1). Two baseline conditions were used.  In the first condition, called *baseline-same*, the auditory words presented in each ear were the same (essentially binaural presentation of a single word), and the auditory word matched the picture (e.g., the child heard *cat* binaurally and the picture was of a cat). The second baseline condition was called *baseline-different*. In this case, the auditory words presented in each ear were again the same, but the picture did not match the words (e.g., *cat* was heard in both ears, but the picture was of an unrelated item such as *bus*). During the experimental conditions, participants were required to direct their attention to a particular channel (right or left ear). The first experimental condition was the *attend* condition, in which the visual stimulus matched the attended auditory stimulus. For example, if the word *cat* was presented in the attended ear, and *bus* in the to-be-ignored ear, the picture was of a cat. The correct response in this condition would be *same*. In the second experimental condition, referred to as the *ignore* condition, the picture matched the to-be-ignored stimulus (in this case, *bus)*. Here the correct response is *different*. In the final, *unrelated* condition, the visual stimulus was different from both auditory stimuli (e.g., *shoe*). The correct response in this condition was again *different*. The complete trial list of word pairs and associated visual stimuli by condition can be found in Appendix A.

| Modality | Condition | | | | |
|---|---|---|---|---|---|
| | ***BaselineS*** | ***BaselineD*** | ***Attend*** | ***Ignore*** | ***Unrelated*** |
|  **Auditory (Attended channel)** | "cat" | "cat" | "cat" | "cat" | "cat" |
|  Auditory (Ignored channel) | "cat" | "cat" | "bus" | "bus" | "bus" |
|  **Visual** |  |  |  |  |  |
| **Correct Response** | **SAME** | **DIFFERENT** | **SAME** | **DIFFERENT** | **DIFFERENT** |

Figure 1. Presentation of sample stimuli in five conditions. Note that presentation of auditory words and pictures occurred simultaneously. Presentation was randomized and attended ear was counterbalanced across participants.

Reaction time was measured by the *E-prime* program from the onset of the auditory stimulus to the participant's response (button press) for each target. To address the research questions and predictions, reaction times between certain conditions were compared to assess facilitation and/or inhibition effects (see Table 2).

Table 2. Pairwise comparisons of interest and associated research questions.

| **Pairwise Comparison** | **Research Question(s) of Interest** |
|---|---|
| *Baseline Same vs. Baseline Different* | Is there a difference in RT between *same* and *different* responses?<br>What is the degree of cross-modal identity priming in the absence of interference? |
| *Baseline Same vs. Attend* | What level of interference is introduced by a non-competing stimulus in an unattended auditory channel (when the response is *same*)?<br>To what degree does this contextual interference affect cross-modal identity priming? |
| *Baseline Different vs. Unrelated* | Compared to a baseline RT, what level of interference is introduced by a non-competing stimulus in an unattended auditory channel (when the response is *different*)? |
| *Baseline Different vs. Ignore* | Compared to a baseline RT, what level of interference is introduced by a *competing* stimulus in an unattended auditory channel? |
| *Unrelated vs. Ignore* | What level of interference can uniquely be contributed to a *competing* (vs. non-competing) auditory stimulus in an unattended channel? |

**<u>Procedure</u>**

The experimental task required that children be seated in front of a PC computer screen while wearing Telephonic TDH-50 headphones. Subjects listened to words presented auditorily and made decisions about black and white pictures presented visually. Written and oral instructions appeared and were presented before each trial block to let the subject know to which ear he or she should attend. The participant was instructed to press a button marked *same* if the picture matched the word he/she heard in the attended ear, and to press a button marked *different* if it did not match. These buttons were aligned vertically to avoid confusion with left/right ears and to avoid any advantage due to handedness. Children were instructed to push the buttons with their preferred/dominant hand, and to press the button as quickly and accurately as possible. The testing session began with familiarization trials with feedback provided. This practice set included five baseline trials, and three trials of each condition per attended ear, or 5 baseline and 18 experimental trials total. The word pairs and visual stimuli were different from those included in the main experiment but met the same specifications. If a child made more than three errors (out of 23 trials) on the familiarization task, they were allowed to repeat it before continuing on to the experiment. If they "failed" the familiarization task a second time, they would have been excluded from the study. No participants were excluded on this basis.

## Additional Tasks

To gain more information about more basic processes that may have contributed to performance on the experimental task, three additional tasks were administered. These included Dichotic Listening, List Recall, and Trailmaking tasks. Descriptions of each follow.

### Dichotic Listening

A dichotic listening paradigm was utilized to determine whether subjects presented with a right or left-ear dominance for auditory processing. Although the stimuli and presentation of trial blocks in the main experimental task were carefully balanced to avoid a lateralized advantage, it was important to determine whether a basic right- or left-ear advantage for either group may have influenced performance. A subset of twenty word pairs from the experimental task was chosen and each pair was presented so that each word appeared in both left and right channels, for a total of 40 stimuli (i.e., *cat-bus* as well as *bus-cat*). The stimuli were presented in random order (making sure that the cognate pairs did not follow one another), and the participant was instructed to report what word they heard "first" or most clearly (free recall procedure). See Appendix C for the dichotic listening trial list.

<u>List Recall Task (Marton & Schwartz, 2003)</u>

Participants completed the List Recall task (Marton & Schwartz, 2003) as a measure of complex verbal working memory. During this task, children were required to listen to sets of five sentences, and recall the sentence-final word of each sentence. Sentence length was determined by number of syllables, with short sentences containing no more than 10 syllables, and long sentences containing at least 15 syllables. The syntactically complex sentences included structures such as embedded and relative clauses. The sets were presented in random order, following a period of practice with the task. This task, an adaptation of Daneman and Carpenter's (1980) reading span task, was designed to examine simultaneous processing in verbal working memory. The task requires that the children not only continually listen to the sets of sentences while encoding and rehearsing the sentence-final words, but then also switch to production mode to respond. Following the child's response for each set, a comprehension question was posed to ensure that the children were processing the sentence content as well as remembering and rehearsing the sentence-final items. See Appendix D for complete listing of stimuli sentences and follow-up questions.

Children's Color Trails Task (Llorente, Williams, Satz, & D'Elia, 1989)

The Trail Making Test is a classic neuropsychological measure of attention switching and executive function in the visual domain. The original version of the task was developed for use with adults, and includes two forms. Form A measures response time while an individual connects circles numbered 1-25. Form B requires that they alternate numbers 1-25 with letters (e.g., 1-A-2-B-3-C and so on). Performance on Form B requires executive control as individuals must continually switch between response modes (letters and numbers) (Arbuthnott & Frank, 2000). Recent investigations have revealed differences between SLI and TLD groups on visuo-spatial tasks of executive function (Marton, 2008; Im-Bolter, Johnson, & Pascual-Leone, 2006), suggesting a more pervasive underlying cognitive impairment that affects multiple sensory modalities. Therefore, the *Children's Color Trails Test* (Llorente et al., 1989), a children's version of the Trail-Making Test, was administered to assess attention shifting and inhibitory skills in the visual domain. The *CCTT* is a pencil-and-paper task in which the child must first connect a sequence of numbers (1-15 on *CCTT-1*) then shift between sequencing numbers and alternating colors (*CCTT-2*). This requires that the participant hold a rule in mind, shift his or her attention between modalities (numbers vs. colors), and inhibit the automatic urge to connect the numbers in sequence regardless of the color. Subjects are timed, with longer times to completion, particularly on the second form, indicating slower processing and/or greater difficulty with the cognitive control aspect of the task.

# Chapter 3: Results

<u>Data Preparation Procedures</u>

The reaction time (RT) data were prepared for analysis via a multi-step process. For each participant, the raw data files from *E-prime* were transferred to Excel files for processing. RT data were first sorted by condition, then examined for accuracy. Incorrect and missed responses were removed from the data set. Errors accounted for 12% of responses overall; accuracy rates were calculated for each condition to be analyzed further. RTs considered outliers (+/- 3 SD from each participants Grand Mean RT) were also removed. This cutoff removed less than 1% of correct responses overall. Mean RTs for each condition (in each ear) were then calculated for each participant. A third column for each condition was created to represent the RT for the condition collapsed across ears. These individual mean RTs (three per condition; one for each ear and one collapsed) were then entered into SPSS for statistical analysis. Identifying information (such as subject number, gender, handedness, and test scores), accuracy data, and data for the supplemental tasks were also entered into the SPSS file. For all analyses, significance was established at $\leq .05$. Effect sizes are reported as partial-eta squared, $\eta_p^2$.

In addition to these individual-level data preparation procedures, an item analysis was conducted before comparing means. To do this, all participants' data (accuracy and RTs) per item were merged into a single file and then analyzed to determine whether any particular items caused significant decreases in accuracy or increases in RT. These analyses led to the removal of four items from each subject's data files; one from the *Baseline-Same* condition in the Right ear block, one from the *Unrelated* condition in the

Left ear block, and two from the *Unrelated* condition in the Right ear block. In all four cases, the trials had been incorrectly coded in Eprime (e.g., the correct answer was *same* but was coded in Eprime as *different*). Removal of these four items accounted for 1.3% of all experimental trials. No word pairs or auditory/visual pairings were identified as problematic based on any acoustic or lexical features.

<u>Statistical Analyses</u>

The results of the experimental task were initially analyzed using a 2 X 5 Repeated Measures ANOVA design (Group X Condition). Multiple analyses were conducted, with outcome measures including mean accuracy and reaction times (RTs). For the reasons that follow, these ANOVAs were completed to provide an omnibus statistical analysis; however, the a priori comparisons of interest were between pairs of conditions (e.g., *baseline-same* and *baseline-different, baseline-same* and *attend, baseline-different* and *ignore*, *baseline-different* and *unrelated*, and *unrelated* and *ignore*).

In this design, note that the response in some conditions is *same*, and in others it is *different*. There may be an inherent difference in reaction time between *same* and *different* responses. Some suggest that subjects will always respond more quickly when the response is *same* than when it is *different* (e.g., Goldfarb & Lenik, 2006), whereas others find no difference between the two response types (Posner & Mitchell, 1967), or speeded reaction times only when items are physically the same as opposed to nominally the same (Blake, Fox, & Lappin, 1970). In the current paradigm, the response in the *unrelated* and *ignore* conditions is *different*, but the response in the *attend* condition is *same*. Faster reaction times in the *attend* condition could be due then, at least in part, to the fact that it is easier to make a *same* decision than *different*. Therefore, we considered pairwise comparisons between baseline, unrelated, and experimental conditions to infer the effects of varying levels of auditory interference. The primary comparisons of interest for the study were made across conditions in which the expected responses are congruent. These comparisons were made both within and between groups. Given the manipulation of attention within of the paradigm and the theoretical basis for our comparisons (i.e., that reaction times would differ between particular pairs of conditions, depending on the level of auditory distraction), it was deemed appropriate to make these selected a priori comparisons, regardless of the results of the omnibus analysis (as per Howell, 2010). As only correct responses were included in the reaction time analyses, accuracy rates will be considered first.

**Accuracy Data**

A 2 X 5 repeated measures ANOVA was calculated with *Group* (SLI versus TLD) as the between subjects factor, *Condition* (5 levels) as the independent variable, and *Accuracy* as the dependent variable. These data did not meet the sphericity assumption, based on Mauchly's test (Mauchly's $W$ = .276, $p < .001$). To compensate for this, the Greenhouse-Geisser adjustment was applied to the degrees of freedom for the following analysis. A main effect for Condition was identified ($F$ (2.739, 76.68) = 17.99, $p$<.001, $\eta_p^{2=}$ .39). Nonsignificant effects were observed for Group ($F$ (1, 28) = 1.48, $p$ = .233, $\eta_p^{2=}$ .05) and for the interaction of Group by Condition ($F$ (2.739, 76.68) = 1.65, $p$ = .167, $\eta_p^{2=}$ .05). SLI and TLD groups performed with generally similar patterns across conditions. See Table 4 for individual mean accuracy rates per condition for all participants, as well as group means and standard deviations. Figure 2 depicts the patterns of performance for both groups.

Table 3. Individual and group mean accuracy (% correct) by condition.

| **Subject ID** | ***Baseline-Same Acc*** | ***Baseline-Diff* Acc** | ***Attend* Accuracy** | ***Ignore* Accuracy** | ***Unrelated* Accuracy** |
|---|---|---|---|---|---|
| TLD01 | 89.8 | 96.67 | 70 | 73.33 | 84.2 |
| TLD02 | 100 | 96.7 | 91.67 | 85 | 100 |
| TLD03 | 89.8 | 86.67 | 81.67 | 76.67 | 89.4 |
| TLD04 | 89.8 | 93.33 | 93.33 | 78.33 | 89.5 |
| TLD05 | 93.2 | 96.67 | 95 | 95 | 100 |
| TLD06 | 83 | 95 | 83.3 | 91.67 | 100 |
| TLD07 | 93.2 | 90 | 85 | 81.67 | 94.9 |
| TLD08 | 84.7 | 90 | 73.3 | 70 | 92.9 |
| TLD09 | 91.5 | 95 | 81.67 | 81.67 | 94.7 |
| TLD10 | 94.9 | 98.33 | 91.67 | 93.33 | 100 |
| TLD11 | 100 | 98.3 | 95 | 93.3 | 96.4 |
| TLD12 | 96.6 | 98.3 | 96.7 | 96.7 | 98.2 |
| TLD13 | 72.8 | 91.7 | 70 | 88.3 | 96.4 |
| TLD14 | 96.6 | 96.7 | 85 | 88.3 | 94.7 |
| TLD15 | 89.8 | 95 | 91.7 | 85 | 94.7 |
| **Mean** | **91.05** | **94.56** | **85.67** | **85.22** | **95.07** |
| **SD** | **7.02** | **3.53** | **9.05** | **8.19** | **4.61** |
| SLI01 | 96.6 | 96.67 | 96.67 | 95 | 96.6 |
| SLI02 | 76.3 | 90 | 80 | 58.33 | 77.9 |
| SLI03 | 96.7 | 88.3 | 68.33 | 65 | 74.7 |
| SLI04 | 94.9 | 93.33 | 93.33 | 88.33 | 92.9 |
| SLI05 | 91.5 | 90 | 93.33 | 91.67 | 94.7 |
| SLI06 | 96.6 | 96.67 | 78.33 | 81.67 | 96.5 |
| SLI07 | 98.3 | 88.33 | 95 | 93.33 | 87.7 |
| SLI08 | 94.9 | 93.33 | 96.67 | 96.67 | 96.5 |
| SLI09 | 91.5 | 96.67 | 66.67 | 70 | 89.4 |
| SLI10 | 94.9 | 93.33 | 86.67 | 50 | 78.9 |
| SLI11 | 93.2 | 91.7 | 95 | 88.3 | 98.2 |
| SLI12 | 89.8 | 83.3 | 86.7 | 70 | 94.7 |
| SLI13 | 96.6 | 96.7 | 90 | 91.7 | 100 |
| SLI14 | 89.8 | 81.67 | 85 | 71.67 | 92.9 |
| SLI15 | 79.6 | 83.3 | 66.7 | 75 | 87.7 |
| **Mean** | **92.08** | **90.89** | **85.23** | **79.11** | **90.62** |
| **SD** | **6.34** | **5.12** | **10.89** | **14.57** | **7.86** |

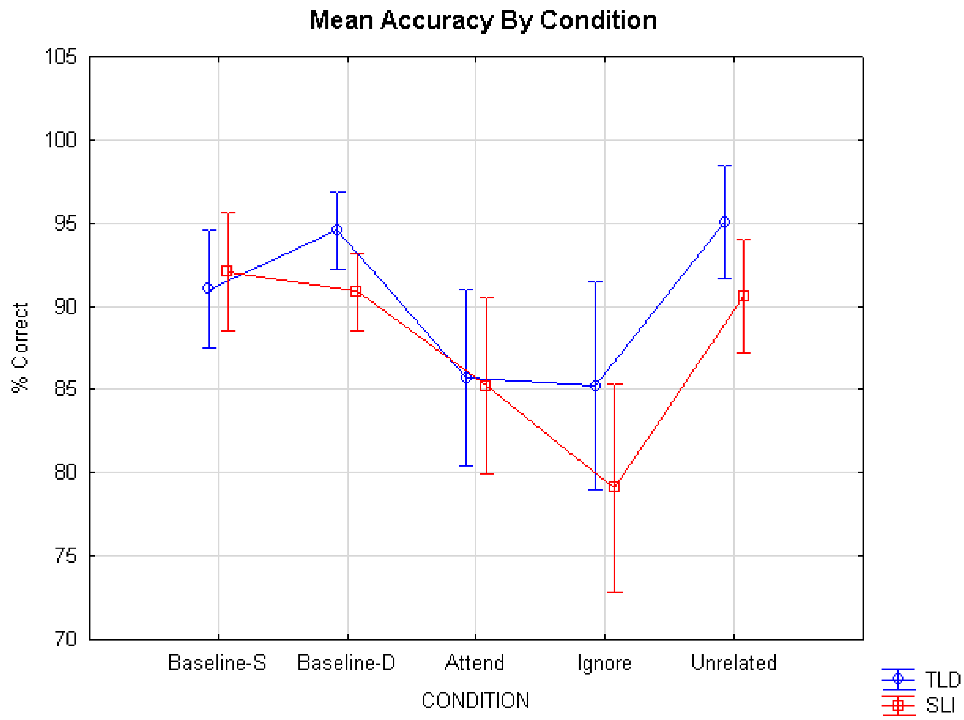


Figure 2. Mean accuracy rates (% correct responses) by condition for SLI and TLD groups.

A series of one-way ANOVAs were completed to compare mean accuracy scores between groups in each condition. It should be noted that accuracy rates approached ceiling levels (above 90%) in some conditions, thereby limiting the variance in the sample and rendering statistical analysis invalid. Comparisons in those conditions should be interpreted cautiously. See Table 3 for means and standard deviations in each condition. For the *baseline-same* condition, TLD and SLI groups performed with similar accuracy ($F\ (1,\ 28)$ = .179, $p$ = .675, $\eta_p^2$ = .006). Accuracy for the *baseline-different* condition was significantly different between groups (F (1,28) = 5.223, $p$ = .03, $\eta_p^2$ = .157). However, the ceiling effect may have been problematic here, as both groups performed with better than 90% accuracy. On the *attend* condition, the two groups demonstrated very similar accuracy rates ($F\ (1,\ 28)$ = .137, $p$ = .714, $\eta_p^2$ = .0005). In the *ignore* condition, where differences were anticipated, the SLI group showed a slight, but nonsignificant decrease in accuracy versus their TLD peers (*F (1,28)* = 2.003, *p* = .168, $\eta_p^2$ = .067). Finally, on the *unrelated* condition, the group differences were significantly different (*F (1,28)* = 3.573, *p* = .06, $\eta_p^2$ = .113); however, both groups performed with better than 90% accuracy on this condition as well, which suggests that this result may be an artifact of the ceiling effect.

Although the between group differences on each condition were not significantly different and the overall pattern of performance appeared similar between groups, we were also interested in within-group patterns of performance. The following a priori comparisons were analyzed via paired sample *t*-tests within each group. See Table 4 for means and standard deviations within each group.

Comparison 1: Baseline Same versus Baseline Different

The first comparison considered was between Accuracy in the *baseline-same* condition and in the *baseline-different* condition. Difference in performance on these two conditions might indicate greater difficulty on the lexical decision task when the visual stimulus and the auditory word were incongruous. The TLD subjects appeared to perform significantly better on baseline-different trials (*t* (14) = -2.267, *p* = .04). However, given the high accuracy rates, this result can be considered an artifact of the ceiling effect. The SLI group performed similarly on these two conditions (*t* (14) = .776, *p* = .451).

Comparison 2: Same versus Attend

Next, accuracy in the *attend* condition was compared to accuracy in the *baseline-same* condition. In the TLD group, the mean accuracy in the *baseline-same* condition was significantly better than in the *attend* condition (*t* (14) = 3.224, *p* = .006). In the SLI group, the mean accuracy in the *baseline-same* and in the *attend* condition were also significantly different ($t$ (14) = 2.656, $p$ =.019). These data indicate that the introduction of an interfering, yet non-competing stimulus, in the unattended channel resulted in reduced accuracy for both groups.

Comparison 3: Different versus Unrelated

Next, accuracy in the *baseline-different* condition was compared to the *unrelated* condition. In the TLD group, the mean accuracy in the *unrelated* condition was similar to accuracy in the *baseline different* condition ($t$ (14) = - .436, $p$ < .669). Similarly, in the SLI group, accuracy scores on the *unrelated* condition did not differ significantly from the *baseline-different* condition ($t$ (14) = .125, $p$ = .902). In this case, the results should again be interpreted with caution given the ceiling effect; however, it appears that the introduction of an interfering stimulus in the unattended channel when the response was *different* did not have an effect on accuracy in either group.

Comparison 4: Different versus Ignore

The fourth comparison was between the *baseline-different* and the *ignore* conditions. In the TLD group, the mean accuracy in the *ignore* condition was significantly reduced compared to the mean in the *baseline-different* condition ($t$ (14) = 5.56, $p$ <.001). In the SLI group, the mean in the *ignore* condition was also significantly different from the *baseline different* condition ($t$ (14) = 3.267, $p$ = .006). Therefore, in both groups, the presence of a *competing* stimulus in the unattended channel had a clear negative effect on accuracy rates.

Comparison 5: Unrelated versus Ignore

Finally, accuracy rates on the *Unrelated* condition were compared to those in the *Ignore* condition. Up to this point, we have compared accuracy rates on the experimental conditions to the baseline(s). Here, we compared accuracy on two experimental conditions to determine the unique effect of the *competing* versus *non-competing* auditory stimulus in the unattended channel on accuracy rates. Subjects with TLD appeared to perform more accurately on the trials with a non-competing stimulus (in the *unrelated* condition) than on those with a competing stimulus (in the *ignore* condition) ($t$ (14) = -7.175, $p$ < .001). However, due to ceiling effects, this result should be interpreted with some caution. SLI subjects showed a difference in accuracy rates between the *Unrelated* condition and the *Ignore* condition ($t$ (14) =4.497, $p$ = .001).

Summary of Accuracy Data

The accuracy data show that overall, the groups performed similarly on the experimental task. However, observed ceiling effects may have concealed differences between groups and between conditions or created artifact effects. There was a significant effect of Condition, indicating that for both groups, the varying degrees of auditory interference affected their accuracy rates. Although there was no significant interaction effect identified (Group X Condition), several a priori comparisons were considered to examine within-group patterns of performance. Paired-samples t-tests within each group confirmed basically similar patterns of performance. It should be noted that the differences between groups were larger when the response was *different* (e.g., in *Baseline-Different, Ignore,* and *Unrelated* conditions) than when the response was *same* (e.g., in *Baseline-Same* and *Attend* conditions). This observation may be indicative of difficulties processing and making *different* judgments in the SLI group, which could negatively affect performance in complex tasks such as the current paradigm. Examination of the reaction time data will help us to further explore this likelihood.

## Reaction Time Data

The reaction time data were first analyzed with ear of presentation as a primary factor, so that we could determine whether TLD and/or SLI subjects showed lateralized dominance (demonstrated by faster reaction times). Since the block order of presentation was counterbalanced (right ear attend vs. left ear attend) across participants, the results were also analyzed by order of presentation (left block versus right block presented first). If differences had been identified based on ear of presentation, this variable would have been entered as a covariate in subsequent analyses.

### Right Versus Left

A (2 X 5 X 2) repeated measures analysis of variance was conducted, with reaction time (RT) as the dependent variable, Condition (5) and Ear (Right/Left) as the within subjects factors, and Group (SLI/TLD) as the between subjects factor. No significant effect of Ear was detected either within or between groups ($F(1,28) = .133$, $p = .718$) and none of the interactions between Group and Ear ($F(1,28) = .017$, $p = .899$), Ear and Condition ($F(4,25) = 1.831$, $p = .154$) or Group, Ear, and Condition ($F(4,25) = 1.301$, $p = .297$) were significant.

### Order of Presentation

An additional between-subjects factor (right first vs. left first) was added to the analysis to determine the effects of order of presentation on reaction time. A total of 14 subjects were presented the right ear block first (7 TLD, 7 SLI), and 16 subjects were presented the left ear first (8 TLD, 8 SLI). No effects were identified for Order of Presentation ($F(1,26) = .020$, $p = .890$), or for the interaction of group by order of presentation ($F(1,26) = 1.108$, $p = .302$). Therefore, the following analyses utilize RT data collapsed across right and left channels.

Reaction Times by Condition

A 2 X 5 repeated measures ANOVA was calculated with *Group* (SLI versus TLD) as the between subjects factor, *Condition* as the independent variable, and *Reaction Time* (RT) as the dependent variable. The reaction time data also did not meet the sphericity assumption, based on Mauchly's Test of Sphericity (Mauchly's $W = .211$, $p < .001$), and the Greenhouse-Geisser adjustment was applied for the following analyses. Effect sizes are reported as partial-eta squared ($\eta_p^2$). In this omnibus analysis, main effects for Group ($F(1,28) = 8.334$, p = .007, $\eta_p^2 = .229$) and Condition ( $F(2.18, 61.1) = 22.167$, $p <.001$, $\eta_p^2 = .442$) were identified. The interaction of Group by Condition was not statistically significant ($F(2.18, 61.1) = 1.720$, $p = .185$, $\eta_p^2 = .058$).

Individual RTs were also viewed via scatter plot to determine whether the individuals within each group performed similarly (see Figures 3-7). Whereas there was considerable variability within each group, it is clear that there was a difference between groups overall. However, a few subjects performed differently than the rest of their group; which may have skewed the group means. For example, one subject with TLD (TLD04; S26 in the graph) was consistently slower than almost all other participants, SLI included. Review of his standardized test scores revealed results within the normal range, and nothing that would indicate an underlying reason for his slow processing. Similarly, one SLI subject (SLI10/S46) demonstrated consistently fast RTs, more in line with the TLD group.

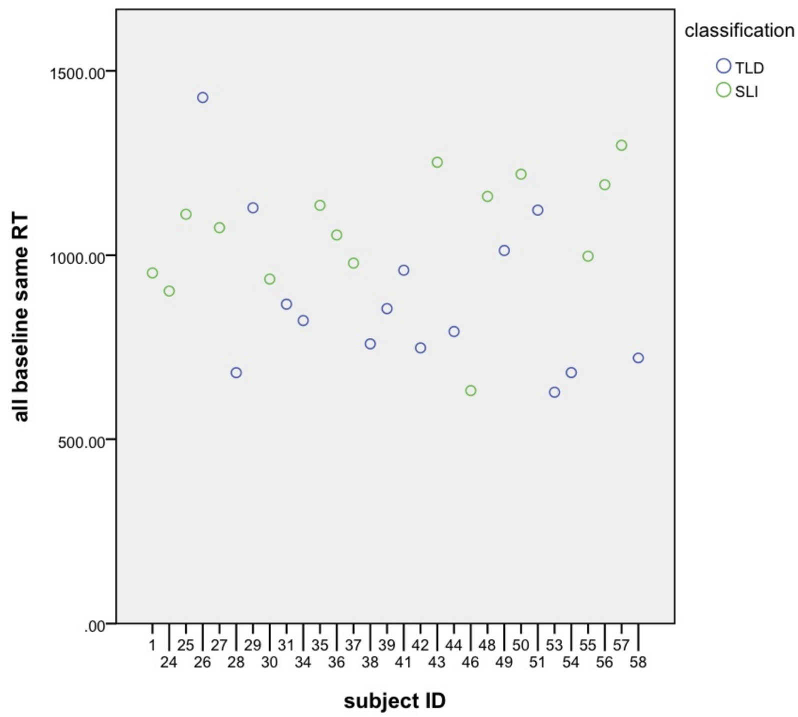


Figure 3. Individual mean RTs in the *Baseline-Same* condition.

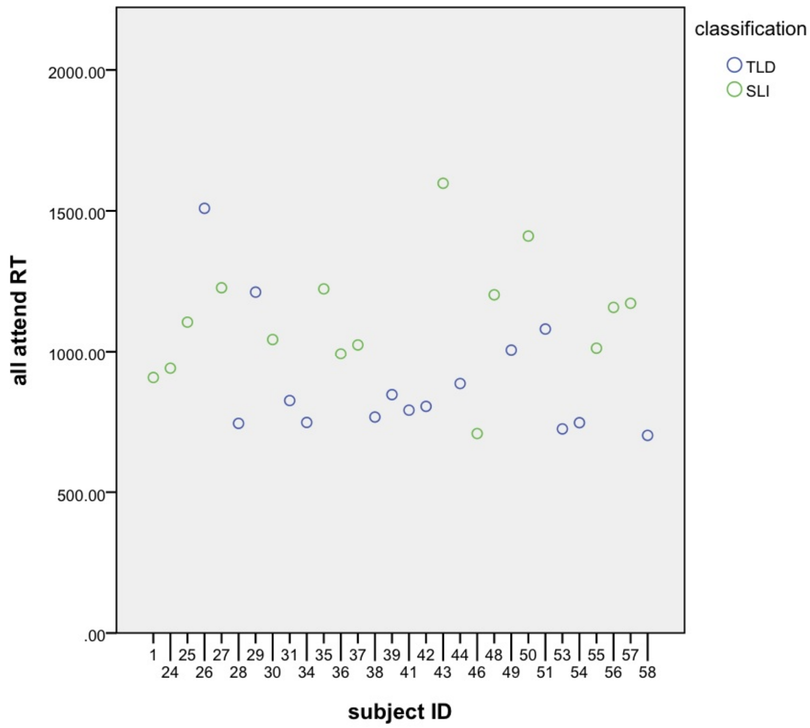


Figure 4. Individual mean RTs in the *Baseline-Different* condition.

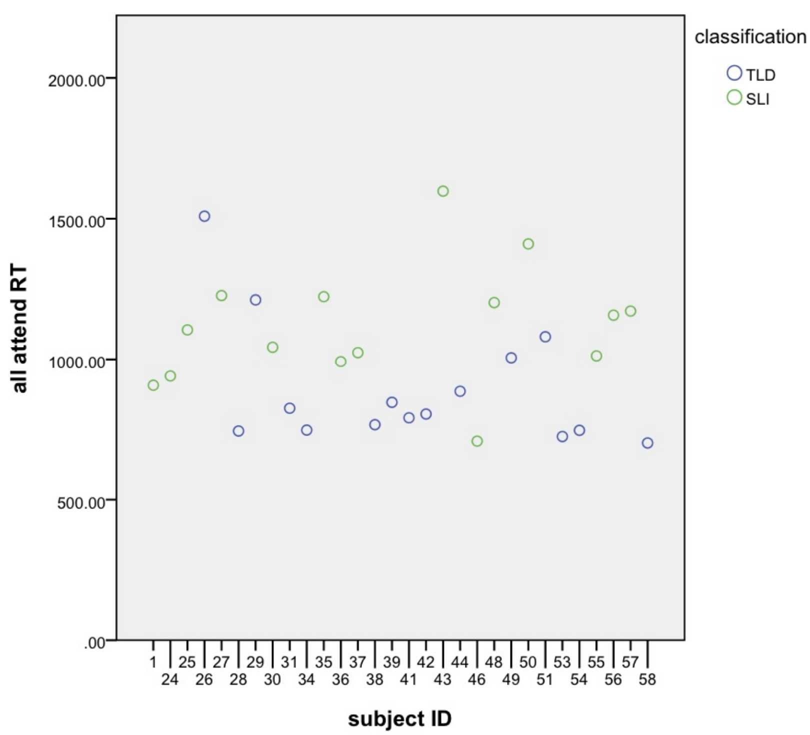


Figure 5. Individual mean RTs in the *Attend* Condition.

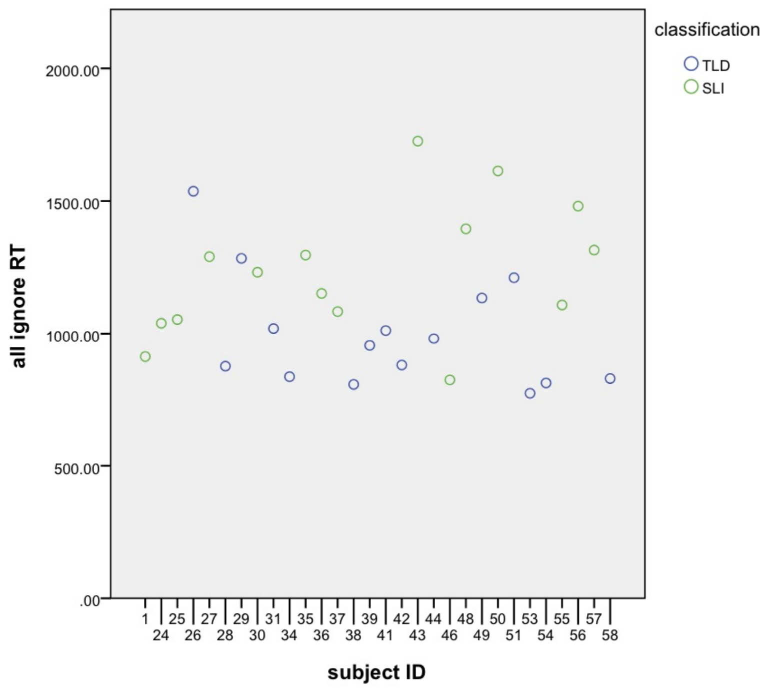


Figure 6. Individual mean RTs in the *Ignore* condition.

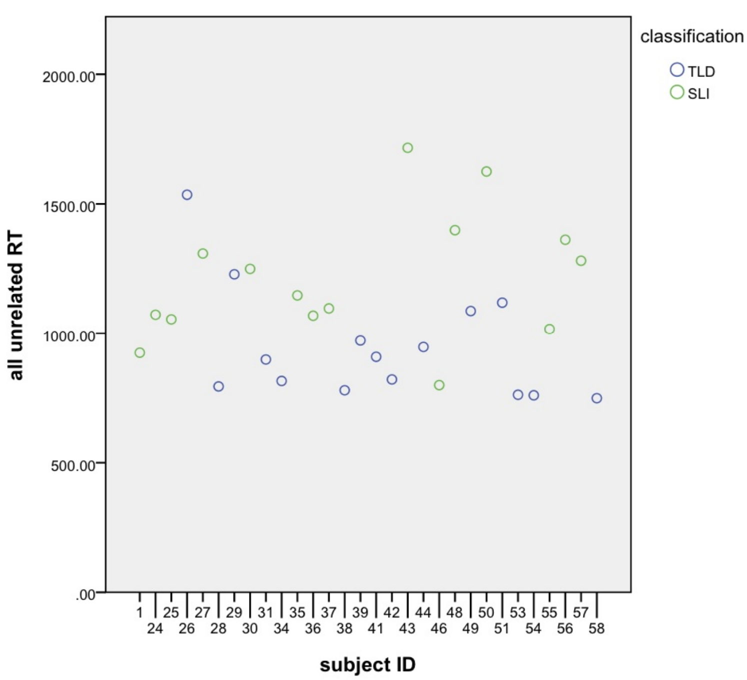


Figure 7. Individual mean RTs in the *Unrelated* condition.

The RT data were analyzed similarly to the Accuracy data. See Table 4 for individual and group mean reaction times in each condition. Following the omnibus repeated measures ANOVA described above, a series of one-way ANOVAs addressing a priori hypotheses was completed to compare mean RTs between groups in each condition. For the *Baseline* conditions, the SLI subjects were significantly slower than their TLD peers on both *baseline-same* ($F(1,28) = 6.378$, $p = .017$, $\eta_p^2 = .185$) as well as *baseline-different* trials ($F(1,28) = 7.322$, $p = .011$, $\eta_p^2 = .207$). The SLI group was also significantly slower than the TLD group on all experimental conditions: *attend* ($F(1,28) = 7.758$, $p =.009$, $\eta_p^2 = .217$); *ignore* ($F(1,28) = 7.757$, $p = .009$, $\eta_p^2 = .219$); and *unrelated* ($F(1,28) = 9.372$, $p =.005$, $\eta_p^2 = .251$). Although the overall pattern of performance appeared similar between groups, we were again interested in within-group patterns of performance, particularly given the differences identified in group patterns on the accuracy measure. Therefore, the following a priori comparisons were considered via paired-sample t-tests within each group.

Table 4. Individual and group mean RTs (in ms) by condition.

| Subject ID | ***Baseline-Same*** **RT** | ***Baseline-Diff*** **RT** | ***Attend*** **RT** | ***Ignore*** **RT** | ***Unrelated*** **RT** |
|---|---|---|---|---|---|
| TLD01 | 1427.66 | 1507.75 | 1508.96 | 1537.05 | 1535.38 |
| TLD02 | 680.24 | 812.75 | 744.04 | 875.86 | 794.20 |
| TLD03 | 1128.66 | 1329.82 | 1211.65 | 1283.98 | 1228.52 |
| TLD04 | 867.36 | 888.58 | 825.06 | 1019.36 | 898.25 |
| TLD05 | 823.03 | 841.73 | 747.32 | 836.12 | 815.33 |
| TLD06 | 759.78 | 796.08 | 766.52 | 807.03 | 779.50 |
| TLD07 | 855.96 | 913.26 | 846.16 | 954.43 | 979.04 |
| TLD08 | 959.40 | 1025.63 | 790.96 | 1011.99 | 912.25 |
| TLD09 | 748.81 | 816.39 | 804.42 | 880.32 | 821.20 |
| TLD10 | 793.18 | 861.75 | 885.55 | 980.91 | 946.84 |
| TLD11 | 1012.84 | 1111.06 | 1005.80 | 1134.54 | 1086.71 |
| TLD12 | 1122.28 | 1028.66 | 1080.57 | 1211.13 | 1116.14 |

| | | | | | |
|---|---|---|---|---|---|
| TLD13 | 627.31 | 675.59 | 724.46 | 773.59 | 776.18 |
| TLD14 | 680.51 | 706.55 | 746.45 | 812.48 | 759.83 |
| TLD15 | 720.86 | 783.17 | 701.44 | 829.17 | 748.91 |
| **Mean** | **880.53** | **939.92** | **892.62** | **996.53** | **946.55** |
| **SD** | **216.54** | **229.76** | **223.60** | **214.47** | **218.14** |
| SLI01 | 951.99 | 987.35 | 906.90 | 912.20 | 925.48 |
| SLI02 | 902.98 | 1081.86 | 939.94 | 1039.42 | 1071.84 |
| SLI03 | 1111.09 | 1202.75 | 1105.11 | 1053.39 | 1054.55 |
| SLI04 | 1074.35 | 1065.10 | 1227.05 | 1290.47 | 1308.69 |
| SLI05 | 941.67 | 1083.13 | 1043.31 | 1231.66 | 1249.49 |
| SLI06 | 1135.37 | 1131.90 | 1223.05 | 1296.60 | 1136.66 |
| SLI07 | 1054.86 | 1096.08 | 991.87 | 1151.74 | 1069.11 |
| SLI08 | 978.66 | 1041.87 | 1024.15 | 1083.47 | 1102.64 |
| SLI09 | 1252.10 | 1390.69 | 1597.89 | 1725.73 | 1719.72 |
| SLI10 | 631.72 | 740.74 | 708.00 | 824.11 | 799.38 |
| SLI11 | 1146.92 | 1259.63 | 1202.06 | 1395.34 | 1398.73 |
| SLI12 | 1219.71 | 1273.53 | 1410.46 | 1613.67 | 1625.05 |
| SLI13 | 997.44 | 1098.83 | 1012.64 | 1108.35 | 1016.82 |
| SLI14 | 1191.20 | 1395.30 | 1157.43 | 1480.85 | 1363.36 |
| SLI15 | 1298.10 | 1208.93 | 1171.99 | 1315.20 | 1298.58 |
| **Mean** | **1059.21** | **1137.18** | **1114.79** | **1234.81** | **1209.34** |
| **SD** | **168.32** | **164.10** | **213.15** | **249.84** | **250.32** |

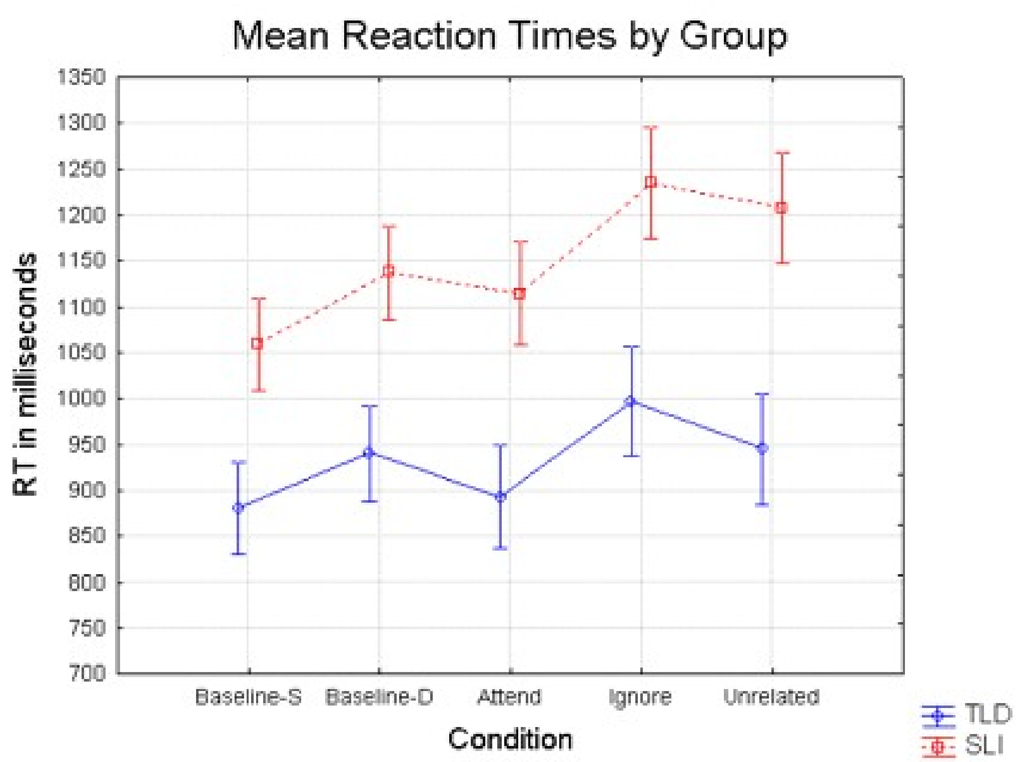


Figure 8. Reaction time (ms) by condition for SLI and TLD groups.

<u>Comparison 1: Baseline Same versus Different</u>

The first comparison was between RTs in the *baseline-same* condition and RTs in the *baseline-different* condition. Although these conditions involved a difference in response types (*same* vs. *different*) and potential cross-modal priming effects (picture matches auditory stimulus versus a neutral, unrelated picture), this comparison is of value in quantifying the difference in RT between *same* and *different* responses. Additionally, significantly faster RTs in the *baseline same* condition might reflect said cross-modal identity priming. It was predicted that these effects would be consistent across groups.

In the TLD group, the difference between mean RTs in the *baseline-same* condition and in the *baseline-different* condition was statistically significant ($t(14) = -3.641$, $p = .003$). The same pattern was observed in the SLI group, albeit with slower RTs overall ($t(14) = -3.925$, $p = .002$). These results indicate that all the children in the study responded somewhat faster when the response mode was *same* versus when it was *different*. It is not clear whether this result can be attributed to a speeded response due to cross-modal priming, or due to a slowed response due to the response modality (*different* versus *same*). Interestingly, although the SLI group reacted more slowly overall, proportionally, the groups performed the same (proportion of same to different RT = .93 in both groups). This would seem to indicate that, although the SLI group was slower to process the cross-modal stimuli and to make a lexical decision, they did not show evidence of decreased cross-modal priming, nor were their RTs affected disproportionately when making a *different* decision.

Comparison 2: Same versus Attend

Next, RTs in the *attend* condition were compared to RTs in the *baseline-same* condition. Here, responses in the *baseline-same* condition were thought to reflect straightforward cross-modal identity priming, in which the auditory word facilitated the child's ability to make a decision (*same*) about the picture. Responses in the *attend* condition should also be *same*. Comparing these two conditions determined the degree to which a to-be-ignored stimulus impedes cross-modal identity priming. In both cases, upon perceiving the auditory word in the attended ear, its representation in the mental lexicon should be activated so that the visual stimulus can be recognized and categorized rapidly. Slower RTs in the experimental (*attend)* condition would be indicative of inhibitory processing of the unattended signal.

In the TLD group, the mean RTs in these conditions were similar ($t(14) = -.624$, $p = .543$). In the SLI group, the mean difference appeared slightly larger; this difference that approached but did not reach statistical significance ($t(14) = -1.865$, $p = .083$). In considering the proportional differences in RTs, the TLD subjects performed similarly on these two conditions (.98) whereas the proportional RTs for SLI (attend: baseline) was .95.

Comparison 3: Different versus Unrelated

RTs in the *baseline-different* condition were then compared to those in the *unrelated* condition. Responses in each of these conditions should be *different*, where a subject must disconfirm a relationship between the attended auditory word and the visual stimulus. The *unrelated* condition can be thought of as another baseline, in that the visual stimulus was neutral in relation to the auditory stimuli. However, as opposed to the *baseline-different* condition in which both auditory words are the same, in the *unrelated* condition there was an interfering stimulus present in the unattended channel. The difference in RT between these two conditions reflects the degree to which this interference affects a child's ability to make this decision. Again, a slight inhibitory effect was predicted for the TLD groups, with a larger effect (reflecting more interference) for the SLI group. In the TLD group the difference between mean RTs in these two conditions was not statistically significant ($t(14) = -.397$, $p = .697$). The difference between these means was not statistically significant for the SLI group either ($t(14) = -1.879$ $p = .081$). Although this result did not reach statistical significance, it is interesting to note the difference in strength of the result between the two groups (e.g., the difference between RTs for the TLD group was clearly not significant, whereas the difference for the SLI group was trending toward significance). Again, the proportional difference in response times (.994 TLD versus .944 SLI) indicates some slight differences in performance. These proportions point out that thus far, the TLD group has essentially performed the same (ratio > .98) in the experimental conditions (attend and unrelated) when compared to the baseline conditions. Conversely, the SLI group has showed some slowing (ratios < .95) in the experimental conditions, indicating some level of interference from the unattended channel.

<u>Comparison 4: Different versus Ignore</u>

The fourth comparison was between the *baseline-different* and the *ignore* conditions. Recall that in the *ignore* condition, the auditory stimulus in the to-be-ignored channel actually matched the visual stimulus. The correct response in this condition was "different," because the picture did not match the attended auditory stimulus. However, we predicted that the unattended signal would undergo some initial processing, activating the lexical unit that does match the visual stimulus. The subject therefore was required to actively inhibit the activation of this stimulus in order to make the correct decision. This comparison should reveal the degree to which a *competing* stimulus in the to-be-ignored channel impacts baseline reaction time.

In both groups, RTs were slowest in the *ignore* condition. The comparison between these conditions was also significant in both groups ($t(14) = -3.561$, $p = .003$ and $t(14) = -2.739$, $p = .016$ for TLD and SLI groups respectively). The RT ratios were similar in this condition, at .944 for TLD subjects, and .922 for the SLI group.

Comparison 5: Unrelated versus Ignore

Finally, and most critically, RTs in the *ignore* condition were compared to the *unrelated* condition. Although both conditions involved interfering stimuli, the irrelevant stimulus in the *ignore* condition should have required greater inhibition than the *unrelated* condition because its activation was strengthened by the matching visual stimulus. The difference in RTs between these two conditions should reflect the unique effects of this inhibitory process when compared to a condition in which an interfering, but non-competing stimulus is present. In the TLD group, the mean difference in RTs was statistically significant ($t(14) = 4.687$, $p < .001$). However, the pattern differed here for the SLI group. The difference between RTs in the *ignore* condition the *unrelated* condition was *not* significant ($t(14) = 1.682$, $p = .115$). This is a critical finding; a *larger* difference for the SLI group would have indicated *slower* inhibitory processing; however it appears that SLI subjects responded more slowly in all of the experimental conditions, regardless of the *type* of auditory/lexical interference (competing or unrelated).

Summary of Reaction Time Data

The reaction time data show that despite similar behavioral accuracy rates, the subjects with SLI responded more slowly on the experimental task. There was also a main effect of Condition identified for both groups, indicating that the manipulation of interference in the unattended channel did have an effect on processing time. Although there was not a significant interaction effect identified (Group X Condition) in the initial analysis, several a priori comparisons were considered to examine within-group patterns of performance. The main difference that was identified via these analyses was in the comparison of RTs in the *unrelated* and the *ignore* conditions. Slower RT in the *ignore* condition is thought to be indicative of active inhibitory processing in the unattended channel. That is, when the stimulus in the unattended channel matches the visual stimulus, it would take longer to respond *different* because the child would have to actively inhibit the cross-modal activation. Conversely, in the *unrelated* condition, this cross-modal activation would not be taking place as the unattended auditory word bore no relationship to the visual stimulus. In fact, children with TLD demonstrated this pattern, with a significant difference observed. Children with SLI however, did not show a difference in reaction time on the two conditions.

## Supplementary Task Results

Dichotic Listening

A dichotic listening task was administered to determine whether subjects presented with a right- or left-ear dominance for auditory processing, separate from the experimental task. The data are presented as a ratio of right-to-left ear responses. Figures greater than 1 indicate a right-ear preference, whereas figures less than 1 would indicate a left-ear advantage. Both TLD and SLI subjects demonstrated a right-ear advantage on this task, with mean ratios of 3.2 (*SD* = 4.7) and 2.0 (*SD* = 1.5), respectively. Both groups also demonstrated a fair amount of variation. The difference between groups on this measure was not significant ($F(1,28) = .902$, $p = .350$). Therefore, we can be reasonably certain that neither group showed any advantage in auditory processing based on ear of presentation.

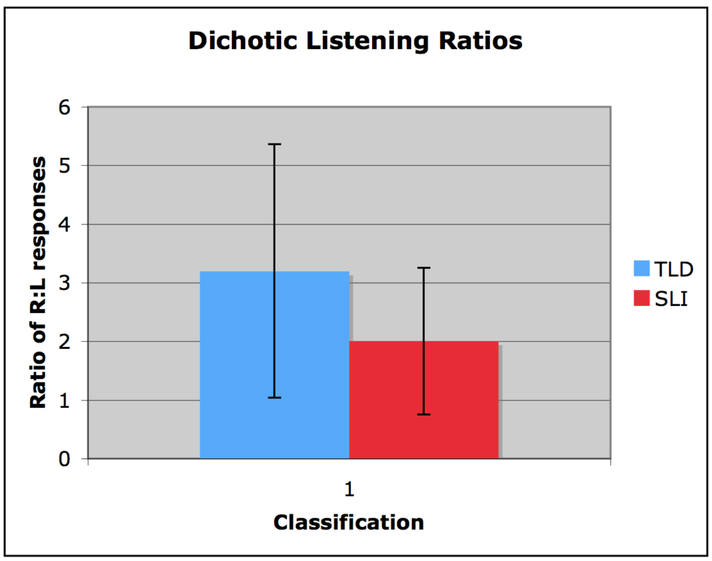


Figure 9. Dichotic Listening Ratios by group (ratio of Right to Left responses in free recall).

In addition to the ear-advantage ratio, the number of errors was recorded and analyzed. Errors were defined as missed responses, unrelated responses (where the participant's response did not resemble either auditory word), or blended responses (where the participant blended the two stimuli, as in *pet* when presented with the pair *pen* and *cat*). Subjects with SLI demonstrated significantly more errors on this task than their TLD peers ($F(1, 28) = 8.746$, $p = .006$). Out of 40 possible responses, TLD subjects, on average, made less than one error each ($M = .87$, $SD = 1.302$), whereas SLI subjects made a mean of 2.47 errors each (*SD* =1.642). These results imply that although a basic ear-advantage did not play a role in performance on the experimental task, it is possible that children with SLI had some deficit in binaural segmentation, which may have contributed to performance deficits.

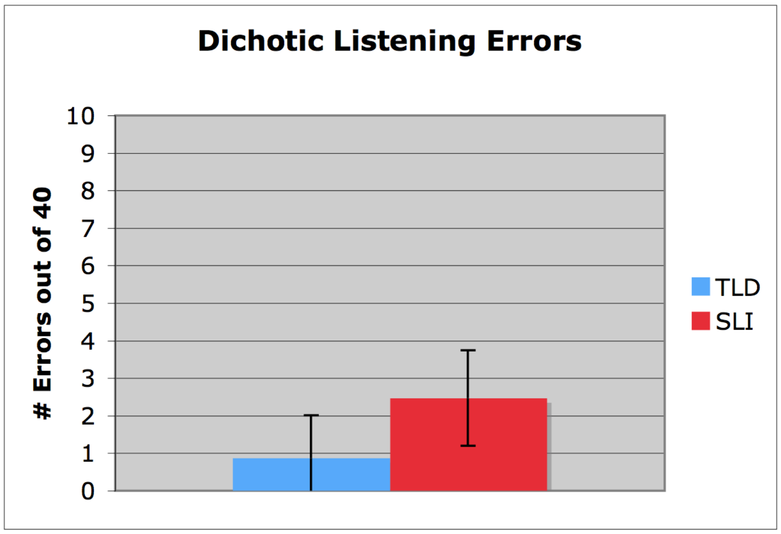


Figure 10. Error rates by group on the dichotic listening task.

<u>Working Memory: List Recall</u>

Participants completed the List Recall task (Marton & Schwartz, 2003) as a measure of complex verbal working memory. During this task, children were required to listen to sets of sentences (five sentences per set), and recall and reproduce the sentence-final word of each group of five. There were nine sets of sentences, comprised of three sets each of syntactically simple, syntactically complex short, and syntactically complex long sentences. Although this task could be scored in multiple ways (see Marton & Schwartz, 2003), the most lenient criteria were used here, where the number of words recalled for each set was tallied and a percentage correct was calculated. The sequence of the children's responses was not taken into consideration. A 2 X 3 (Group X Sentence

Type) Repeated Measures ANOVA was completed to examine performance both between and within groups. These data did not meet the sphericity assumption (Mauchly's $W = .784$, $p = .037$); subsequently, the Greenhouse-Geisser adjustment was applied to the degrees of freedom for the following comparisons. There was a main effect of Group ($F(1,28) = 40.50$, $p < .001$, $\eta_p^2 = .591$) indicating that children with SLI performed more poorly than their TLD peers on the task in general. Nonsignificant effects were observed for Sentence Type ($F(1.644, 56) = 2.787$, $p = .082$, $\eta_p^2 = .091$) and for the interaction of Group by Sentence Type ($F(1.644, 56) = 2.564$, $p = .098$, $\eta_p^2 = .084$). Although the interaction term was not statistically significant, differences in accuracy rates between groups on each sentence type were examined. Differences between groups were significant on each of the three sentence types, with the largest difference apparent on short, syntactically complex sentence sets ($F(1,28) = 35.19$, $p < .001$, $\eta_p^2 = .557$). The patterns of performance also differed between groups; TLD subjects were affected primarily by sentence length; they performed similarly on short/simple and short/complex items (*M* = 82.2 and 83.2% correct, respectively) but significantly worse on the long/complex sentences (*M* = 74.3% correct). SLI subjects, on the other hand, demonstrated reduced performance on syntactically complex sentences regardless of length (*M* = 53.33% for short/complex sentences; *M* = 57.03% for long/complex), as compared to syntactically simple sentences (*M* = 63.23% correct). These results indicate that children with SLI showed decreased working memory capacity overall, and that they were differentially affected by increasing processing load (by increasing syntactic complexity), whereas children with TLD were affected primarily by increased memory load (by increasing length).

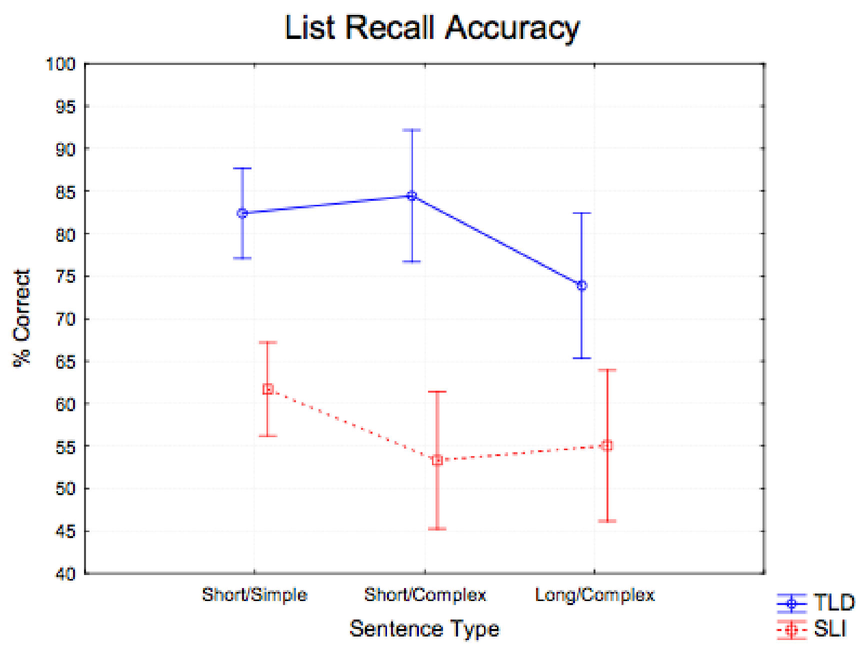


Figure 11. Accuracy (% Correct) by group on the List Recall task.

<u>Visuo-Spatial Executive Function: Children's Color Trails Task</u>

A series of one-way ANOVAs were completed to analyze each groups' performance on three measures: CCTT-1 Speed (RT), CCTT-2 Speed, and the difference between RT on the first and second forms of the test (CCTT 2-1). The difference score is thought to represent the amount of additional processing time required to exert executive control over the more cognitively demanding aspects of the second form (alternating between colors and numbers/attention shifting). Results indicated that children with SLI were slower than their peers on Form 1 ($F(1, 28) = 5.171$, $p$=.031, $\eta_p^2$ =.156) and on Form 2 ($F(1,28) = 6.833$, $p$=.014, $\eta_p^2$ = .196). However, the difference between groups on the third measure (CCTT 2-1) was not significant ($F(1,28) = 1.336$, $p$=.258, $\eta_p^2$ =.046). This result indicates that although subjects with SLI were generally slower on this measure, they did not show additional slowing that could be attributed to the executive control aspect of the task.

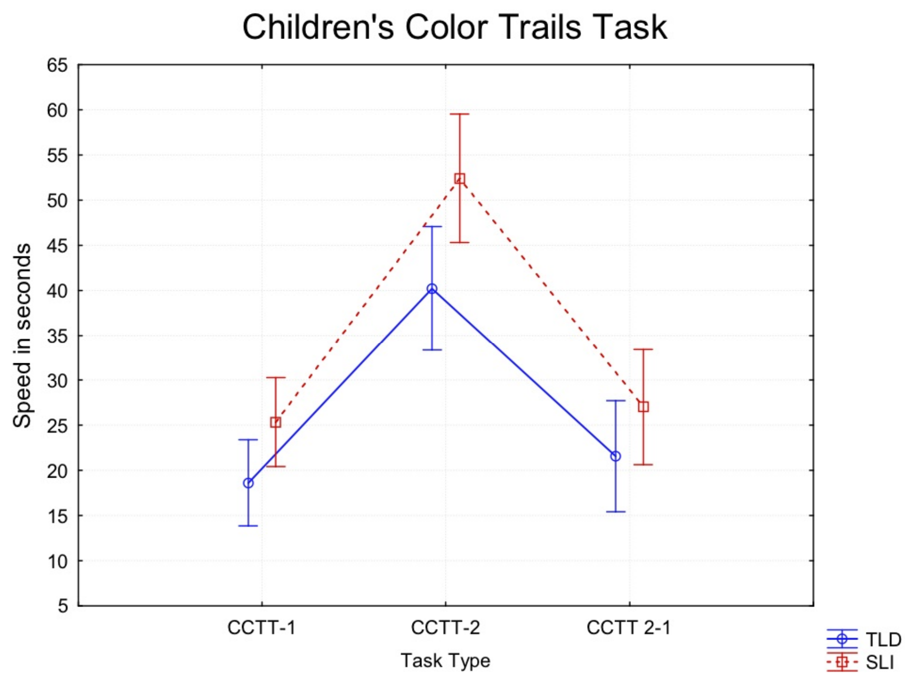


Figure 12. Speed (in seconds) on the CCTT-1 (Form 1), CCTT-2 (Form 2), and CCTT 2-1 (difference in time between Forms 2 and 1).

Correlation and Regression Analyses

Given the differences identified between groups on both standardized measures of language function and on the supplementary tasks, a multiple regression analysis was conducted to infer the relative contribution of various underlying processes to the variance observed on the experimental task. However, given the large number of predictive variables (e.g., multiple levels of each supplementary task and standardized test scores) and the relatively low number of subjects, analysis via regression model would be problematic. Therefore, it was necessary to first determine which variables were most likely to be related to performance on the experimental task. This was accomplished by first examining correlations and then entering only those variables that were significantly correlated into the regression analysis. See Tables 5 and 6 for Pearson's *r*-values and significance levels.

Correlations were examined between performance on the selective attention task and performance on the dichotic listening, List Recall, and Color Trails tasks. These analyses provided some information about the relative contributions of underlying processing skills (e.g., hemispheric lateralization, cognitive control processes, and working memory, respectively) to performance on the experimental task. Since accuracy rates did not differ between groups, only the reaction time data for the experimental task were considered here.

Table 5. Correlation matrix of supplemental task performance with experimental task RT. Pearson's *r* and significance level (*p*) are reported in each cell; statistically significant results are denoted in bold and with (*).

| Condition | **DL Errors** | **List Recall1** | **List Recall2** | **List Recall3** | **CCTT-1** | **CCTT-2** | **CCTT-2-1** |
|---|---|---|---|---|---|---|---|
| **Baseline-S** | .219<br>.244 | -.202<br>.284 | -.324<br>.081 | **-.374<br>.042*** | .319<br>.086 | .228<br>.226 | .015<br>.937 |
| **Baseline-D** | .091<br>.632 | -.280<br>.134 | **-.439<br>.015*** | **-.409<br>.025*** | **.388<br>.034*** | .350<br>.058 | .106<br>.575 |
| **Attend** | .125<br>.511 | -.226<br>.229 | **-.377<br>.040*** | -.338<br>.068 | .344<br>.062 | .241<br>.199 | .010<br>.956 |
| **Ignore** | .130<br>.494 | -.233<br>.215 | **-.387<br>.035*** | **-.412<br>.024*** | **.374<br>.042*** | .219<br>.246 | -.041<br>.829 |
| **Unrelated** | .092<br>.631 | -.268<br>.152 | **-.426<br>.019*** | **-.398<br>.029*** | **.372<br>.043*** | .262<br>.162 | .013<br>.947 |

Note: DL Errors= errors on the dichotic listening task; List Recall1 = short, simple sentence type on the List Recall measure; List Recall2 = short, complex sentence type on the List Recall measure; List Recall3 = long, complex sentence type on the List Recall Measure; CCTT-1 = Form 1 on the Children's Color Trail Task; CCTT-2 = Form 2 on the Children's Color Trails Task; CCTT 2-1 = Difference between Forms 2 and 1 on the Children's Color Trails Task.

The dichotic listening ratio (i.e., ratio of right-to-left responses in a free recall procedure) did not differ between groups, so this variable was not entered into the analysis. The number of errors on the dichotic listening task did however differ between groups, with a greater number of errors (e.g., missed, unrelated, or blended responses) possibly indicative of difficulties with binaural separation skills. Pearson's correlations however, showed that this factor was not significantly correlated with performance on any of the experimental conditions. Therefore, differences in RT on the experimental task cannot be attributed to underlying difficulties in dichotic listening abilities.

Correlations between performance on the List Recall task with performance on the experimental task conditions were then examined. Recall that there were three levels of complexity on this task, dependent upon sentence type (short/simple, short/syntactically complex, long/complex). Accuracy rates on the short/simple sentence types were not correlated with performance on any of the experimental task conditions. Accuracy rates for short/syntactically complex sentence types were significantly correlated with performance on *baseline-different* ($r$ = -.439, $p$ = .015), *attend* ($r$ = -.377, $p$ = .04), *ignore* ($r$ = -.387, p = .035), and *unrelated* ($r$ = -.426, $p$ = .019) trials. These negative correlations suggest that lower accuracy rates on the List Recall task were associated with higher (slower) RTs in these conditions. Accuracy rates for long/syntactically complex sentence types were also negatively correlated with performance on the experimental task, for *baseline-same* ($r$ =.374, $p$ =.042) , *baseline-different* ($r$ = - .409, $p$ = .025), *ignore* ($r$ = - .412, $p$ = .024) and *unrelated* ($r$ = -.398, $p$ = .029) trials. The correlation with *attend* trials approached, but did not meet, statistical significance ($r$ = -*.338, p* = .068). These results indicate that limitations in verbal working memory were associated with limitations in auditory selective attention. This is not surprising, given the close relationship of working memory and executive control in many language processing models. It should be noted that the moderate level of these correlations suggest that although there appears to be a relationship between complex verbal working memory skills and performance on the experimental task, differences between groups should not be attributed *primarily* to this limitation.

Reaction time on the Color Trails Task was then correlated with RTs on the experimental task. Correlations between these tasks would suggest that a common mechanism underlies processing speed on both the visuo-spatial and the auditory tasks. Of the three levels of the Color Trails Task that were measured (speed on Form 1, Form 2, and the difference between the two (Form 2 – 1)), the only significant correlations were between speed on Form 1, and some, but not all of the experimental conditions. CCTT-1 speed was moderately correlated with RTs on the *baseline-different* ($r$ = .388, $p$ = .038), *ignore* ($r$ = .374, $p$ = .042) and *unrelated* conditions ($r$ = .372, $p$ = .043).

Correlations between performance on the experimental task and standardized test scores were also analyzed (See Table 7). Examining correlations between task performance and composite language scores helped to determine whether deficits in selective attention relate directly to language deficits. Total language scores were negatively correlated with RTs on the *baseline-different* ($r$ = -.385, $p$ = .036) and *unrelated* ($r$ = -.356, $p$ = .054) conditions, indicating that lower total language scores were associated with higher (slower) RTs on these conditions. Receptive language composite scores were more closely associated with performance on the experimental task; they were negatively correlated with the *ignore* (*r* = - .366, *p* = .047) and *unrelated* conditions (*r* = -.402, *p* = .028). Conversely, expressive language composite scores were correlated only with the *baseline-different* responses (*r* = -.365, *p* = .047). These negative correlations show that lower composite scores were also associated with slower RTs.

Table 7. Correlation matrix of standardized test scores with experimental RTs. Pearson's *r* and significance level (*p*) reported in each cell; statistically significant results are denoted in bold and with (*).

| Condition | **CELF-Total** | **CELF-Receptive** | **CELF-Expressive** | **TONI-3** | **CRS-R** |
|---|---|---|---|---|---|
| **Baseline-S** | -.294<br>.114 | -.235<br>.210 | -.289<br>.121 | -.331<br>.074 | .283<br>.240 |
| **Baseline-D** | **-.385**<br>**.036*** | .332<br>.073 | **-.365**<br>**.047*** | **-.443**<br>**.014*** | **.464**<br>**.046*** |
| **Attend** | -.301<br>.106 | -.322<br>.082 | -.256<br>.173 | **-.410**<br>**.024*** | .373<br>.115 |
| **Ignore** | -.322<br>.083 | **-.366**<br>**.047*** | -.272<br>.145 | **-.401**<br>**.028*** | .399<br>.090 |
| **Unrelated** | **-.356**<br>**.054*** | **-.402**<br>**.028*** | -.291<br>.119 | **-.393**<br>**.032*** | .423<br>.071 |

Note: CELF-Total = Total Language Score on the *Clinical Evaluation of Language Fundamentals;* CELF-Receptive = Receptive Language composite on the *Clinical Evaluation of Language Fundamentals;* CELF-Expressive= Expressive Language Composite score on the *Clinical Evaluation of Language Fundamentals;* TONI-3= *Test of Nonverbal Intelligence, 3rd Edition;* CRS-R = *Conners' Rating Scale- Revised.*

Scores on the nonverbal cognition measure (*TONI-3*) were significantly correlated with performance on the experimental tasks, in all conditions except *baseline-same.* Negative correlations between the TONI-3 and *baseline-different* (*r* = -.443, *p* =.014), *attend* (*r* = -.410, *p* = .024)*, ignore* (*r* = -.401, *p* = .028)*, and unrelated* (*r* = .-.393, *p* = .032) trials indicates that cognitive skills were implicated in performance on the task.

Finally, scores on the *Conner's (CRS-R*) were analyzed for their correlation to performance on the experimental tasks. It should be noted that we were missing data on this measure for 10 of the 30 participants, most of whom were members of the TLD group. Similar to the findings for Total Language Scores, *CRS-R* scaled scores were correlated only with RTs on the *baseline-different* condition ($r$ = .464, $p$ = .046). That is, increased scores on the *CRS-R* ADHD Index were associated with slower RTs in that condition only. This implies that the attention deficits characteristic of ADHD may not be the same attention deficits that contribute to limitations in *executive control* of attention and language processing.

Given these results, the variables entered into the following regression models included *TONI-3* scores, *CELF*-Receptive language scores (*CELF-R*), List Recall-2 scores (*LR2*; short/complex sentence type), and *CCTT-1* scores (basic form). Separate analyses were conducted for each of the three experimental conditions of the reaction time task (*Attend, Ignore, Unrelated).*

First, RT in the *Attend* condition for all 30 participants was entered into a multiple linear regression model as the dependent variable, with TONI-3, CELF-R, LR2, and CCTT1 as the independent or predictor variables. This model resulted in an adjusted $R^2$ value of .123 ($F$(4,25) = 2.02, $p$ = .12), indicating that only 12% of the variance in RT in the *Attend* condition could be accounted for by this model. None of the independent variables entered significantly predicted RT in this model; TONI scores came the closest with a $b$ value of -.25 ($t$(25) = -1.24, $p$ = .22), yet this variable was not a statistically significant predictor of performance on this condition. See Figure 13.

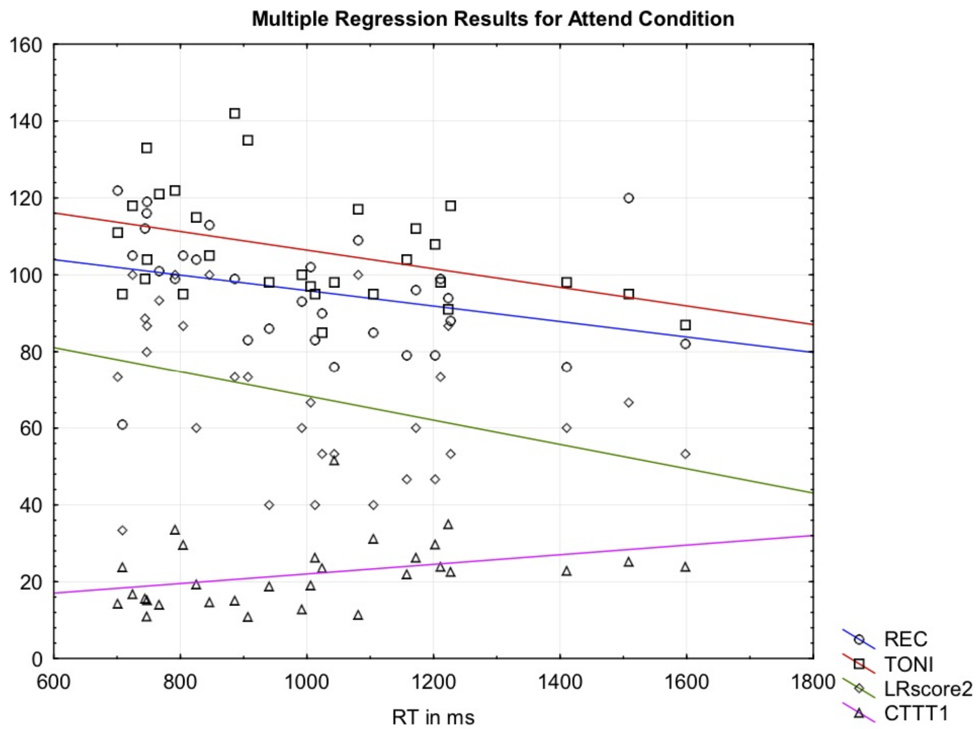


Figure 13. Scatterplot of the multiple linear regression analysis predicting RTs in the *Attend* condition.

The second model utilized the same predictor variables with RT in the *Ignore* condition as the dependent measure. In this case, the model accounted for 14% of the variance in RT (Adjusted $R^2$ = .141, $F$(4,25) = 2.19, $p$ = .099). This model overall is not statistically significant; nor did any of the individual predictor variables reach statistical significance. See Figure 14.

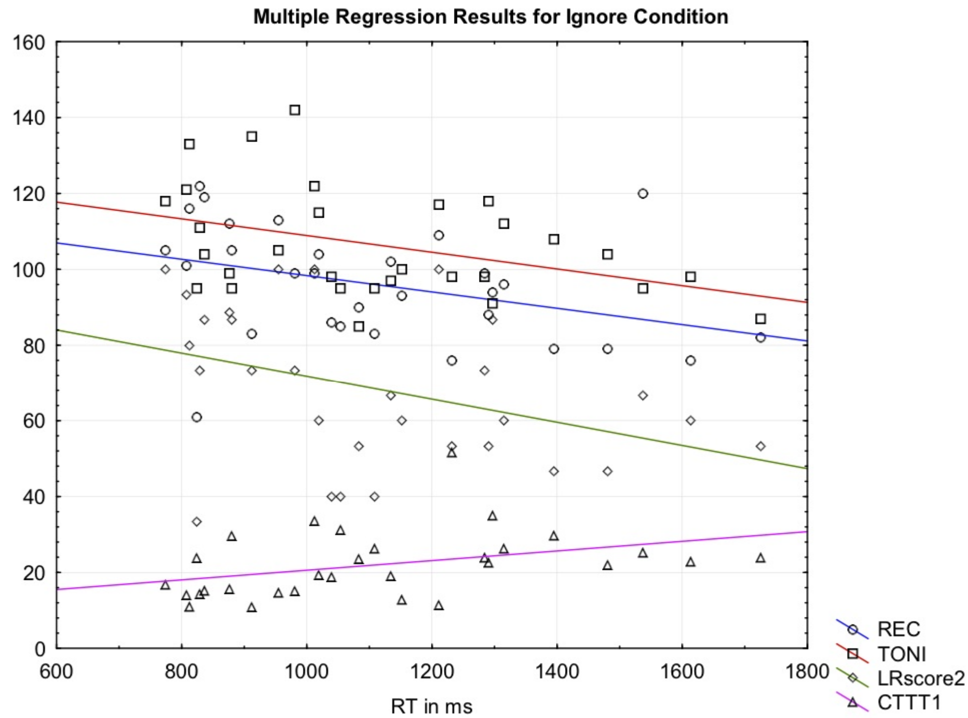


Figure 14. Scatterplot of the multiple linear regression analysis predicting RTs in the *Ignore* condition.

Finally, the same model was run with RT in the *Unrelated* condition as the dependent variable. The model accounted for slightly more of the variance in RTs in this condition (Adjusted $R^2$ = .16, and the model approached statistical significance ($F$ (4,25) = 2.38, $p$ = .078). However, none of the independent variables individually predicted RT (See Figure 15).

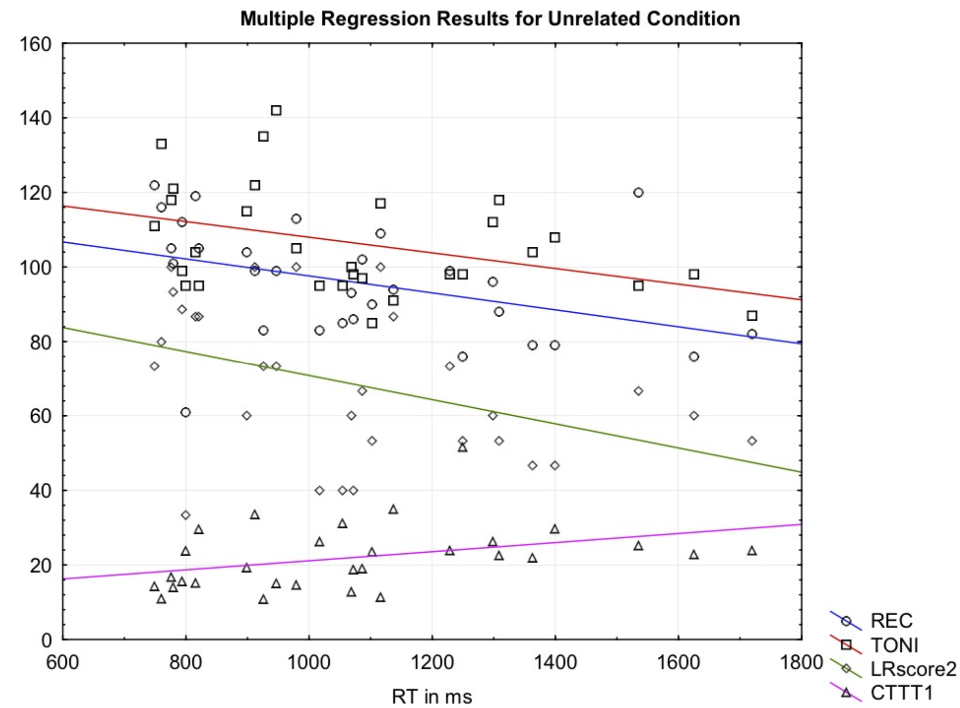


Figure 15. Scatterplot of the multiple linear regression analysis predicting RTs in the *Unrelated* condition.

**Summary of Results**

SLI and TLD groups performed with similar accuracy rates on the experimental task, and SLI subjects presented with slower reaction times overall. A main effect of Condition was identified for both groups. Within group patterns differed mainly in the comparison of the *unrelated* and the *ignore* conditions. Children with TLD demonstrated the expected pattern, with slower RTs in the *ignore* condition indicative of active inhibitory processing. Children with SLI however, did not show a difference in reaction time on the two conditions, indicating that they processed competing and non-competing stimuli in the unattended channel similarly.

Analysis of performance on the supplementary tasks indicated that both TLD and SLI subjects had a slight right ear advantage. Performance on the free-recall dichotic listening task was not correlated with experimental task performance. Children with SLI demonstrated decreased accuracy for all sentence types on the List Recall Task; analysis of within group patterns showed that children with SLI were disproportionately affected by syntactic complexity (processing load), whereas children with TLD were affected primarily by sentence length (memory load). Negative correlations with experimental conditions suggested that limitations in verbal working memory (lower LR scores) were associated with limitations in auditory selective attention (higher/slower RTs). A lack of correlation between the short/simple sentence condition and experimental task performance however may indicate that the *complexity* of the verbal working memory skills required for the LR task was related to selective attention abilities, as opposed to simple working memory capacity. Significant negative correlations were also identified between receptive language scores on the *CELF, TONI-3* scores, and experimental RTs. Correlations between *Conner's Rating Scale* scores and most experimental conditions were not significant. These results provide some direction regarding the underlying skills required for the selective attention task; as complex working memory, nonverbal cognition, and language comprehension skills were all significantly correlated with task performance, whereas behavioral attention ratings were not.

However, upon further analysis using a multiple linear regression model, even those variables that were most correlated with performance on the experimental task were *not* found to be significant predictors of RT. Regression models revealed that only a small percentage of the variance (12-16%) in RT on the experimental conditions (*Attend,* *Ignore, Unrelated)* could be explained by the predictor models. These results suggest that the predictor variables may not have sufficiently isolated the intended underlying constructs, or, that additional, unidentified factors contributed more significantly to the variance.

# Chapter 4: Discussion

This study examined auditory selective attention and associated cognitive control processes in children with SLI and their peers with TLD. The focus of the study was to explore and elucidate the relationship between auditory selective attention and language processing in children with SLI. As a clinical group, children with SLI exhibit a great deal of heterogeneity in their language-specific skills as well as in their domain-general cognitive skills. The very use of the word "specific" as a diagnostic term has been questioned in light of the limitations many children experience in working memory, attention, and visuo-spatial processing skills (Ebert & Kohnert, 2009).

Auditory selective attention was examined using a novel task that combined dichotic listening with a cross-modal lexical decision paradigm. Levels of auditory interference were manipulated in the unattended channel in an attempt to isolate the dual processes of activation and inhibition. The current study indeed revealed differences between groups on the auditory selective attention measure. The major findings that differentiated children with SLI from TLD were in performance on the *ignore* and *unrelated* conditions. Children with TLD demonstrated intact selection mechanisms whereby they took longer to process stimuli in the presence of competing auditory distracters, but they did not demonstrate significant decreases in accuracy between experimental conditions. In the TLD group, activation and inhibitory processes worked together. Conversely, children with SLI took just as long to process stimuli in the presence of competing distraction as they did in conditions where the distracters were unrelated to the target. These results indicate that children with SLI had trouble with the activation and selection of the relevant stimulus for processing, regardless of the type or level of distraction. Additionally, despite few differences in behavioral accuracy between groups, and no basic advantage for dichotic listening in the TLD group, generally slower and/or deficient processing for SLI subjects on a range of tasks was identified, including the auditory attention task, a verbal working memory task, and visuo-spatial executive functioning. Experimental task performance was significantly correlated with language test scores, *TONI-3* scores, and List Recall scores, but not with *Conner's Rating Scale* scores. However, regression analyses revealed only limited contributions of these correlated variables to the overall variance in each condition.

## Attention and Executive Function

Children with SLI demonstrate limitations in working memory capacity and function (Ellis-Weismer, Evans, & Hesketh, 1999; Gathercole & Baddeley, 1990; Montgomery, 2000, 2002; Marton & Schwartz, 2003). Engle and colleagues (Engle, 2002, 2010; Kane & Engle, 2003) have suggested that in typical individuals, working memory capacity is mediated by the domain-general aspect of *attention control*, or the ability to keep relevant stimuli in mind while inhibiting distracters. Using this theory as a framework, the current study focused on auditory *selective* attention. Selective attention is the process by which individuals select a relevant stimulus for processing, while suppressing or inhibiting irrelevant stimuli. This skill in particular was of interest, as it is considered an active process that requires cognitive control. Children with SLI appear to have subtle impairments in non-linguistic cognitive skills, particularly in aspects of executive function (Marton, 2008; Noterdaeme et al., 2001). Some researchers have postulated that deficits in attention and executive function may play a causal role in language impairment (e.g., Montgomery, Evans, & Gillam, 2009). However, most recent investigations have focused on sustained attention, or on a combined (sustained-selective) construct (Finneran, Leonard, & Francis, 2009; Spaulding, Plante, & Vance, 2008). Although the process of sustained attention tends to be the simplest to measure (e.g., with established measures such as the Continuous Performance Test), it is not clear how sustained attention is implicated in language *processing* in children with SLI. By definition, the construct of sustained attention has to do with *time*: the maintenance of attention over time (Gomes et al., 2002). Certainly, if children with SLI are unable to sustain their attention to auditory input (e.g., in a classroom environment), they will miss out on critical information and may subsequently limit conceptual knowledge and vocabulary use, for example. Likewise, pragmatic language skills may be impaired by difficulties sustaining attention within social interactions. However, looking only at sustained attention leaves out a critical piece of the equation, the attention that is being sustained. Studying *selective* attention more specifically examines the cognitive processes involved in attention: specifically the dual processes of activation and inhibition. Some investigators (Hanson & Montgomery, 2002; Spaulding, Plante, & Vance, 2008) attempted to account for this by studying sustained selective attention. However, it has been shown that Continuous Performance Tasks do not adequately differentiate between these two processes (Armstrong, 1997), thereby making it difficult to ascertain whether limitations on experimental tasks were due to difficulties with sustained attention, selective attention, or both. In the current study, the stimuli did not require sustained attention. Auditory and visual stimuli were presented simultaneously, and the dependent variables were accuracy and reaction time for each individual trial. Manipulating the unattended signal and measuring RTs in multiple conditions within a single task isolated the contributions of activation and inhibitory processing. Although this has been explored using primarily nonlinguistic stimuli with ERP methods, it was useful to expand upon those findings with a behavioral measure that could be more widely replicated and that avoided limitations inherent to ERP methods such as stimulus repetition.

Given that attention is a multi-faceted process, and that it is closely related to other executive function skills, the present study controlled for confounding EF factors in the experimental task. By presenting stimuli simultaneously (as opposed to with some interstimulus delay) and requiring an immediate response, working memory requirements were limited. Despite this control, there was a significant correlation between performance on the experimental task and on the verbal working memory measure (List Recall). This finding can be explained in one of two ways. Although the task controlled for working memory demands in the experimental task, the List Recall task did not control for attention. That is, the correlation between the two results may be due to common attention requirements. On the List Recall Task, limitations in performance could be explained by difficulties with attending to and selecting the sentence-final word, or with inhibiting intrusion from all the other words in the sentences, from words in previous sentence sets, or from the questions that follow the sentences. Another way of looking at the results is to suggest that a common construct underlies performance on both selective attention and complex working memory tasks. This common process might be described broadly as cognitive control. In this study, it should be noted that stimuli in both the main experiment and in the supplemental WM task were *linguistic*. Therefore, we cannot infer based on these results that an overall limitation in cognitive control exists in SLI; we can, however, suggest that limited cognitive control is an important mediating factor in performance on language processing tasks.

Models of Selective Attention

Models of selective attention attempt to account for two aspects of attentional processing: the time course of processing and the selection mechanism(s). In typical individuals, early selection of targets is thought to occur, with electrophysiological responses reflecting early and preattentive stimulus selection, whereas later responses are thought to reflect further, active processing of targets (Hillyard, Woldorff, Mangun, & Hansen, 1987). Stevens et al. (2006) indicated that this early modulation appears to be affected in children with SLI. The current study examined timing from the presentation of cross-modal stimuli to the initiation of the response. Therefore, we were able to measure differences in overall processing time, and found that children with SLI were slower to respond in all task conditions. However, our design was not sensitive enough to determine whether these delays occurred at an early or later point in processing.

Regarding the selection mechanism, these results have implications for determining whether excitatory, inhibitory, or both types of mechanisms were responsible for delays in stimulus selection in our SLI group. By systematically manipulating the auditory/lexical interference in the unattended channel, the study attempted to isolate the contribution of excitatory from inhibitory processing. It was hypothesized that the SLI group's performance would fit one of three patterns. First, disproportionately increased RT or decreased accuracy in the *ignore* condition compared to TLD would indicate specific difficulties with inhibitory control. Secondly, increased RT or decreased accuracy on all experimental conditions (relative to baseline), but no difference in the pattern of performance between groups, would suggest that the difficulty lies more broadly in the activation of relevant stimuli. Thirdly, if response times in all conditions (including baseline) were increased compared to TLD, with no differences in patterns of performance, it was suggested that selective attention per se would not be implicated, but rather the generalized slowing hypothesis could account for the results. In fact, the observed patterns fit features of both the second and third predictions. RTs were indeed increased for SLI subjects across the board, including on baseline measures. Although this was unexpected, it is possible that the basic nature of the task required increased processing for the children with SLI. Because the baseline task was a language processing task (in which children were required to compare the auditory word and the visual representation and determine whether they were the *same* or *different*) it may have taken children with SLI longer to recognize the auditory word, call up its meaning in memory, and compare it to the visual stimulus. Although the stimuli were chosen for their phonological simplicity and high familiarity, it is possible that the task of comparing and making a lexical decision required more processing time for the SLI subjects. Alternatively, it is possible that the dual-modality aspect of the task (auditory and visual) posed a challenge for the children with SLI. Thus, although the SLI subjects were slower overall on the experimental task, the explanation may not be as simple as a generalized slowing account would suggest. Future investigations might explore performance on various measures that require processing in dual modalities or dual task processing.

Comparisons of accuracy and RT on pairs of conditions were examined. These comparisons were made within and between groups. Between group comparisons on accuracy measures were generally non-significant, or problematic to interpret due to ceiling effects with accuracy rates >90% on several conditions. Both groups showed statistically significant decreases in performance between baseline and experimental conditions, indicating that the presence of a distracter stimulus (regardless of type) in the unattended channel led to decreases in accuracy from the baseline. The TLD group did not demonstrate any differences in accuracy rates on two of the three experimental conditions (attend and ignore), although they did appear to perform more accurately on the *unrelated* condition where the distracter was not related to either relevant stimulus. This result should be interpreted with some caution given the ceiling effects. Generally, these patterns show that children with TLD could actively suppress the auditory stimulus in the unattended channel and respond appropriately, even if it was more cognitively demanding to do so. Children with SLI however, showed significantly decreased accuracy in the *ignore* condition, compared to the *unrelated* condition. This indicates that the presence of the competing auditory stimulus in the unattended channel (it matched the visual stimulus in the *ignore* condition) led to more errors in the lexical decision task, compared to when the interfering stimulus was non-competing, or unrelated to the visual target.

The analyses also compared within-group patterns of performance by comparing RTs between pairs of conditions. A main effect of Condition was identified for both groups, indicating that the manipulation of interference in the unattended channel did have an effect on processing time. Upon examination of the within-group patterns of performance, the main difference was in the comparison of the *unrelated* and the *ignore* conditions. Slower RTs in the *ignore* condition reflect active inhibitory processing in the unattended channel, the active inhibition required to suppress the activation of the matching visual stimulus and unattended auditory stimulus. Conversely, in the *unrelated* condition, this cross-modal activation would not be taking place as the unattended auditory word bore no relationship to the visual stimulus. In fact, children with TLD demonstrated this pattern, with significantly different RTs in the *ignore* condition. Recall though, that despite this slower processing, they performed with similar accuracy rates on the two conditions. Children with SLI however, did not show a difference in reaction time on the two conditions. It took them just as long to process the unrelated/non-competing stimuli as the competing stimuli. Yet, they showed decreased accuracy rates on the *ignore* condition, compared to *unrelated.* What could account for this finding?

As predicted, the critical difference lies in the comparison between the *unrelated* and *ignore* conditions. The expected difference, based on previous research focusing on inhibitory control, would have been for the SLI subjects to be not only less accurate but also slowest in the *ignore* condition. However, the SLI group had apparent difficulty inhibiting both unrelated and competing stimuli in the unattended channel. It is possible that they were generally less efficient in processing and comparing the auditory stimuli to the visual stimulus. In the *attend* condition, where the visual stimulus matched the *attended* word, this cross-modal activation may have facilitated a rapid and correct decision, even though an (unrelated) distracter stimulus was present in the unattended channel. However, in the absence of this facilitation, the children with SLI took longer to process the relevant auditory stimulus and make the comparison with the visual stimulus, regardless of the level of distraction from the unattended channel. This suggests a more widespread problem with distracter processing than one specific to inhibitory control at the lexical level. Slower response times could not be attributed uniquely to the active inhibitory processing required in the *ignore* condition, rather, children with SLI had difficulty inhibiting any distracting stimulus in this paradigm.

## Measuring Attention in Children with SLI

Although other standardized and experimental tasks exist to measure various aspects of attention, this study utilized a novel task to separate the effects of selective attention on language processing from other constructs such as sustained attention and working memory function. The task was designed to be more sensitive than other tasks (e.g., the ACPT) recording accuracy and reaction time data in multiple conditions. As previously noted, the accuracy data revealed no significant differences between groups on the ability to match auditory words and visual representations in the presence of auditory distracters. In contrast, previous studies (e.g., Hanson & Montgomery, 2002) have used accuracy measures alone to determine that children with SLI did not differ from TLD children on measures of auditory attention. A behavioral task without RT measurements, might have led to the same incorrect conclusion. Although the SLI subjects appeared to perform less accurately overall, the differences were not statistically significant, and in some cases the performance levels for both groups approached ceiling and rendered statistical analysis irrelevant. The fact that both groups were relatively accurate indicated that the task was manageable and appropriate for this age group (9-11 year olds). Had the SLI group been significantly less accurate on all conditions, this would have suggested that other factors may have been confounding the results, such as linguistic or auditory processing demands. Thus, the experimental task targeted differences in auditory selective attention rather than other processing or linguistic skills.

Reaction time data were used to measure differences in processing time between groups on the experimental task. As noted previously, results indicated a pattern of generalized slowing for the SLI group, relative to the TLD subjects. There is some disagreement in the field as to whether children with SLI are generally slower across modalities (Kail, 1994; Miller et al., 2001, Windsor & Hwang, 1999, Windsor et al., 2001) or slower only on cognitive-linguistic tasks. In retrospect, a baseline simple RT task (non-linguistic, single modality) would have been useful to more conclusively address this question. An additional factor should be taken into consideration in light of these results. Very recently, authors have attempted to differentiate between language and information processing profiles in children with SLI and ADHD (Cardy, Tannock, Johnson & Johnson, 2010; Redmond, Thompson, & Goldstein, 2011). Cardy et al. (2010) compared SLI, ADHD, and TLD groups on measures of nonlinguistic RT as well as an auditory rapid temporal processing (RTP) task. They found that children with ADHD were slower than *both* TLD and SLI groups overall on both tasks. They suggest that given the high-comorbidity of ADHD and SLI diagnoses, it is possible that previous findings suggesting generally slower processing in children with SLI could be attributed to limitations in attention. Given that 8 of the 15 children in our SLI group received ADHD Index scores above the screening cutoff on the *CRS-R,* we might also conclude that limitations in attention in general could be the cause of the slower RTs in the SLI group. To test this notion, RTs on the experimental task for the eight participants who had elevated *CRS-R* scores were compared with the 5 who scored below the cutoff (data were missing for two subjects), and found that there was no difference in performance between these two groups ($F(1,10) = .282$, $p = .607$). Increased *CRS-R* scores did not relate to differences in performance within the SLI group. Therefore, general inattentiveness, as measured by the *CRS-R*, could not account for differences in performance on the experimental task. Granted, this comparison was made between two small samples ($n = 7$ and n = 5). Future studies should attempt to account for ADHD status more systematically in order to address these questions.

Another way of considering whether ADHD-like symptoms affected performance in the current study would be to examine correlations between *CRS-R* scores with experimental task data. In fact, these measures were not significantly correlated, indicating that status on the *CRS-R* was not associated with performance on the auditory selective attention task. This finding raises questions about how we operationalize the construct of attention in research; it appears likely that the aspects of attention measured on diagnostic or screening measures such as the *CRS-R* may not be the same aspects of attention that relate to language processing in children with SLI. In fact, examined from a slightly different perspective, it has actually been shown that selective attention abilities appear to be intact in 8-12 year old children with ADHD diagnoses (Huang-Pollock, Nigg, & Carr, 2005). Therefore, while there are reportedly high levels of co-morbidity between SLI and ADHD diagnoses, we should not assume that the attention deficits that are apparent in ADHD are the same as those observed in children with SLI.

So what aspect of attention did the experiment measure? It is useful to consider correlations with other supplemental tasks and standardized testing to address this question. Moderate correlations were noted between experimental task performance and List Recall performance, particularly on the two sentence types that involved higher cognitive load. Earlier, it was suggested that the shared feature between the two tasks might be *cognitive control*. Given the theoretical basis for testing selective attention in this experiment (i.e., Engle's conceptualization of working memory and attention control) it is not surprising that deficits on these two tasks were correlated. There also was a moderate to strong correlations between experimental task performance and *TONI-3* scores. At first glance, this correlation may seem puzzling. The two tasks have little in common on the surface; the experiment was cross-modal in nature, requiring auditory attention and lexical processing, whereas the *TONI-3* is strictly visual and nonverbal, requiring skills such as pattern completion and mental rotation. Additionally, as a criterion for inclusion into the study, children in both groups had to have *TONI-3* above 85. In other words, children with SLI were not clinically impaired in their nonverbal cognitive skills. Despite this fact, it is clear that some common construct contributed to performance on these two measures. There is some evidence that children with SLI demonstrate limitations in visuo-spatial executive functions (Hick, Botting, Conti-Ramsden, 2008; Marton, 2008) as well as in other non-verbal cognitive skills such as mental imagery and mental rotation (Johnston & Ellis Weismer, 1983). Perhaps the SLI participants had subtle impairments in these areas that were not sufficient to push their *TONI-3* scores below the average range, but were sufficient to differentiate them from their TLD peers. On closer examination, it is clear that aspects of cognitive control were required for successful performance on the *TONI-3*, including comparing target stimuli with multiple response options, and inhibiting distracter choices which may have differed from the correct response in subtle ways. Despite these assertions; it should again be noted that even those variables that were strongly correlated did *not* predict the variance in experimental RTs in a multiple regression model. Further research will be required to better design and choose predictor variables, and/or to identify additional factors that may be influencing performance.

Limitations

The relatively small sample size in the current study ($n$ = 15 in each group) may have limited the power of our findings. With a larger sample, apparent trends in the data and differences that approached statistical significance may have reached significance. Whereas a main effect of group (SLI versus TLD) was clear in the reaction time data, the important differences on performance in the experimental conditions were made apparent by examining within-group patterns. Perhaps with a larger sample these patterns would have become more definitive and an interaction between Group and Condition may have been identified.

A younger, language-matched group was not included as a control in the current study. In light of the slower RTs in the SLI group across conditions (including baseline), it would be informative to determine whether they were performing similarly to younger peers with similar language levels. Likewise, a younger TLD group might have permitted a trajectory approach (Thomas et al., 2009) to examine the patterns of impairment in the SLI group; whether attention processing was simply delayed or deviant when compared to typically developing peers.

A possible sample limitation was the large proportion of children who scored above the screening cutoff for ADHD on the *CRS-R,* despite not having clinical diagnoses of ADHD. We might have chosen to exclude those participants, but it seemed imprudent to do so. The reality of SLI is that it is not really “specific” in clinical terms. Children with SLI are a notoriously heterogeneous group, and speech-language clinicians must evaluate and treat children with a variety of needs that differ somewhat in terms of language modality (receptive versus expressive), language domain (phonology, morphology, syntax, semantics, pragmatics) and related cognitive skills (nonverbal cognition, executive function, attention). From a researcher’s perspective, we need to find balance between controlling for confounding factors (e.g., cognitive skills below the average range, frank neurological or social-emotional dysfunction) yet not limiting our sample such that it becomes an unrealistic comparison to clinical samples. Therefore the children with elevated *CRS-R* scores were included and their performance was examined.

Finally, the study was limited by the absence of a baseline, nonlinguistic RT task. This limited our interpretation of the slower SLI performance even in baseline conditions. With such a baseline, it might have been possible to say more about this differential. However, it should be noted that differences on nonlinguistic RT tasks (e.g., basic motor or auditory detection) are not always significant (e.g., Kohnert & Windsor, 2004; Miller et al., 2001). Therefore, the cross-modal, linguistic nature of the experimental task contributed to slowed responses in the SLI group. It would have also been potentially useful to include more detailed examinations of both executive functions and auditory processing skills to more clearly identify aspects of each that were involved in the experimental task performance. In particular, although a basic dichotic listening advantage was not identified for either group, there were subtle differences in performance such as more frequent errors on the free recall procedure. This finding could be indicative of difficulties with binaural separation or integration, which could have contributed to difficulties with the experimental task. Although correlations none of the correlations between dichotic listening ratio and error rates and the experimental task were significant, a more thorough examination of dichotic listening skills may have highlighted weaknesses that contributed to performance deficits in the SLI group.

## Clinical Implications and Directions for Future Research

The current study was also motivated by clinical concerns. Older elementary-age children with a history of language delay are at risk for a variety of continued language and learning difficulties (Rescorla, 2005). Difficulties with classification and diagnosis in this age group are also apparent, with overlapping diagnoses often including SLI, ADHD, Dyslexia, and Language-Learning Disability (Snowling et al, 2006). Furthermore, clinical impressions indicate that these children do not seem to be developing the more sophisticated executive function skills that would be expected in later childhood. This places children with language impairment at ever increasing risk of academic and social difficulty as they proceed toward adolescence.

Better profiling of language and executive function skills in older children with SLI is of vital importance. To do this however, we must better operationalize our definitions of executive functions in general, and attention skills in particular. If we are to discriminate better between children with SLI and ADHD, we must be cognizant of which aspects of attention we are measuring in research and how they affect language processing. Although it may not be possible to isolate sublevels of attention, a better understanding of the relationship between attention and language processing would be helpful. The results of the current study seem to indicate that the attention problems measured on the *CRS-R* are not the same as those implicated in language processing tasks. An intriguing option to consider that the difference is one of vigilance and self-regulation versus cognitive control of attention. However, this hypothesis should be tested systematically by controlling variables in the clinical versus control groups or by improved experimental design. Thus, converging evidence in the literature points to limitations in attention in children with SLI. A primary aim of research going forward should be to define better the aspects of attention that are impaired, examine how those aspects of attention affect language processing, and how and if they develop over time in both SLI and TLD populations.

Apparent difficulties in dual-task performance also suggest that future investigations should aim to more accurately and definitively identify areas of weakness in children with SLI. Previous studies have also identified difficulties with dual-task performance in this population (Marton & Schwartz, 2003; Seiger-Gardner & Schwartz, 2008). The current task could be modified to control for effects of modality (auditory, visual, and cross-modal stimuli), domain (e.g., linguistic versus nonlinguistic stimuli), and/or complexity (e.g., high versus low processing load). Additional experiments might assess performance in a variety of dual tasks.

Another clinical implication and direction for future research relates to treatment. Although neuropsychiatric treatment methods currently exist for children with ADHD, it appears that the attention problems in children with SLI differ in important ways from clinically diagnosed ADHD, and would require separate treatment protocols. Stevens, Fanning, Coch, Sanders, & Neville (2008) extended Stevens et al.'s (2006) findings regarding limitations in activation of relevant stimuli; they designed a treatment study in which children with SLI participated in a period of intense computerized intervention aimed at improving language skills. They found that children who had received the training showed enhanced neural processing of attended stimuli, which were specific to changes in the signal enhancement of attended stimuli. Likewise, Ebert and Kohnert (2009) found that targeted treatment of nonlinguistic cognitive skills (auditory memory and visual speed of processing) led to increases in expressive language skills. A recent randomized controlled trial (RCT) study by Gillam, Loeb, Hoffman, Bohman, and Champlin (2008) which compared treatment effects of multiple interventions, including Fast ForWord, Academic Enrichment, Computer Assisted Language Intervention, and Individualized Language Intervention showed no effects that were specific to one treatment. Rather, they suggested that each of these methods might have addressed underlying skills such as attention regulation, which subsequently led to improvements in language skills. These results are promising but still somewhat limited in direct clinical applications. Although the assumption may be that facilitating attention will improve language processing and performance, we do not know specifically which aspects of attention are most important to address, nor do we have clearly delineated methods for treatment. The current study represents a starting point for a line of research to better operationalize these constructs and to design treatment protocols to address these critical weaknesses.

Additional extensions of the current research might involve manipulation of lexical variables, perhaps to examine performance under increasing processing loads. As noted previously, we designed the main experiment using phonologically simple, semantically familiar stimuli to reduce potentially confounding linguistic factors. However, children with SLI often demonstrate particular weakness in processing under conditions of increased load (Spaulding, Plante, & Vance, 2008). Timing variables (e.g., introducing interstimulus intervals between visual/auditory stimuli or between relevant/distracter stimuli) could also be manipulated to examine the time course of selection in SLI and TLD populations. Finally, given that the experimental task was mainly passive in nature (no expressive responses required, the main response is a button press), it lends itself to use with electrophysiological recordings or with eye tracking. Such methods may provide finer grained detail about attention over time within trials. The behavioral findings support Stevens et al.'s (2006) electrophysiological data, but these are different tasks. It would be interesting to test whether the hypothesized limitations in activation versus suppression on our task would hold upon examination of ERP responses in the various conditions.

## Summary and Conclusions

The current study utilized a novel task to examine auditory selective attention abilities and their relationship to language processing in children with and without SLI. It contributes to a growing body of literature identifying impairments in attention and executive function in children with SLI. By utilizing a task that specifically measured auditory *selective* attention, the experiment avoided confounds with related constructs such as sustained attention and working memory. Correlations of experimental task performance with standardized test scores and supplemental task performance revealed significant negative correlations primarily between receptive language status and RT, List Recall accuracy and RT, and importantly, *TONI-3* scores and RT. There was an association between lower scores on these measures and increased reaction time on the experimental task. *CRS-R* scores (reflecting ADHD characteristics) were *not* correlated with task performance. These findings suggest that the experimental task measured aspects of attention that are dependent upon *cognitive control*.

Overall, children with TLD were efficient in processing linguistic stimuli, even in the presence of auditory distracters. Although their RTs were increased in conditions where inhibitory processing was required, their rates of accuracy were consistent. The RT and accuracy data together show that children with TLD select the relevant stimuli and inhibit the irrelevant stimuli effectively within language processing tasks. Children with TLD also demonstrated better verbal working memory skills on the List Recall task, and faster processing on the visuo-spatial Color Trails task.

Children with SLI were less efficient at processing the linguistic stimuli in the presence of distraction. They were slower to process lexical items when presented in a cross-modal format, regardless of interference. Breakdowns in selective attention at the level of activation of the relevant stimulus for processing were evidenced by decreased accuracy but equivalent processing time when interference from the unattended channel was related to the target versus when it was unrelated. Had the breakdown been due to inefficient inhibition specifically, we would have observed longer RTs in the condition that required active inhibitory processing. Children with SLI also exhibited significantly reduced accuracy on the List Recall measure, indicating problems with complex verbal working memory, and significantly slower processing speeds on the Children's Color Trails task, indicating deficits in visuo-spatial processing as well. Overall, the evidence points to deficits in cognitive control of attention in children with SLI, which relate directly to their language processing limitations.

# APPENDIX A

## All Stimuli Sorted by Trial List and Condition

### Left Ear Block: Baseline Trials

| Condition | Auditory | Visual |
|---|---|---|
| baseSL | kite-kite.wav | kite.bmp |
| baseSL | book-book.wav | book.bmp |
| baseSL | dog-dog.wav | dog.bmp |
| baseSL | watch-watch.wav | Watch.bmp |
| baseSL | ball-ball.wav | ball.bmp |
| baseSL | fork-fork.wav | fork.bmp |
| baseSL | heart-heart.wav | heart.bmp |
| baseSL | plane-plane.wav | plane.bmp |
| baseSL | bus-bus.wav | bus.bmp |
| baseSL | crown-crown.wav | Crown.bmp |
| baseSL | bird-bird.wav | bird.bmp |
| baseSL | cat-cat.wav | cat.bmp |
| baseSL | star-star.wav | star.bmp |
| baseSL | hand-hand.wav | hand.bmp |
| baseSL | brush-brush.wav | Brush.bmp |
| baseSL | corn-corn.wav | corn.bmp |
| baseSL | bed-bed.wav | bed.bmp |
| baseSL | cake-cake.wav | cake.bmp |
| baseSL | shoe-shoe.wav | shoe.bmp |
| baseSL | sun-sun.wav | sun.bmp |
| baseSL | car-car.wav | car.bmp |
| baseSL | tree-tree.wav | tree.bmp |
| baseSL | train-train.wav | train.bmp |
| baseSL | house-house.wav | House.bmp |
| baseSL | moon-moon.wav | Moon.bmp |
| baseSL | horse-horse.wav | Horse.bmp |
| baseSL | bread-bread.wav | Bread.bmp |
| baseSL | flag-flag.wav | flag.bmp |
| baseSL | foot-foot.wav | foot.bmp |
| baseSL | key-key.wav | key.bmp |
| baseDL | flag-flag.wav | ring.bmp |
| baseDL | house-house.wav | pear.bmp |
| baseDL | bed-bed.wav | sun.bmp |
| baseDL | hand-hand.wav | cow.bmp |
| baseDL | horse-horse.wav | cheese.bmp |
| baseDL | star-star.wav | broom.bmp |
| baseDL | bird-bird.wav | nose.bmp |
| baseDL | sun-sun.wav | bell.bmp |
| baseDL | book-book.wav | tree.bmp |
| baseDL | bread-bread.wav | spoon.bmp |
| baseDL | moon-moon.wav | pen.bmp |
| baseDL | shoe-shoe.wav | cup.bmp |
| baseDL | car-car.wav | bed.bmp |
| baseDL | key-key.wav | fork.bmp |
| baseDL | bus-bus.wav | cat.bmp |
| baseDL | train-train.wav | couch.bmp |
| baseDL | cake-cake.wav | fish.bmp |

| | | |
|---|---|---|
| baseDL | plane-plane.wav | wheel.bmp |
| baseDL | heart-heart.wav | chain.bmp |
| baseDL | kite-kite.wav | hand.bmp |
| baseDL | dog-dog.wav | shoe.bmp |
| baseDL | cat-cat.wav | moon.bmp |
| baseDL | foot-foot.wav | house.bmp |
| baseDL | watch-watch.wav | train.bmp |
| baseDL | brush-brush.wav | brush.bmp |
| baseDL | tree-tree.wav | door.bmp |
| baseDL | ball-ball.wav | hat.bmp |
| baseDL | corn-corn.wav | foot.bmp |
| baseDL | fork-fork.wav | ball.bmp |
| baseDL | crown-crown.wav | swing.bmp |

**Left Ear Block: Experimental Trials**

| Condition | Auditory | Visual |
|---|---|---|
| attendL | flagL-broomR.wav | flag.bmp |
| attendL | starL-knifeR.wav | star.bmp |
| attendL | bedL-cupR.wav | bed.bmp |
| attendL | forkL-wheelR.wav | fork.bmp |
| attendL | watchL-pantsR.wav | watch.bmp |
| attendL | moonL-doorR.wav | moon.bmp |
| attendL | carL-noseR.wav | car.bmp |
| attendL | horseL-clownR.wav | horse.bmp |
| attendL | shoeL-duckR.wav | shoe.bmp |
| attendL | planeL-couchR.wav | plane.bmp |
| attendL | ballL-cowR.wav | ball.bmp |
| attendL | crownL-cheeseR.wav | crown.bmp |
| attendL | heartL-bowlR.wav | heart.bmp |
| attendL | dogL-hatR.wav | dog.bmp |
| attendL | treeL-eyeR.wav | tree.bmp |
| attendL | bookL-pearR.wav | book.bmp |
| attendL | cakeL-bellR.wav | cake.bmp |
| attendL | birdL-ringR.wav | bird.bmp |
| attendL | trainL-clockR.wav | train.bmp |
| attendL | cornL-beltR.wav | corn.bmp |
| attendL | houseL-chainR.wav | house.bmp |
| attendL | handL-fishR.wav | hand.bmp |
| attendL | brushL-spoonR.wav | brush.bmp |
| attendL | busL-earR.wav | bus.bmp |
| attendL | keyL-bearR.wav | key.bmp |
| attendL | kiteL-sealR.wav | kite.bmp |
| attendL | footL-bowR.wav | foot.bmp |
| attendL | breadL-swingR.wav | bread.bmp |
| attendL | sunL-combR.wav | sun.bmp |
| attendL | catL-penR.wav | cat.bmp |
| filler | pearL-handR.wav | pear.bmp |
| filler | clownL-horseR.wav | clown.bmp |
| filler | knifeL-starR.wav | knife.bmp |
| filler | cupL-bedR.wav | cup.bmp |
| filler | duckL-starR.wav | duck.bmp |

| | | |
|---|---|---|
| filler | spoonL-trainR.wav | spoon.bmp |
| filler | broomL-watchR.wav | broom.bmp |
| filler | swingL-forkR.wav | swing.bmp |
| filler | eyeL-dogR.wav | eye.bmp |
| filler | doorL-handR.wav | door.bmp |
| filler | earL-catR.wav | ear.bmp |
| filler | combL-houseR.wav | comb.bmp |
| filler | ringL-breadR.wav | ring.bmp |
| filler | wheelL-crownR.wav | wheel.bmp |
| filler | bellL-flagR.wav | bell.bmp |
| filler | bowL-carR.wav | bow.bmp |
| filler | noseL-keyR.wav | nose.bmp |
| filler | cowL-forkR.wav | cow.bmp |
| filler | hatL-ballR.wav | hat.bmp |
| filler | bearL-cakeR.wav | bear.bmp |
| filler | bowlL-heartR.wav | bowl.bmp |
| filler | penL-moonR.wav | pen.bmp |
| filler | sealL-ballR.wav | seal.bmp |
| filler | clockL-brushR.wav | clock.bmp |
| filler | couchL-moonR.wav | couch.bmp |
| filler | beltL-cornR.wav | belt.bmp |
| filler | cheeseL-trainR.wav | cheese.bmp |
| filler | fishL-bookR.wav | fish.bmp |
| filler | pantsL-crownR.wav | pants.bmp |
| filler | chainL-breadR.wav | chain.bmp |
| ignoreL | bowL-footR.wav | foot.bmp |
| ignoreL | combL-sunR.wav | sun.bmp |
| ignoreL | duckL-shoeR.wav | shoe.bmp |
| ignoreL | broomL-flagR.wav | flag.bmp |
| ignoreL | knifeL-starR.wav | star.bmp |
| ignoreL | spoonL-brushR.wav | brush.bmp |
| ignoreL | beltL-cornR.wav | corn.bmp |
| ignoreL | penL-catR.wav | cat.bmp |
| ignoreL | duckL-shoeR.wav | shoe.bmp |
| ignoreL | couchL-planeR.wav | plane.bmp |
| ignoreL | ringL-birdR.wav | bird.bmp |
| ignoreL | sealL-kiteR.wav | kite.bmp |
| ignoreL | wheelL-forkR.wav | fork.bmp |
| ignoreL | cheeseL-crownR.wav | crown.bmp |
| ignoreL | cowL-ballR.wav | ball.bmp |
| ignoreL | earL-busR.wav | bus.bmp |
| ignoreL | swingL-breadR.wav | bread.bmp |
| ignoreL | pantsL-watchR.wav | watch.bmp |
| ignoreL | noseL-carR.wav | car.bmp |
| ignoreL | doorL-moonR.wav | moon.bmp |
| ignoreL | clownL-horseR.wav | horse.bmp |
| ignoreL | bearL-keyR.wav | key.bmp |

| | | |
|---|---|---|
| ignoreL | bellL-cakeR.wav | cake.bmp |
| ignoreL | fishL-handR.wav | hand.bmp |
| ignoreL | eyeL-treeR.wav | tree.bmp |
| ignoreL | bowlL-heartR.wav | heart.bmp |
| ignoreL | cupL-bedR.wav | bed.bmp |
| ignoreL | hatL-dogR.wav | dog.bmp |
| ignoreL | chainL-houseR.wav | house.bmp |
| ignoreL | clockL-trainR.wav | train.bmp |
| unrelL | bookL-pearR.wav | tree.bmp |
| unrelL | busL-earR.wav | cat.bmp |
| unrelL | brushL-spoonR.wav | brush.bmp |
| unrelL | breadL-swingR.wav | spoon.bmp |
| unrelL | houseL-chainR.wav | pear.bmp |
| unrelL | horseL-clownR.wav | cheese.bmp |
| unrelL | forkL-wheelR.wav | ball.bmp |
| unrelL | flagL-broomR.wav | ring.bmp |
| unrelL | kiteL-sealR.wav | hand.bmp |
| unrelL | moonL-doorR.wav | pen.bmp |
| unrelL | birdL-ringR.wav | nose.bmp |
| unrelL | watchL-pantsR.wav | train.bmp |
| unrelL | ballL-cowR.wav | hat.bmp |
| unrelL | shoeL-duckR.wav | cup.bmp |
| unrelL | catL-penR.wav | moon.bmp |
| unrelL | crownL-cheeseR.wav | swing.bmp |
| unrelL | keyL-bearR.wav | fork.bmp |
| unrelL | trainL-clockR.wav | couch.bmp |
| unrelL | footL-bowR.wav | house.bmp |
| unrelL | treeL-eyeR.wav | door.bmp |
| unrelL | sunL-combR.wav | bell.bmp |
| unrelL | heartL-bowlR.wav | chain.bmp |
| unrelL | dogL-hatR.wav | shoe.bmp |
| unrelL | starL-knifeR.wav | broom.bmp |
| unrelL | handL-fishR.wav | cow.bmp |
| unrelL | bedL-cupR.wav | sun.bmp |
| unrelL | cornL-beltR.wav | foot.bmp |
| unrelL | planeL-couchR.wav | wheel.bmp |
| unrelL | carL-noseR.wav | bed.bmp |
| unrelL | cakeL-bellR.wav | fish.bmp |

**Right Ear Block: Baseline Trials**

| Condition | Auditory | Visual |
|---|---|---|
| baseSR | pear-pear.wav | pear.bmp |
| baseSR | belt-belt.wav | belt.bmp |
| baseSR | bow-bow.wav | bow.bmp |
| baseSR | duck-duck.wav | duck.bmp |
| baseSR | chain-chain.wav | chain.bmp |
| baseSR | seal-seal.wav | seal.bmp |
| baseSR | door-door.wav | door.bmp |
| baseSR | ear-ear.wav | ear.bmp |
| baseSR | wheel-wheel.wav | wheel.bmp |
| baseSR | bear-bear.wav | bear.bmp |

| | | |
|---|---|---|
| baseSR | clown-clown.wav | clown.bmp |
| baseSR | bowl-bowl.wav | bowl.bmp |
| baseSR | broom-broom.wav | broom.bmp |
| baseSR | pants-pants.wav | pants.bmp |
| baseSR | nose-nose.wav | nose.bmp |
| baseSR | fish-fish.wav | fish.bmp |
| baseSR | spoon-spoon.wav | spoon.bmp |
| baseSR | cup-cup.wav | cup.bmp |
| baseSR | pen-pen.wav | pen.bmp |
| baseSR | hat-hat.wav | hat.bmp |
| baseSR | bell-bell.wav | bell.bmp |
| baseSR | couch-couch.wav | couch.bmp |
| baseSR | eye-eye.wav | eye.bmp |
| baseSR | comb-comb.wav | comb.bmp |
| baseSR | knife-knife.wav | knife.bmp |
| baseSR | clock-clock.wav | clock.bmp |
| baseSR | ring-ring.wav | ring.bmp |
| baseSR | cow-cow.wav | cow.bmp |
| baseSR | swing-swing.wav | swing.bmp |
| baseSR | cheese-cheese.wav | cheese.bmp |
| baseDR | nose-nose.wav | bed.bmp |
| baseDR | broom-broom.wav | shoe.bmp |
| baseDR | belt-belt.wav | foot.bmp |
| baseDR | ear-ear.wav | cat.bmp |
| baseDR | pen-pen.wav | moon.bmp |
| baseDR | cup-cup.wav | sun.bmp |
| baseDR | spoon-spoon.wav | brush.bmp |
| baseDR | ring-ring.wav | tree.bmp |
| baseDR | couch-couch.wav | wheel.bmp |
| baseDR | pear-pear.wav | nose.bmp |
| baseDR | comb-comb.wav | bell.bmp |
| baseDR | cow-cow.wav | hat.bmp |
| baseDR | bow-bow.wav | house.bmp |
| baseDR | fish-fish.wav | cow.bmp |
| baseDR | chain-chain.wav | pear.bmp |
| baseDR | clock-clock.wav | couch.bmp |
| baseDR | clown-clown.wav | cheese.bmp |
| baseDR | door-door.wav | pen.bmp |
| baseDR | duck-duck.wav | cup.bmp |
| baseDR | wheel-wheel.wav | ball.bmp |
| baseDR | knife-knife.wav | broom.bmp |
| baseDR | cheese-cheese.wav | swing.bmp |
| baseDR | bowl-bowl.wav | chain.bmp |
| baseDR | bear-bear.wav | fork.bmp |
| baseDR | seal-seal.wav | hand.bmp |
| baseDR | eye-eye.wav | door.bmp |
| baseDR | hat-hat.wav | ring.bmp |
| baseDR | bell-bell.wav | fish.bmp |
| baseDR | pants-pants.wav | train.bmp |
| baseDR | swing-swing.wav | spoon.bmp |

**Right Ear Block: Experimental Trials**

| Condition | Auditory | Visual |
|---|---|---|
| attendR | bowlL-heartR.wav | heart.bmp |
| attendR | chainL-houseR.wav | house.bmp |
| attendR | bowL-footR.wav | foot.bmp |
| attendR | cowL-ballR.wav | ball.bmp |
| attendR | clockL-trainR.wav | train.bmp |
| attendR | bearL-keyR.wav | key.bmp |
| attendR | clownL-horseR.wav | horse.bmp |
| attendR | doorL-moonR.wav | moon.bmp |
| attendR | pantsL-watchR.wav | watch.bmp |
| attendR | knifeL-starR.wav | star.bmp |
| attendR | spoonL-brushR.wav | brush.bmp |
| attendR | fishL-handR.wav | hand.bmp |
| attendR | sealL-kiteR.wav | kite.bmp |
| attendR | duckL-shoeR.wav | shoe.bmp |
| attendR | penL-catR.wav | cat.bmp |
| attendR | pearL-bookR.wav | book.bmp |
| attendR | cheeseL-crownR.wav | crown.bmp |
| attendR | wheelL-forkR.wav | fork.bmp |
| attendR | bellL-cakeR.wav | cake.bmp |
| attendR | broomL-flagR.wav | flag.bmp |
| attendR | noseL-carR.wav | car.bmp |
| attendR | ringL-birdR.wav | bird.bmp |
| attendR | earL-busR.wav | bus.bmp |
| attendR | combL-sunR.wav | sun.bmp |
| attendR | cupL-bedR.wav | bed.bmp |
| attendR | swingL-breadR.wav | bread.bmp |
| attendR | beltL-cornR.wav | corn.bmp |
| attendR | couchL-planeR.wav | plane.bmp |
| attendR | eyeL-treeR.wav | tree.bmp |
| attendR | hatL-dogR.wav | dog.bmp |
| filler | spoonL-trainR.wav | train.bmp |
| filler | swingL-forkR.wav | fork.bmp |
| filler | combL-houseR.wav | house.bmp |
| filler | couchL-moonR.wav | moon.bmp |
| filler | wheelL-crownR.wav | crown.bmp |
| filler | bearL-cakeR.wav | cake.bmp |
| filler | earL-catR.wav | cat.bmp |
| filler | clockL-brushR.wav | brush.bmp |
| filler | bellL-flagR.wav | flag.bmp |
| filler | chainL-breadR.wav | bread.bmp |
| filler | knifeL-birdR.wav | bird.bmp |
| filler | cupL-bedR.wav | bed.bmp |
| filler | bowlL-heartR.wav | heart.bmp |
| filler | eyeL-dogR.wav | dog.bmp |
| filler | bowL-carR.wav | car.bmp |
| filler | pearL-handR.wav | hand.bmp |

| | | |
|---|---|---|
| filler | ringL-breadR.wav | bread.bmp |
| filler | hatL-ballR.wav | ball.bmp |
| filler | pantsL-crownR.wav | crown.bmp |
| filler | noseL-carR.wav | cat.bmp |
| filler | beltL-cornR.wav | corn.bmp |
| filler | cowL-forkR.wav | fork.bmp |
| filler | doorL-handR.wav | hand.bmp |
| filler | fishL-bookR.wav | book.bmp |
| filler | clownL-horseR.wav | Horse.bmp |
| filler | sealL-ballR.wav | ball.bmp |
| filler | broomL-watchR.wav | Watch.bmp |
| filler | penL-moonR.wav | Moon.bmp |
| filler | duckL-starR.wav | star.bmp |
| filler | cheeseL-trainR.wav | train.bmp |
| ignoreR | birdL-ringR.wav | bird.bmp |
| ignoreR | keyL-bearR.wav | key.bmp |
| ignoreR | footL-bowR.wav | foot.bmp |
| ignoreR | dogL-hatR.wav | dog.bmp |
| ignoreR | cakeL-bellR.wav | cake.bmp |
| ignoreR | sunL-combR.wav | sun.bmp |
| ignoreR | catL-penR.wav | cat.bmp |
| ignoreR | shoeL-duckR.wav | shoe.bmp |
| ignoreR | brushL-spoonR.wav | Brush.bmp |
| ignoreR | trainL-clockR.wav | train.bmp |
| ignoreR | treeL-eyeR.wav | tree.bmp |
| ignoreR | bedL-cupR.wav | bed.bmp |
| ignoreR | heartL-bowlR.wav | heart.bmp |
| ignoreR | forkL-wheelR.wav | fork.bmp |
| ignoreR | crownL-cheeseR.wav | Crown.bmp |
| ignoreR | planeL-couchR.wav | plane.bmp |
| ignoreR | ballL-cowR.wav | ball.bmp |
| ignoreR | busL-earR.wav | bus.bmp |
| ignoreR | bookL-pearR.wav | book.bmp |
| ignoreR | watchL-pantsR.wav | Watch.bmp |
| ignoreR | starL-knifeR.wav | star.bmp |
| ignoreR | horseL-clownR.wav | Horse.bmp |
| ignoreR | houseL-chainR.wav | House.bmp |
| ignoreR | cornL-beltR.wav | corn.bmp |
| ignoreR | breadL-swingR.wav | Bread.bmp |
| ignoreR | moonL-doorR.wav | Moon.bmp |
| ignoreR | carL-noseR.wav | car.bmp |
| ignoreR | handL-fishR.wav | hand.bmp |
| ignoreR | kiteL-sealR.wav | kite.bmp |
| ignoreR | flagL-broomR.wav | flag.bmp |
| unrelR | combL-sunR.wav | bell.bmp |
| unrelR | noseL-carR.wav | bed.bmp |
| unrelR | clockL-trainR.wav | Couch.bmp |
| unrelR | knifeL-starR.wav | Broom.bmp |
| unrelR | couchL-planeR.wav | Wheel.bmp |
| unrelR | spoonL- | Brush.bmp |

| | | |
|---|---|---|
| | brushR.wav | |
| unrelR | cowL-ballR.wav | hat.bmp |
| unrelR | hatL-dogR.wav | shoe.bmp |
| unrelR | earL-busR.wav | cat.bmp |
| unrelR | bowL-footR.wav | House.bmp |
| unrelR | chainL-houseR.wav | pear.bmp |
| unrelR | pantsL-watchR.wav | train.bmp |
| unrelR | sealL-kiteR.wav | hand.bmp |
| unrelR | duckL-shoeR.wav | cup.bmp |
| unrelR | eyeL-treeR.wav | door.bmp |
| unrelR | pearL-bookR.wav | book.bmp |
| unrelR | clownL-horseR.wav | cheese.bmp |
| unrelR | bearL-keyR.wav | fork.bmp |
| unrelR | bowlL-heartR.wav | chain.bmp |
| unrelR | cupL-bedR.wav | sun.bmp |
| unrelR | bellL-cakeR.wav | fish.bmp |
| unrelR | cheeseL-crownR.wav | Swing.bmp |
| unrelR | beltL-cornR.wav | foot.bmp |
| unrelR | fishL-handR.wav | cow.bmp |
| unrelR | broomL-flagR.wav | ring.bmp |
| unrelR | penL-catR.wav | Moon.bmp |
| unrelR | ringL-birdR.wav | nose.bmp |
| unrelR | doorL-moonR.wav | pen.bmp |
| unrelR | wheelL-forkR.wav | ball.bmp |
| unrelR | swingL-breadR.wav | Spoon.bmp |

# APPENDIX B

## Dichotic Listening Word Pairs

cupL-bedR.wav
hatL-ballR.wav
birdL-ringR.wav
kiteL-sealR.wav
bellL-flagR.wav
bowL-carR.wav
sunL-combR.wav
hatL-dogR.wav
fishL-handR.wav
ballL-hatR.wav
bearL-cakeR.wav
sealL-kiteR.wav
couchL-planeR.wav
duckL-shoeR.wav
earL-busR.wav
planeL-couchR.wav
keyL-noseR.wav
dogL-hatR.wav
crownL-cheeseR.wav
busL-earR.wav
penL-catR.wav
brushL-spoonR.wav
cheeseL-crownR.wav
cakeL-bearR.wav
noseL-keyR.wav
pearL-bookR.wav
carL-bowR.wav
clockL-trainR.wav
crownL-wheelR.wav
handL-fishR.wav
ringL-birdR.wav
combL-sunR.wav
bookL-pearR.wav
bedL-cupR.wav
catL-penR.wav
flagL-bellR.wav
shoeL-duckR.wav
spoonL-brushR.wav
wheelL-crownR.wav
trainL-clockR.wav

## APPENDIX C

## List Recall Task Stimuli

Syntactically simple sentences

Dad washed the car last night.

The baseball players lost their game.

Today is the first day of school.

The flowers are yellow.

The man drives the truck.

Who washed the car?

Bill is waiting for the train.

Red is my favorite color.

The school guard helps the children.

Computer games are fun.

Sam has a new desk.

What is my favorite color?

Trains go from city to city.

The pumper truck is black.

Jack never drinks coke.

Sue likes my toys.

Buses carry people.

Who does not drink coke?

Syntactically complex short sentences

Ask the man who plays with the ball.

Dad told me to give him the bread.

The city near New York is big.

The dog saw the cat chasing the mouse.

The boy who watched the baby was happy.

What did Dad ask for?

She drank it like it was soda.

The boy scratched by the cat was sick.

I will catch that one from the falling stones.

Watch me how I run the car.

The girl who helped the man had red hair.

Who was sick?

Joe ate the soup that went cold.

We can leave the one that Bill brings back.

I like the way Mom bakes cookies.

The girl helped by the man was safe.

The cat ate the plastic like it was food.

Who bakes good cookies?

Syntactically complex long sentences

Sometimes I wish I did not have to clean my room every week.

I needed three guesses until I learned what the content of those boxes was.

The children think that Jacob is always being picked on by our teacher.

The elephant risked his life to save the squirrel who could not swim.

He lives in a small house, but he has plenty of room to play.

Who is picked on by the teacher?

The teacher loved by the students was very knowledgeable and nice.

The boy carrying the big truck is watching the girl who pulls the boat.
Jonathan remembered that the homework in English was easy to write.
Robin Hood wanted to know if his men would bring us back to the forest.
It was finally decided for Harry to receive the green bicycle and Joanne the yellow roller skates.

Which homework was easy?

There was so much camping gear that the children had to get behind Daddy and push to make it all fit into the bus.
Although I forgot to study for the exam that was right after the holiday, I still did well on the test.
The young deer who was hunted by the men never stopped running or looked behind him till he got home.
Everyone helped preparing dinner for Grandpa's birthday that was celebrated by all his children.
The little rabbit, who ran into a gooseberry net, got caught by the large buttons on his coat.

Who were hunting the young deer?

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