Electronic Thesis and Dissertation Repository

7-27-2015 12:00 AM

The Relation Between Auditory Integration, Inspection Time, and Language in Children

Rachael E. Smyth
The University of Western Ontario

Supervisor
Dr. Janis Oram Cardy
The University of Western Ontario

The Relation Between Auditory Integration, Inspection Time, and Language in Children

(Thesis format: Monograph)

by

Rachael E. <u>Smyth</u>

Graduate Program in Health and Rehabilitation Sciences

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science

The School of Graduate and Postdoctoral Studies
The University of Western Ontario
London, Ontario, Canada

Abstract

It has been proposed that impairment in auditory temporal integration (ATI) may be related to impaired language development in children, although results have been inconsistent. We investigated the relation between ATI and language development and whether it is domain-specific (i.e., isolated to the auditory system) or domain-general (i.e., part of a larger, global processing system) using behavioural measures. We measured ATI and global processing speed using experimental tasks, and language and intelligence using standardized tests, in 26 5-6 year old children with typical development. Results revealed no significant relations between ATI and language, between ATI and global processing speed, or between global processing speed and intelligence. Although the correlations between our experimental and standardized tasks were not significant, further research using a larger sample with a broader range of language abilities and intelligence may offer more insight into these relations.

Keywords

Co-Authorship Statement

Dr. David Purcell contributed to the article presented in Appendix A. His role was supervising the timing test and helping to complete the technical components of the process, namely, creating the circuit to measure the camera accuracy. He was also involved in manuscript preparation for manuscript submission.

Acknowledgments

First and foremost, I would like to express my heartfelt gratitude to my supervisor, Dr. Janis Oram Cardy, for her ongoing support and guidance over the course of my MSc. I am so grateful to have had the opportunity to learn from such an incredible mentor for the last two years and I look forward to the learning and laughter that is bound to occur in the years to come. I would also like to gratefully acknowledge my thesis committee members for their contributions: Dr. Andrew Johnson, for his ongoing support, statistical and academic, and his knowledge and insight into inspection time, and Dr. David Purcell, for his positive presence and endless patience in counting frame after frame in timing test after timing test. I could not have asked for a better committee.

I would also like to thank my ASLD lab mates, Elaine, Olivia, Amanda, Margot and Heather, and my Shared Lab lab mates, Nicolette, Monica, Laura, Areej and Kristen, for their support and advice throughout this study. You are all so wonderful.

Lastly, I would like to express my appreciation for my family and friends, in particular, my parents and Jason, for helping me always focus on the bigger picture. Your support has meant so much to me.

Table of Contents

List of Tables

List of Figures

List of Appendices

Introduction

The human brain processes sensory information as it enters through various sensory pathways. The speed at which this processing occurs can impact the success with which information is processed. While specific sensory systems process specific types of sensory information, an over-arching global processing mechanism plays a role in processing all incoming sensory information on some level (Kail, 2000). One way in which the human auditory system processes sound is by integrating the incoming acoustic information over time to create the sounds that we perceive. This process is called Auditory Temporal Integration (ATI). In ATI, the auditory system *chunks* the incoming information. When this process occurs within small windows of time, the signal has good resolution (Näätänen & Winkler, 1999). Whether ATI is simply one reflection of global processing, or is an independent processing mechanism, is unclear.

Research conducted principally with children who have developmental language impairments has suggested that language development may be impacted by the resolution of ATI. In these studies, children who struggle to process auditory stimuli presented in rapid succession at an age appropriate level have tended to be those who have impairments in language (Bishop & McArthur, 2005; McArthur & Bishop, 2004; Oram Cardy, Flagg, Roberts, Brian, & Roberts, 2005; Oram Cardy, Tannock, Johnson, & Johnson, 2010). These results raise the possibility that ATI may be particularly important for language development. An alternate possibility is raised by evidence that global processing is related to overall intelligence. That is, if ATI is merely a component of global processing, its relation with language ability may simply be a reflection of the

overall relation between global processing and global cognitive functions that include, but extend beyond, language ability.

Independent bodies of research have suggested that language is related to ATI and intelligence to global processing speed. This study addressed these two separate hypotheses to investigate whether there is any relation between them. We aimed to understand whether the relation between ATI and language development is independent from, or part of, a larger, global processing mechanism. A review of the relation between ATI and global processing and how differences in the speed of these mechanisms impact other areas of development, namely language and intelligence, is provided in the sections that follow.

Auditory Temporal Integration

ATI is the perceptual process by which the human brain processes incoming acoustic information over time (Cowan, 1984). Auditory information is encoded in short periods of time and unitary auditory percepts are created as the brain integrates this incoming acoustic information. To integrate information successfully over time, all of the information that occurs between the first time point and the second time point must become one auditory percept (Cowan, 1984). Various features of the input, including loudness, pitch, amplitude modulation and formant transitions are integrated so that the percept is a neural representation of the acoustic input (Bailey & Snowling, 2002; Näätänen & Winkler, 1999). The successful perception of these auditory cues depends on temporal resolution that includes slow changes happening over longer periods of time, such as across an entire phrase, as well as changes happening quickly, such as across

phoneme articulation (Bailey & Snowling, 2002). The ability to integrate acoustic

information across slow and fast changes ensures the successful perception of speech.

Early evidence suggests that integrating acoustic features effectively over time

requires that the auditory input occur with enough time to allow for full processing of the

various acoustic features. Foyle and Watson (1984) measured the time between two tones

required by adults in order to accurately identify whether the first tone was lower or

higher in pitch than the second tone. As the time between tones decreased in length,

accuracy on the task decreased. Foyle and Watson (1984) estimated that the time required

between stimuli to accurately identify the pitch of the first tone relative to the second was

slightly higher than 100 ms. When the time between stimuli was shorter than 100-200 ms,

the auditory features of the first sound were not completely perceived. This study

demonstrated that acoustic information that occurs in close succession can be lost

depending on the length of the individual's *temporal window of integration*. This window

is a sliding, temporal window in which acoustic information is integrated into one

auditory percept (Näätänen & Winkler, 1999). Any information occurring outside the

window of ATI becomes a part of the next auditory percept (Wang, Datta, & Sussman,

2005; Winkler, Czigler, Jaramillo, Paavilainen, & Näätänen, 1998; Yabe, Tervaniemi,

Reinikainen, & Näätänen, 1997). Acoustic information in the latter part of the window of

integration is weighted more heavily, and can interfere with the consolidation of

information occurring earlier in the window. While this process is beneficial because it

segments the incoming acoustic information in an organized way, there is a risk of losing

acoustic information that occurs too close together and becomes part of one percept

(Näätänen & Winkler, 1999). The window of ATI has been estimated to be

approximately 100-200 ms in length in adults (Foyle & Watson, 1984; Yabe et al., 1998, 1997).

Auditory Temporal Integration and Language Development

There is reason to believe that the window of ATI may be important for early language development. Kuhl et al. (1997) provided an overview of support for the idea that infants acquire knowledge about features of the phonology and prosody specific to their native language through exposure to their native language in conversation around them. The smallest unit of meaningful sound that an infant must learn is the phoneme (Tallal, Miller, & Fitch, 1993; Tallal, 2000). Phonemes are not often produced in a simple, understandable way, one by one with natural boundaries between them. Instead, they occur in combination, as part of a long string of sounds, with no identifiable boundaries, and often with varying acoustic features. The features of surrounding phonemes affect the features of the phoneme being processed (Bailey & Snowling, 2002; Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967; Tallal, 2000). The inconsistencies in phoneme perception require the brain to break down the incoming strings of acoustic information systematically into consistent sections that represent the phonemes in the infant's language (Tallal, 2000). The temporal window of integration breaks a string of incoming acoustic information into percepts that ideally represent these phonemes.

This premise of phoneme perception was tested using syllable combinations in children with and without language impairment (Tallal et al., 1993). Different syllables contain different formant transitions. For example, Tallal et al. (1993) used two conditions, one with two different vowel sounds and one with two CV pairs to investigate

the role of temporal processing on phoneme perception. The vowels, /æ/ and /ɛ/, were steady-state, lasted 250 ms, and did not contain any formant transitions. The CV pairs were /ba/ and /da/ and had different consonant sounds, /b/ and /d/, occurring in the formant transition that occurred in the first 40 ms. The consonants transitioned to the same vowel sound in the final 210 ms. In both conditions, children were trained to associate a certain response button each of the responses in both pairs and in the test session, upon hearing a syllable, had to select the button that was associated with that syllable. In the steady-state condition, both groups of children had similar performance in correct identification of syllables. The difference between groups occurred in the CV syllable condition. Children with language impairment struggled to learn the buttons associated with the CV pairs and 10 of 12 participants with language impairment failed to reach threshold in learning the button associations, whereas children without language impairment performed well above chance (Tallal et al., 1993). The results from this study suggest that children with language impairment struggle to distinguish features that occur across short amounts of time. While performance didn't differ between groups on the syllables that were steady-state and occurred across 200 ms or more, children with language impairment struggled to identify phonemes that occurred quickly, across 40 ms, in this case.

The window of temporal integration can explain these results. As the temporal window of integration becomes smaller in size, the acoustic signal's resolution improves because less acoustic information makes up each individual percept. Conversely, the acoustic signal has poorer resolution when the temporal window of integration is longer, as more acoustic information is being integrated and thus there is a risk that some will be

lost to perception (Tallal, 2000). Applied to language development, it is easier if the infant's temporal window of integration is shorter, as percepts can be formed at the individual phoneme level, making phoneme segmentation a less daunting task. When the temporal window of integration is longer and crosses phoneme boundaries, perceptual chunking may capture information at the syllable level rather than at an individual phoneme level (Tallal, 2000). Processing phonemes at the syllable level makes learning the phonemes more difficult because there is an extra level of parsing that must happen. Alongside the challenges of finding consistencies in the features of individual phonemes, infants must find consistencies in the phonemes occurring within syllables (Tallal, 2000). Based on this theory, it is plausible that children with larger windows of ATI would experience difficulty in acquiring language.

Auditory Temporal Integration and Language Impairment

A number of studies have suggested that there is a relation between language development and ATI in children with specific language impairment (SLI). Children with SLI display impaired development of expressive and/or receptive language despite normal hearing, at least average non-verbal intelligence and absence of neurological impairment (Leonard, 2014). As per the DSM-V, language disorder is a neurodevelopmental disorder closely aligned with SLI, with diagnostic criteria that include: a) Difficulties in language acquisition and language use across spoken, written and sign language due to comprehension and production impairments, b) Language abilities that are noticeably lower than age-matched peers, c) Symptom onset early in development, and d) Difficulties in language that are not due to sensory or motor

impairment, medical or neurological conditions, or intellectual disability (American

Psychiatric Association, 2013).

To investigate its relation with language, ATI has been measured behaviourally

and neurophysiologically. Behavioural measures of ATI require participants to make

some type of decision about rapidly presented auditory stimuli. McArthur and Bishop

(2001) provide an excellent review of common behavioural tasks used to measure ATI.

The *Rapid Perception* task asks participants to identify the order of tones of different

frequencies (Tallal & Piercy, 1973). In the *Same-Different* task, participants must

discriminate whether two tones are the same pitch or different pitches (Tallal & Piercy,

1973). The *Auditory Choice Reaction Time* test requires participants to identify targets

that are presented randomly within a string of frequent standard sounds (Neville, Coffey,

Holcomb, & Tallal, 1993). *Backward Masking* tasks present an initial target stimulus

followed by trials in which the participant must decide whether the test stimulus, which is

followed by a mask stimulus, matches the target stimulus (Winkler & Näätänen, 1992).

The *Auditory Repetition* task uses an adaptive staircase procedure (described in more

detail in the Method section) to determine the smallest time required between two tones

to accurately repeat the sequence (Oram Cardy et al., 2010; Tallal, 1980).

The relation between ATI and language impairment has also been studied using

various types of brain imaging including electroencephalography (EEG), which measures

the electrical activity of the brain, magnetoencephalography (MEG), which records the

magnetic fields of the brain, and functional magnetic resonance imaging (fMRI), which

measures brain activity based on blood flow. In these studies, brain activity is measured

while participants perform tasks of ATI and the neural activation of participants with

language impairment is compared to that of participants without language impairment. As detailed below, although several studies provided support for a relation between ATI and language, other studies have found no such relation.

Behavioural Support

Behavioural studies have yielded inconsistent findings in terms of whether children with and without language impairment performed differently on tasks of ATI. Many studies have found results that support a relation between auditory temporal processing and language impairment. One of the earliest studies investigating this relation in children was conducted by Tallal and Piercy (1973). They asked children aged 6-9 years, both with and without SLI, to identify the temporal order of two tones of different pitches in a temporal order judgment task and to determine whether the two tones were the same or different in a same-different task. The tones were presented first with an interstimulus interval (ISI) of 428 ms and then with varying gaps between them, ranging from 8 ms to 4062 ms. Tallal and Piercy (1973) found that at an ISI of 428 ms, children with and without SLI met criterion (20 out of 24 consecutive correct responses). When the tones were presented with varying ISIs, children without SLI performed significantly better than chance when the gap between tones was as small as 8 ms, whereas the children with SLI required tones separated by longer gaps of over 300 ms to reach the same level of accuracy. The performance of both groups was similar on the same-different task; children without SLI performed with high levels of accuracy with ISIs of 8 ms, whereas children with SLI required 305 ms to reach the same level of accuracy (Tallal & Piercy, 1973)(Tallal & Piercy, 1973). The difference between the performance

of children with and without SLI on both tasks suggests that children with SLI have impairments in processing rapidly occurring acoustic information.

Following this study, other researchers also found support for a relation between auditory temporal processing and language. Studies have been completed on children with and without language impairment and with reading disabilities, which includes children with concomitant reading and language impairment. Many results from these studies have supported Tallal and Piercy's findings (Benasich & Tallal, 2002; Heath, Hogben, & Clark, 1999; Tallal & Stark, 1982; Tallal, 1980). For example, Benasich and Tallal (2002) investigated the relation between auditory temporal processing and language longitudinally in infants up until they were three years of age. They used a look and listen paradigm to measure auditory temporal processing at 7.5 months and performance on that task was highly correlated with language scores at 12, 16, 24 and 36 months (Benasich & Tallal, 2002). Heath, Hogben and Clark (1999) examined the auditory temporal processing skills of children with typical development, children with reading delays without concomitant language impairment and children with reading delays and concomitant language impairment using an *auditory repetition task* and a version of the *rapid perception task*. While there were no group differences between children with typical development and children with reading delays without language impairment nor between children with readings delays without language impairment and children with reading delays and language impairment, there was a significant group difference in auditory temporal processing performance between children with typical development and children with reading delays and concomitant language impairment (Heath et al., 1999). One implication of these studies is that there is a relation between

ATI and language. These studies all measured ATI behaviourally in different ways and each study demonstrated a relation between ATI and language or a group difference in ATI based on language ability.

By contrast, some researchers have failed to find group differences or relations between ATI and language ability. For example, Smyth, Archibald, Purcell and Oram Cardy (2014) measured ATI in children with SLI (n = 15) and typical development (n = 21) between the ages of 8 and 13 years and found no difference in their ATI thresholds. The behavioural task measured ATI by asking children to identify the longer of two gaps between pairs of tones. The two groups differed significantly in language ability, but did not differ in age or IQ. Despite differences in language ability, children with and without SLI did not differ in their ATI thresholds (LI = 70 ms, TD = 56 ms, p > .05). Although there was no significant difference in ATI thresholds, ATI threshold and language ability were significantly correlated, r = -.335, p = .046. While this correlation supports a relation between language development and ATI, the lack of group difference suggests that this sample of children with SLI did not have impaired ATI.

Oram Cardy et al. (2010) used the *auditory repetition task* to investigate ATI in children with typical development, children with SLI and children with attention-deficit/hyperactivity disorder (ADHD). While they did find group differences in ATI between children with typical development and children with SLI, they also found group differences between children with typical development and children with ADHD. There were no group differences between children with SLI and children with ADHD. While these results suggest ATI impairment in children with SLI, ATI also appears to be impaired in children with ADHD who have no concomitant language impairment. These

results call into question whether impaired ATI is a unique characteristic of SLI or whether it is something that exists as part of a number of, potentially co-occurring, disorders, including those that don't involve impaired language development. The results also raised the possibility of an issue with the face validity of the auditory repetition task; it is possible that impairments in functions other than ATI (such as attention in children with ADHD) can lead to poor performances on this task.

A study by McArthur and Hogben (2001) also called the relation between ATI and language into question. They measured ATI using a *backward masking task* in children with typical development, children with SLI who were poor readers, children with SLI who were average readers and children who had a reading disability but average language. While a subset of children with language impairment and poor reading skills demonstrated impaired performance on the ATI task, another subset of children with language impairment who were poor readers performed no differently than children with typical development or reading disability. These results are equivocal with respect to which language profiles are associated with impaired ATI, because a seemingly homogeneous language group (SLI poor readers, in this case) demonstrated heterogeneous ATI abilities. These group inconsistencies suggest that a correlation between language and ATI may be mediated by other factors and not solely language abilities.

Neurophysiological Support

Oram Cardy et al. (2005) used MEG to examine neural activity during a passive ATI task in children and youth with SLI, autism, Asperger's syndrome, typical development, and in typical adults. Participants viewed a silent movie while passively

listening to a series of tone pairs each separated by a 150 ms gap. The passive paradigm removed confounds such as attention, learning, and memory associated with behavioural measures of temporal integration. That is, MEG was used to record brain responses to the tone pairs without the participant having to make a decision about the stimuli. Neural responses to the first tone were expected for all participants, while responses to the second tone were taken as indicative of the participant's ATI window. Oram Cardy et al. (2005) found no group differences in the neural response to the first tone, but that significantly fewer participants with SLI and autism (i.e., the groups with language impairment) showed neural responses to the second tone than their peers with typical language. The response to the second tone was indicative of adequate resolution of ATI at 150 ms, thus the groups with SLI and autism appeared to have impaired ATI (Oram Cardy et al., 2005). These results suggest that impairment in ATI is associated with language impairment.

Benasich et al. (2006) used EEG to measure ATI passively in infants with and without a family history of SLI. Two interstimulus intervals (ISIs) were used in this study, 70 ms and 300 ms. Infants heard 708 standard tone pairs (two tones of 100 Hz with an ISI of 70 or 300 ms depending on the condition) with 120 deviant tone pairs (a 100 Hz tone followed by a 300 Hz tone separated by an ISI of 70 or 300 ms depending on the condition) randomly interspersed for a total of 828 stimuli. Children with a family history of SLI performed no differently than infants without a family history of SLI when tones were separated by an ISI of 300 ms, but when tones were separated with an ISI of 70 ms, significant group differences were observed in ERP responses to deviant tone pairs

(Benasich et al., 2006). Responses were smaller in infants who had a family history of SLI at an ISI of 70 ms, but not at an ISI of 300 ms.

By contrast, Kwok (2013) measured ATI in children with and without language impairment and found no significant differences between groups. Her study measured ATI using a passive event-related potential (ERP) paradigm, which offered the same benefits as reported by Oram Cardy et al. (2005). The sample consisted of 50 children between the ages of 6 and 11 years (TD: $n = 25$, $M = 9.23$ years, $SD = 1.14$; SLI: $n = 25$, $M = 9.25$ years, $SD = 1.44$). Participants listened to five conditions: one of a single tone presented repeatedly (One Tone) and four consisting of tone pairs that were presented with ISIs of 100ms, 200ms, 300ms or 400ms. Brain responses from the One Tone condition were subtracted from responses for each of the tone pair conditions to investigate whether children with typical development differed from children with language impairment in their neural responses to the second tone when different ISIs were used. There were no significant differences in neural responses between groups in any of conditions used in this study (Kwok, 2013). This study suggested that there is no difference in ATI between children with and without language impairment.

Maturation of Auditory Temporal Integration

The differences in ATI between children with and without language impairment imply that there is a relation between the development of ATI and the development of language. No studies to date have specifically examined the development of these two processes in children with typical development. However, studies have demonstrated that ATI does mature with age in children (Fox, Anderson, Reid, Smith, & Bishop, 2010; Wang et al., 2005). That is, as children become older, their windows of integration

become smaller. Fox et al. (2010) used EEG to examine ATI in 28 children aged 7 to 9 years and 15 young adults. Participants heard two tones that were separated by ISIs of 25, 50, 100, 200, 400, and 800 ms. The children showed a distinct neural response to the second tone when the tones were presented with an ISI of 200 ms or higher, while the adults demonstrated a neural response when the tones were presented with an ISI of 25 ms or higher (Fox et al., 2010). This suggests that adults have a shorter temporal window of integration than children, indicating maturation of ATI.

Wang, Datta and Sussman (2005) used MEG to investigate the length of the temporal window of integration of young children aged 5-8 years ($n = 11$), older children aged 9-11 years ($n = 9$), and young adults ($n = 6$) using a double-deviant mismatch field (MMF) paradigm. Each group of participants listened to a stream of standard tones of 440 Hz played at 80 dB that were randomly replaced on 15% of trials with a frequency deviant tone of 494 Hz played at 80 dB that was immediately followed by an intensity deviant tone of 440 Hz played at 65 dB. Four thousand stimuli were presented in total (3400 standards and 600 double-deviant pairs) in each of four stimulus onset asynchronies (SOA) conditions: 150, 200, 250, and 300 ms. An identifiable MMF response to the second deviant in the double-deviant pair was taken as evidence that the second tone fell outside the temporal window of integration for that group at that SOA. Results revealed that temporal integration occurred at SOAs as large as 300 ms for the young children, 250 ms for the older children, and 150 ms for the adults (Wang et al., 2005). In other words, increasing age was associated with a decrease in the length of the temporal window of auditory integration.

Processing Speed in Children with Language Impairment

From the review above, it is clear that children with LI have atypically long windows of ATI and that the window of ATI decreases with increasing age in typical development. What is unknown is whether the processing involved in ATI is isolated to the auditory system, or part of a larger, global processing system. Miller, Kail, Leonard and Tomblin (2001) studied a variety of linguistic and non-linguistic reaction time measures in children with SLI (impaired language and PIQ in the normal range) and Nonspecific Language Impairment (NLI; impaired language and PIQ below the normal range). The children with typical language development performed faster on both linguistic and non-linguistic tasks than children with SLI, who performed faster on both linguistic and non-linguistic tasks than children with NLI. Their results support a theory of generalized slowing in children with SLI as explained by Kail (1994), which stipulates that children with SLI perform more slowly than children with typical development on all types of processing tasks by a constant factor.

Maturation of Information Processing Speed

The human central nervous system processes incoming sensory stimuli using multiple processing systems. Perception is the mechanism by which incoming sensory stimuli is received and interpreted by the body (Julesz & Hirsh, 1978). The time it takes to react to this incoming stimuli and to make a decision about it is termed global processing speed, or *information processing speed* (Coyle, Pillow, Snyder, & Kochunov, 2011). Information processing speed is not specific to any one system, but is thought to provide an overall measure of thinking, reasoning and remembering (Kail, 2000).

Information processing speed, like auditory processing and ATI, has been shown

to mature with age. Kail (1991) compiled data, by age band, from 72 studies that

compared response times (RT) of 1,826 children or youth with typical development (TD),

to those of adults. The developmental age bands Kail used were 3-4, 5, 6, 7, 8, 9, 10, 11,

12, 13 and 14 years. Using RT = a + b + c… as a formula for RT, where a, b and c are the

time required for various mental processes, Kail was able to adjust the formula using a

constant, *m,* as a slowing coefficient for each age band, in order to demonstrate the

maturation of information processing speed. Using the slope of the function to compare

the children's RTs to the adults' RTs, Kail calculated *m* values for each age band. The

calculated *m* values, or slowing coefficients, ranged from 3.102 for 3-4 year-olds to 1.290

for 14 year-olds and showed a general decline. That is, RTs become faster as age

increases. This suggests that as children become older, their RTs in speeded tasks of

information processing become closer to adult levels.

Kail (1992) performed a similar analysis using studies that had investigated the

RTs of individuals with varying levels of impaired cognitive development compared to

age matched individuals with TD. Subgroups were created based on age and level of

cognitive ability, as indexed by IQ. The RTs of individuals in three age bands (12-16, 17-

33 and 39-45), with four ranges of IQ (SS = $\leq$ 33, 50-63, 64-67, and 68-71), were

compared to the RTs of age-matched individuals with TD. Using the same formula as

Kail (1991), slowing coefficients were compared by group. Each group with below

average IQ had a slowing coefficient between 1.428 and 2.343 relative to same-age peers.

The small number of studies (i.e. *n* = 2-5 in some cases) limits the generalizability of

these results, but they tentatively support the concept that lower cognitive function

involves slower RTs, which may reflect slower information processing speed (Kail, 1992).

Information Processing Speed and Intelligence

Investigating the relation between information processing speed and intelligence dates back to the 1920's. In 1927, Thorndike, Bregman, Cobb and Woodyard concluded that, "Other things being equal, the more quickly a person produces the correct response, the greater is his intelligence." (p. 24). General intelligence, that is, psychometric *g*, and IQ are two ways in which intelligence is frequently reported in studies of information processing speed.

First Kranzler and Jensen (1991), then Carroll (1991), performed a factor analysis investigating the make-up of psychometric *g*, with different results. Kranzler and Jensen initially addressed the question of whether psychometric *g* is one unitary process or multiple independent processes. Kranzler and Jensen reported that *g* is composed of multiple, independent processes that share some common variance, potentially due to a common speed of processing factor. They determined this by performing a stepwise multiple regression on independent variables. Each variable added a significant contribution to R^2 in predicting *g*. Thus, they concluded that psychometric *g* cannot be a unitary process (Kranzler & Jensen, 1991). Carroll performed slightly different analyses and concluded that it was more probable that *g* is one unitary process. In Carroll's expanded factor analysis, a second-order factor had the same loadings as the *g* factor (i.e., on Verbal and Performance IQ). Based on its loadings on other decision making first-order factors, this second-order factor can be understood as a measure of "efficiency in complex information processing" (Carroll, 1991, p.434). These two findings support that,

although efficiency of information processing is not a perfect measure of *g,* it does make an important contribution to *g.*

Coyle, Pillow, Snyder and Kochunov (2011) performed the first study to directly link information processing speed to the development of *g.* Coyle et al. used the Armed Services Vocational Aptitude Battery (*CAT-ASVAB forms 1 & 2,* 2006; *CAT-ASVAB forms 3 & 4,* 2009; *CAT-ASVAB forms 5-9,* 2008; *P&P-ASVAB forms 23-27,* 2012) to measure the correlation between information processing speed and *g* in a group of adolescents aged 13-17 years. They found that both information processing speed and *g* improved with age. The mean effect of age on information processing speed was 0.34, and the mean effect of age on *g* was 0.29. Information processing speed and *g* were more strongly related, with a mean effect of 0.77 (Coyle et al., 2011). The results indicated that performance on information processing speed tasks and *g* in individuals are related. As *g* is a general measure of intelligence, those with faster information processing speeds have higher levels of intelligence (Coyle et al., 2011).

Inspection Time and Intelligence

Inspection Time (IT) is one measure of information processing speed. Vickers and Smith (1986) defined IT as "the time required by a subject to make a single observation or inspection of the sensory input on which a discrimination of relative magnitude is based" (p. 609). IT is often measured using a variation of the classic IT paradigm created and tested by Vickers, Nettelbeck and Willson (1972). In this paradigm, two vertical lines appear side by side on the screen. One line is slightly longer than the other. A backward mask then appears to hide the test stimulus and the participant must report whether the line on the right of the screen or the left of the screen was longer (Vickers et al., 1972).

The presentation time of the two lines is adjusted to determine the shortest duration at which the participant can identify the longest line. The participant's required accuracy (i.e, % correct response rate) varies depending on the specific paradigm being used. IT measures processing speed irrespective the motor confounds associated with reaction time tasks (Williams, Turley, Nettelbeck, & Burns, 2009). The length of time that is required to respond is not important relative to the amount of time required by the participant to make a correct observation about the stimuli (Williams et al., 2009). This eliminates some of the behavioural (motor speed) confounds of other reaction time tasks on measuring information processing speed.

Sheppard and Vernon (2008) performed a meta-analysis spanning 50 years and including 172 studies, which examined the relation between intelligence and information processing speed, as measured by IT. They investigated the correlations between IT and RT and between IT and g. Overall, they found that reaction time and IT were negatively correlated with g ($r = -0.26$). This means that longer reaction times or slower speeds of information processing signify overall lower g. IT was more highly correlated with g ($r = -.36$) than RT, although there were only 36 studies in the IT-g analysis relative to 112 studies included in the RT-g analysis.

The conclusions drawn by Sheppard and Vernon reinforce previous research which suggests that IT offers a measure of information processing speed that is highly correlated with intelligence (Grudnik & Kranzler, 2001; Nettelbeck & Kirby, 1983). Grudnik and Kranzler (2001) performed a meta-analysis specifically examining the relation between IT and intelligence and found the correlation (corrected for sampling error, attenuation and range variation) between these two functions to be $r = -0.51$. The

uncorrected correlation between IT and intelligence in this meta-analysis was $r = -0.30$, which is similar to the correlation between IT and g found by Sheppard and Vernon (2008). While an overall correlation was reported, there are gaps in the results that are not fully explained. Confidence intervals are reported for some, but not all, analyses, and the corrections made on the correlations are not explained in detail. Since the publication of these meta-analysis results, use of IT as a measure of information processing speed has increased.

Aims

To summarize, there is support for a relation between ATI and language development, and there is support for a relation between speed of information processing, as measured by IT, and intelligence. What remains unclear is whether ATI connections with language are domain specific (i.e., isolated in the auditory and language systems) or domain general (i.e., part of a larger global processing function). The purposes of this study were to investigate: (a) the relation between ATI and language, (b) the relation between information processing speed and IQ, and (c) the relation between ATI and other cognitive processes, namely intelligence and information processing speed (as measured by IT), in 5- to 6-year old children with typical development.

Hypotheses

We hypothesized that ATI would be related to language. This hypothesis is supported by differences in ATI in children with and without language impairment found in previous behavioural and neurophysiological studies, as well as, by the significant relation found between ATI and core language score in a sample of older children with and without language impairment (Oram Cardy et al., 2005; Smyth et al., 2014; Tallal &

Piercy, 1973). We also hypothesized that information processing speed and intelligence would be related, as supported by earlier studies (Coyle et al., 2011; Grudnik & Kranzler, 2001). Our final hypothesis, based on the ATI theory of SLI, is that ATI and IT, and ATI and IQ, would not be correlated. Under this theory, difficulties specific to auditory temporal processing, rather than global processing abilities, are a key contributor to language impairments. By extension, language functioning should be correlated with ATI but not with an index of global processing, IT. An alternate hypothesis is that ATI is merely one index of maturation of the overall processing system, and is only linked to language abilities to the extent that linguistic development is driven by overall processing ability. Under this alternate hypothesis, ATI and IT would be correlated with one another and with language ability.

Method

Participants

A total of 29 five and six-year-old children were recruited for this study through an existing epidemiological pool of children from London, Ontario schools who participated in a language screening study in early 2014 and indicated they would be willing to be contacted again about studies in the future. Three participants were excluded because they had a first language other than English, resulting in a final sample of 26 five and six-year-old children ($M = 6.05$, $SD = 0.24$ years), all with typical development. Participants were recruited through phone calls and personal emails.

Five and six-year-olds were recruited because Smyth et al. (2014) found no group difference in ATI thresholds between 8-13 year old children with and without SLI, but found a significant correlation between ATI and language ability. It is possible the

relation between ATI and language, and the distinction between those with and without
LI in ATI thresholds, is more evident at younger ages. Examining this relation earlier in
development may allow us to capture a relation that had slowed or begun to plateau by 8-
13 years of age.

All 26 participants in the final sample spoke English as their primary language
and had no neurological, hearing or visual impairments according to their parents/
guardians. Participants either came to Western University or were tested in their homes.
Each participant spent approximately one hour completing tests of language ability,
intelligence, ATI and information processing speed.

Measures

Participants completed a battery of tests assessing language ability, intelligence,
ATI and information processing speed.

Language Ability

Language ability was assessed using the *Clinical Evaluation of Language
Fundamentals-Preschool 2* (CELF-P2, Wiig, Secord, & Semel, 2004). The *CELF-P2* is a
standardized test that is used to measure language ability and identify language
impairments in children aged 3 to 6. The Core Language Score (CLS) is derived from
three subtests: Sentence Structure, Word Structure and Expressive Vocabulary. Sentence
Structure taps the ability to understand and interpret sentences of varying length and
grammatical complexity by asking the child to point to the picture that corresponds to the
spoken sentence. Word Structure evaluates the child's use of morphology, that is, rules of
word structure, by having the child finish sentences about pictures. Lastly, Expressive

Vocabulary measures the child's ability to name pictures of objects, actions and people (Wiig et al., 2004).

Language ability was also assessed using the *Peabody Picture Vocabulary Test-Fourth Edition* (PPVT-IV, Dunn & Dunn, 2007). The *PPVT-IV* is a valid and reliable norm-referenced receptive vocabulary test for people aged 2 years, 6 months to 90 years. In the *PPVT-IV*, children are orally presented with a word and shown four pictures. They are required to choose the one picture that best goes with the given word (Dunn & Dunn, 2007).

Each participant's *CLS* and *PPVT* standard scores were averaged to create an overall language composite. This composite ensured that receptive and expressive vocabulary, and receptive and expressive language structure were included in the language measure used to investigate the correlation between ATI threshold and language.

Non-Verbal Intelligence

Intelligence was measured using the *Wechsler Preschool and Primary Scale of Intelligence-Third Edition* (WPPSI-III, Wechsler, 2002). The *WPPSI-III* measures perceptual reasoning using three non-verbal tasks, Block Design, Matrix Reasoning and Picture Concepts (Wechsler, 2002). Block Design measures the child's ability to use blocks to recreate a pictured pattern. Matrix Reasoning evaluates the child's ability to follow a pattern and identify the next part of a sequence. Finally, Picture Concepts measures the child's ability to group objects based on shared characteristics. The three subtests are used to compute the Performance IQ (PIQ), an overall index of non-verbal intelligence.

We elected to examine PIQ rather than overall (full scale) IQ because PIQ offers an opportunity to measure intelligence independent from language, which was measured using the *CELF-P2* and the *PPVT-IV*. In samples that include children with language impairment, PIQ provides a measure of IQ that is not confounded by linguistic ability. Using Verbal IQ (VIQ) or Full Scale IQ (FSIQ) as measures of IQ include tests that draw on language ability. When the sample contains children whose language ability is known to be impaired, PIQ offers an IQ score that is not artificially lowered by the language ability of those participants with language impairment.

Although a number of the previously reviewed studies of the relation between inspection time and IQ used FSIQ measures, links specifically between inspection time and PIQ have been reported. Of particular relevance here, Nettelbeck and Young (1989) demonstrated a significant correlation between PIQ and inspection time in a sample of six-year-old children.

Auditory Temporal Integration

The Bird Task is a computerized behavioural task that measured ATI. The participants were tasked with listening to a pair of birds chirp twice each and identifying which bird chirped with a longer gap between chirps. In each trial, one bird chirped with 0 ms between chirps. The other bird chirped with a gap of varying lengths depending on accuracy of earlier trials. Which of the two birds had the 0 ms gap varied with each trial. The Bird Task generated an ATI threshold, which is the threshold at which the participant was 75% accurate in identifying the slowest chirp.

The program used a 4-interval, 2-alternative forced choice (4I-2AFC) virulent parameter estimation by sequential testing (PEST) protocol (Findlay, 1978; Sutcliffe &

Bishop, 2005) to adjust the gap size between chirps for each trial. In this protocol, four tones were presented in pairs and participants were required to make a choice about which tone pair had a longer gap between tones before moving on to the following trial. Gap sizes varied depending on the accuracy of the responses to earlier trials. Participants began with five practice trials, which started with a gap size of 500 ms. These practice trials followed the same PEST procedure as the experimental task itself. After each response, the program provided feedback on response accuracy in the form of a celebratory tone for correct responses or a sigh for incorrect responses. The examiner provided additional explanations and coaching as needed, and, where necessary, repeated the practice trial if the child appeared not to understand the task. Participants then started the task and had to complete eight reversals or 40 trials, whichever occurred first. A reversal occurred when a correct response was followed by an incorrect response, or an incorrect response was followed by a correct response.

In the Bird Task, the first tone of each tone pair was a 50 ms 440Hz tone and the second tone of each pair was a 50 ms 490Hz tone. Both tones were recorded with onset/offset ramps of 10 ms, meaning that the first 10ms of the tone contains an increase in amplitude from 0-100% and the final 10ms of the tone contains a decrease in amplitude from 100-0%. The tones were digitized at a sampling rate of 41.1 kHz using Praat software (Boersma & Weenink, 2014). The tones are separated by a silent gap ranging between 0 ms and 500 ms. Gap sizes increase or decrease in 5 ms increments between 0 and 100 ms, 10 ms increments between 100 and 300 ms, and 20 ms increments between 300 and 500 ms. Table 1 summarizes the gap sizes used in between tones. The total duration of each wav file was controlled by adding a silent gap to the end of the

tones that ensured a file duration of 600 ms, so as to prevent visual cues in the task. The first trial contains a gap of 500 ms and following two correct responses the length of the gap between tones is reduced. Based on the participant's accuracy, the length of the gap between tones is adjusted. The threshold, in ms, is determined using the average gap size following the fourth reversal.

Table 1.

Gap Sizes Between Tones

Step (wav file)	Gap Size (ms)	Step (wav file)	Gap Size (ms)
000	0	026	160
001	5	027	170
002	10	028	180
003	15	029	190
004	20	030	200
005	25	031	210
006	30	032	220
007	35	033	230
008	40	034	240
009	45	035	250
010	50	036	260
011	55	037	270
012	60	038	280
013	65	039	290
014	70	040	300

015	75	041	320
016	80	042	340
017	85	043	360
018	90	044	380
019	95	045	400
020	100	046	420
021	110	047	440
022	120	048	460
023	130	049	480
024	140	050	500
025	150		

Each bird in the bird task moved up and down with the two tones, that is, when they were "chirping." It was intended that this would provide a visual cue about which bird was chirping, but not provide any visual cues about the *duration* of their chirps. However, at the outset of the study, the birds were unintentionally programmed to move up and down with the specific timing of the two tones. For example, the bird whose chirps were separated by 0 ms moved up, and then moved down 0 ms later (i.e., immediately), whereas, the bird whose chirps were separated by 500 ms moved up, and then moved down 500 ms later. Eleven participants completed the task with these visual cues about gap duration. Following detection of this programming error, these visual cues were adjusted so that the timing in between the birds' movements was standard across birds. Following this adjustment, both birds moved up and then down 500 ms later,

irrespective of the length of the gap in between chirps. An independent samples t-test confirmed that visual cues about gap duration did not result in any differences in the ATI estimates between the children who performed the task before versus after the adjustment.

At the outset of the study, the task instructions to the children were:

These two birds make different sounds. One bird chirps slowly. He makes one chirp, waits, than makes another chirp. The other bird chirps really fast. Listen very carefully and tell me which bird chirps the slowest. Is it the bird on the red box or the bird on the yellow box? You need to listen carefully because it won't always be the same bird. Let's practice a few first.

During data collection, we observed that these instructions were not sufficient for some participants during the practice trials. Specifically, some children were confused by the task of identifying the bird that *chirped the slowest*. To make the instructions more understandable, alternative explanations were used, including asking the child to select the bird that *chirped twice instead of once*, *waited longer in between its chirps*, or *chirped, had a long pause and chirped again*. The use of these alternate explanations made the instructions more understandable for children in this sample.

Information Processing Speed

The Benny Bee IT task was used to measure information processing speed through the measurement of IT (Williams et al., 2009). The Benny Bee IT task uses pattern backward masking to assess IT. Participants were told that Benny is the fastest bee in the world. Two identical flowers appeared on the screen (one at the top of the screen and one at the bottom), and Benny the Bee appeared on one of the flowers. Seven

bumblebees then appeared on both flowers to mask the initial stimulus (i.e., Benny).

Participants were tasked with identifying which flower Benny the bee landed on before

the mask (see Figure 1 for an example; Williams et al., 2009). Using an adaptive staircase

algorithm, the time between Benny landing on the flower and his friends arriving at the

flower changes depending on the accuracy of previous trials. The Benny Bee IT task

produces a threshold at which the participant is 79% accurate at identifying the flower

that Benny the Bee landed on first.

The Benny Bee IT task was validated against the Pi-figure IT task, which is

commonly used to test IT in adults (Evans & Nettelbeck, 1993; Vickers et al., 1972). The

Benny Bee IT task correlated $r = .527$ $p < .001$ with the Pi-figure IT task in a group of

adults. Williams et al. (2009) presented the Benny Bee IT task at two time points to 71

four-year-old children ($M = 4.45$, $SD = 0.27$). The test-retest reliability between time 1

and time 2 for the children was $r = .793$, $p < .001$, indicating no practice effects and good

reliability.

A cathode-ray-tube (CRT) monitor was required for the Benny Bee IT task to

ensure visual timing properties were of high quality. A timing task was run on the Benny

Bee IT task using external hardware and the CRT monitor to verify that the results

produced by the Benny Bee IT task were being reported accurately. The method in this

timing test is described in greater detail in Appendix A.

Figure 1. The Benny Bee Inspection Time Task (Williams, Turley, Nettelbeck, & Burns, 2008). Top panel: The flowers appear. Middle panel: Benny the Bee appears on one flower as the target stimulus. Bottom panel: Benny's friends appear to mask which flower Benny appeared on.

Statistical Analyses

Pearson's product-moment correlations were run between the following variables: age, language ability (CLS, PPVT and Language Composite), PIQ, ATI threshold (ms) and IT threshold (ms). Direct entry regression analyses were also run on ATI and IT using Age, CLS, PIQ and ATI or IT as predictors.

Results

Demographic information for the sample on all variables is provided in Table 2.

Table 2

Demographic Information

	Mean	SD	Min	Max
Age (years)	6.05	0.24	5.42	6.50
PPVT	116.69	10.33	94.00	136.00
CELF-CLS	106.23	10.04	88.00	123.00
Language Composite	111.46	9.21	97.00	126.50
PIQ	108.27	13.34	82.00	131.00
IT Threshold (ms)	167.67	79.46	51.45	314.58
ATI Threshold (ms)	116.87	115.67	4.00	451.00

Note. Peabody Picture Vocabulary Test (PPVT), Clinical Evaluation of Language Fundamentals (CELF) and Performance IQ (PIQ) are standard scores with $M = 100$ and $SD = 15$.

Outlier Analysis

Outliers were defined as participants with scores that fell more or less than 3 SD from the mean. In both experimental tasks (The Bird Task and The Benny Bee IT task), there were no participants whose ATI threshold or IT threshold fell outside +/- 3 SD.

Therefore, no participants were excluded for being outliers based on their ATI thresholds or their IT thresholds.

Pearson's Product-Moment Correlations

Correlations were run between the experimental tasks and the other behavioural measures. There was a significant correlation between inspection time threshold and age, $r(25) = -.51$, $p < .01$. The correlations between the other standardized and experimental variables were not significant. The expected relations between processing speed tasks and language and IQ were not significant (see Table 3).

Table 3

Bivariate Correlations Between Experimental Measures and Psychometric Measures

	Age	PPVT	CLS	Language Composite	PIQ	ATI Threshold (ms)
IT Threshold (ms)	-.51**	-.05	-.11	-.09	-.12	.24
ATI Threshold (ms)	-.33	-.16	-.09	-.14	.15	-

** $p < .01$

Regression

Two direct entry regressions were run. The first was conducted on ATI threshold with Age, CLS, PIQ and IT threshold as predictors. The second was conducted on IT threshold with Age, CLS, PIQ and ATI threshold as predictors. In the regression predicting ATI threshold, there were no significant predictors in the model and the model predicted 1% of the variation in ATI threshold (see Table 4). In the model predicting IT threshold, Age was the only significant predictor, $\beta = -.469$, $p < .05$. Other variables did

not significantly predict variation in IT threshold. Overall, the model explained 14% of

the variability in IT threshold (see Table 5).

Table 4

Summary of Coefficients, Confidence Intervals, t-values, p-values and Partial Correlations for ATI

Predictors of ATI	B	95% CI [lower bound, upper bound]	*t*	*p*	Partial Correlations
Age	-126.260	-354.266, 101.746	-1.152	.262	-.244
Core Language Score	-2.042	-7.442, 3.357	-.787	.440	-.169
Performance IQ	2.217	-1.846, 6.279	1.135	.269	.240
IT Threshold (ms)	.165	-.538, .868	.488	.631	.106

Note. Model accounts for 1% of the variability in ATI; $p > .05$; CI = confidence interval; * = significant variable; ATI = Auditory Temporal Integration; IT = Inspection Time.

Table 5

Summary of Coefficients, Confidence Intervals, t-values, p-values and Partial Correlations for IT

Predictors of IT	B	95% CI [lower bound, upper bound]	*t*	*p*	Partial Correlations
Age	-152.804	-286.734, -18.875	-2.373	.027*	-.460
Performance IQ	-.622	-3.292, 2.048	-.484	.633	-.105
Core Language Score	-.145	-3.659, 3.369	-.086	.932	-.019
ATI Threshold (ms)	.068	-.222, .357	.488	.631	.106

Note. Model accounts for 14% of the variability in IT, $p > .05$; CI = confidence interval; * = significant variable, $p < .05$; IT = Inspection Time; ATI = Auditory Temporal Integration.

Discussion

In the current study, we measured ATI, language, information processing speed and intelligence to investigate whether ATI is related to language and isolated to the auditory processing system, or whether it is a more global process related to global processing speed and intelligence in young children. We sought to examine the relations between ATI and language, and between IT and intelligence, and to determine whether ATI may be domain specific (i.e., isolated to the auditory system) or domain general (i.e., part of a larger, global processing system). To do this, ATI and information processing speed were measured behaviourally, using the Bird Task and the Benny Bee Inspection Time task, respectively. Standardized tests evaluated participants' oral language abilities and PIQ. Correlational analyses investigated the relation between ATI and language and between ATI and other cognitive processes, namely information processing speed as measured by IT and nonverbal intelligence. Regression analyses examined the predictive effect of language, intelligence and age on ATI and IT, separately.

As reported in the Results section, the correlation between age and IT was significant. By contrast, there were no significant correlations between ATI and language, ATI and IT, and IT and PIQ, suggesting that these processes are not related. Not only were the correlations not significant, but they also were quite weak and could have occurred due to chance. The absence of expected correlations between these cognitive processes makes it difficult to interpret whether ATI is a domain-specific or domain-general process. Despite the lack of significant results, we do not have sufficient information to conclude that the relations in question do not exist. The section to follow outlines possible interpretations and explanations for the results obtained in this study.

The Relation Between ATI and Language

The primary aim of this study was to investigate the relation between ATI and language in young children using a behavioural measure of ATI. We hypothesized that ATI and language would be related in our sample based on support from prior studies demonstrating this relation between ATI and language (Benasich & Tallal, 2002; Bishop & McArthur, 2005; Korpilahti & Lang, 1994; Oram Cardy et al., 2005; Tallal & Piercy, 1973; Tallal & Stark, 1982). Children who performed better on the *CELF-P2* were hypothesized to require smaller gaps between chirps on the Bird Task to identify the bird that chirped the slowest, and children with lower *CELF-P2* scores were expected to require larger gaps between chirps to detect a difference between the two birds. Contrary to these findings, our analysis did not show a significant correlation between ATI and language ability. Possible explanations for this unexpected result, discussed in further detail below, relate to (a) an issue with sample composition, (b) an issue with the nature of the Bird task, and (c) a relation that may not, in fact, exist.

Sample Composition

Smyth, Archibald, Purcell, and Oram Cardy (2014) found that ATI as measured by the Bird Task and language were significantly correlated in a combined sample of 36 8-13 year old children with and without language impairment. However, the correlation was not evident within each group alone. That is, ATI and language were not significantly correlated within the group of children with typical development ($n = 21$) or within the group of children with language impairment ($n = 15$). When the groups were analyzed together, the correlation was significant (Smyth et al., 2014). One possible explanation for this disparity in findings is range restriction of scores when the sample

was split by language ability. The sample studied in the present thesis, much like the group with typical development in our prior study, consisted of 26 children whose language scores were within the average to above average ranges, with many participants approaching 2 *SD* above the mean. This range restriction was unintentional, but rather an artefact of recruitment from the epidemiological sample: parents who agreed to participate happened to have children who were developing language normally or even precociously. This might account for the low correlations between ATI and language found here.

When there is a restricted range of scores, the sensitivity to detect a correlation between measures is highly reduced because there is small variability (Sackett & Yang, 2000). In the present study, to detect how differences in language scores are related to differences in ATI, differences in both scores must exist (Howell, 2010). Although the variation in ATI is large in our sample, the variation in language scores was less so, decreasing the ability to detect a correlation in this sample.

What Does the Bird Task Measure?

Another possible reason for the lack of ATI and language correlation in this study is that the Bird Task may not be tapping the level of ATI at which an impairment exists in children with SLI, or that is related to language development more broadly. Tallal (2000) hypothesized based on data collected using the *Rapid Perception* task and the *Same Different* task that the primary processing impairment in children with SLI is temporal in nature (Tallal & Piercy, 1973; Tallal, 2000). Children with TD were able to perform significantly better than chance at the smallest ISI, while children with SLI required ISIs of 300 ms or greater (Tallal & Piercy, 1973). While it is possible that the processing

impairment is temporal, other hypotheses may explain the differences in performance on these tasks. The tones presented in these tasks are often different frequencies. Researchers have questioned whether the impairment has to do with discrimination at the temporal level, discrimination at the frequency level, or some interaction of the two (Burlingame, Sussman, Gillam, & Hay, 2005; Hill, Hogben, & Bishop, 2005). The Bird Task requires children to make a decision about the relative gap size between two tone pairs. Although the tones within each tone pair are not the same frequency, the task does not require the participant to discriminate the frequencies because both tone pairs have the same two tones in the same sequence. If, as has been questioned, the impairment in children with SLI exists at a frequency discrimination level, the Bird Task would likely not capture this difference between children with TD and children with SLI. A more thorough analysis of what the Bird Task measures is discussed towards the end of the Discussion.

No Relation between ATI and Language?

A final explanation for the lack of significant correlation between ATI and language is that there may be no relation between ATI and language development. As discussed in the Introduction, behavioural paradigms have shown inconsistencies in identifying group differences in ATI between individuals with and without language impairments. The literature investigating the relation between ATI and language development has also presented contradictory results. McArthur and Bishop (2001) reviewed the results of 35 studies that measured ATI behaviourally and found a mix of results, some of which support a difference in ATI, and some of which identify no difference in ATI between children with and without language impairment. The tasks that

researchers used to measure ATI have been varied. Although different tasks are often used to measure ATI, if an impairment in ATI exists in children with a language impairment, the tasks should all capture this impairment (McArthur & Bishop, 2001). If some tasks are finding impaired ATI and some are not, there may be an inconsistency in what the tasks themselves are measuring.

It may be that the tasks capturing a difference in ATI between children with and without language impairment are actually capturing a difference in some other cognitive factor. Factors such as attention, memory, motivation and learning could also influence performance on these tasks (McArthur & Bishop, 2001; Protopapas, 2014). Tasks measuring ATI that require active participation, as is the case with most behavioural paradigms, may tap these other cognitive factors. Attention, memory, motivation and learning can be controlled in different ways. Control tasks can be used to compare against performance on tasks of ATI to show that differences in performance are related to ATI. Individuals with impairments in ATI should succeed at the control tasks, but perform poorly on tasks measuring ATI (McArthur & Bishop, 2001; Protopapas, 2014). Although control tasks do safeguard against some cognitive processes, the most effective way of controlling for these other cognitive factors is to measure them separately to assess the impact that they have on participants' performance on tasks thought to measure ATI (McArthur & Bishop, 2001). Our sample consisted solely of children who did not have language impairment. The children in our sample were all typically developing and, as such, may have been less susceptible to the impact of attention, memory, motivation and learning on their performance on the Bird Task.

How Do We Explain Neurophysiological Evidence?

While there are confounding variables that are associated with measuring ATI using behavioural tasks, there remains support for the relation between ATI and language ability from passive neurophysiological paradigms. For the present study, the absence of a relation between ATI and language might be explained by confounds associated with using the Bird Task, an active paradigm. If there is really no relation between ATI and language, the passive neurophysiological results supporting impaired ATI in individuals with SLI remain unexplained. Many of the neurophysiological studies of ATI use passive auditory paradigms in which ATI is assessed based on neural responses to simple tones without any active response required by the participant (See Clunies-Ross, Brydges, Nguyen, & Fox, 2015; Fox, Anderson, Reid, Smith, & Bishop, 2010; Kwok, 2013; Oram Cardy, Flagg, Roberts, Brian, & Roberts, 2005 for examples). The passive component of the paradigms ensures that external factors, such as attention, memory, motivation and learning, are not confounding. The support in the literature for a relation between ATI and language based on the use of passive neurophysiological tasks limits the likelihood that the lack of correlation between ATI and language in the present study reflects a true lack of relation between these functions.

The Relation Between ATI and Cognitive Processes

As was expected, ATI was not significantly correlated with IT or with PIQ. These results can be interpreted in several ways. Based on the discussion in the previous section, the absence of a significant correlation could suggest that some of the issues that potentially impacted the relation between ATI and language also impacted its relation with other cognitive functions such as IT and PIQ. The absence of a significant

correlation could also suggest that domain-general information processing speed is related to a level of auditory processing that is not captured by tests of ATI. Finally, the absence of a significant correlation could suggest that ATI is a domain-specific process and is isolated to the auditory system, as we hypothesized.

Study Design Issues

As has been previously discussed in the section on ATI and language, there were aspects of study design that may have impacted the correlational results. First, the sample composition may have affected not only the correlation between ATI and language, but also other correlations in the study. Reduced variability in scores may have reduced the ability for the study to detect relations between all tasks (Howell, 2010). The PIQ scores in this study ranged from 82-131. There was only one child who scored below 90 and the rest of the sample ranged from 90-131. The IT task also showed a reduction in range. The range of thresholds in the Benny Bee IT task for this study was 51-315 ms. When compared to the range of IT reported by Williams et al. (2009), which was 88-644 ms, it is apparent that our study had a truncated range in IT thresholds. The difficulty associated with a reduced range of scores to detect correlations between ATI and language is much the same as the difficulty in finding correlations between ATI and PIQ and between ATI and IT threshold.

Second, the Bird Task may not capture ATI at the level at which an impairment exists, or may be confounded by other cognitive factors. If ATI and PIQ or ATI and IT are indeed related, it may be this relation needs to be captured by a different type of ATI task.

Domain-General Process at Another Level of ATI

The theory of domain-general processing cannot be ruled out due to the absence of a significant correlation between ATI and PIQ and between ATI and IT. It may be that on some level, ATI is a domain-general process that is related to overall information processing speed and that the Bird Task is tapping ATI at an auditory specific level. There is support in the literature for the possibility of a domain-general theory. The theory of rapid temporal processing posits that auditory temporal processing is dependent on the speed at which information can be processed at a pansensory level, that is, including but not restricted to the auditory modality (Tallal, Stark, & Mellits, 1985). Rammsayer and Brandler (2007) collected data on 15 intelligence tasks and 8 temporal tasks. They performed a principal components analysis on the psychometric tasks of intelligence to estimate psychometric *g*. Seven temporal tasks that were auditory in nature, loaded on a temporal *g* factor that was significantly correlated with psychometric *g* ($r = 0.56, p < .01$). These results suggest that higher psychometric *g* is correlated with better performance on temporal auditory tasks (Rammsayer & Brandler, 2007). This supports a relation between auditory temporal processes and overall psychometric *g*. In the study by Rammsayer and Brandler, one auditory temporal task did not load on the temporal *g* factor, and was not significantly correlated with psychometric *g*. Extrapolating the results from Rammsayer and Brandler (2007) to the present study, it is possible that the Bird Task is not measuring auditory processing at a level that is related to PIQ or IT. It may be that the Bird Task measures ATI at a domain-specific level, but that there are levels of ATI that are domain-general in nature.

ATI as a Domain-Specific Process

The absence of a significant correlation between ATI and PIQ and between ATI and IT in this study may also suggest that ATI is, in fact, a domain-specific process. While there is support in the literature for a domain-general theory, there is also support in the literature for ATI as a domain-specific process. According to the definition of SLI, children with SLI have impaired language without impairments in nonverbal intelligence (Leonard, 1998). It may then be reasonable that ATI, a process thought to be related to language, and PIQ and IT, processes related to intelligence, may be independent. However, the absence of a relation between ATI and IQ and ATI and IT found here would provide more compelling support for the domain-specificity of ATI if the relation between ATI and language had been significant in this study. The lack of a relation between ATI and language raises significant questions about the Bird Task, which limit the ability to draw conclusions from the absence of correlations between ATI and IQ and between ATI and IT.

The Relation Between IT and PIQ

In this sample of children, the correlation between IT and PIQ was not significant. The absence of this correlation is surprising, as studies dating back to the 1970's have found strong support for the relation between IT and IQ in populations made up of individuals of various ages and cognitive capacities, and using various IT tasks (Brand & Deary, 1982; Burns & Nettelbeck, 2003; Deary, Caryl, Egan, & Wigh, 1989; Grudnik & Kranzler, 2001; Nettelbeck & Young, 1989, 1990; Petrill, Luo, Anne, & Detterman, 2001; Williams et al., 2009). The Benny Bee IT task, which was used in this study, is a relatively new task designed to measure IT specifically in young children. While

possible, it seems unlikely that limitations of the task itself account for the lack of a significant correlation between IT and PIQ, as the validity and reliability of the Benny Bee IT task were well documented (Williams et al., 2009). In the Williams et al. validation sample, a correlation of $r(67) = -.535$, $p < .01$ was found between the Benny Bee IT task and the unrotated first principal component of a principal component analysis of four psychometric tests, which represented an approximation of g.

Because the correlation between IT and IQ has been widely established, there are two more probable explanations for the absence of a significant correlation between IT and IQ in this study. The first is a reiteration of the explanation for other non-significant correlations in this study, study design. The second explanation is that our decision to use PIQ as our measure of intelligence may have impacted the correlation between IT and IQ.

Study Design

Limitations in the sample composition and sample size may account for the lack of correlation between IT and IQ. It has been shown that the established correlation between information processing speed as measured by IT and IQ is dependent on a sample including children with lower IQ (Brand & Deary, 1982; Nettelbeck & Young, 1989). Deary, Caryl, Egan and Wigh (1989) calculated that studies investigating the relation between IT and IQ with small sample sizes ($n \approx 20$) would fail to find significant correlations between the two 70% of the time. Small sample sizes and reduced variance, both of which occur in our study, could be responsible for an absence of correlation (Howell, 2010). A non-significant correlation does not necessarily imply that IT and IQ are not correlated (Deary et al., 1989); It may simply mean that our sample was too small with too little variance to detect the relation.

PIQ as a Measure of IQ

The decision to use PIQ as a measure of IQ in this study stemmed from our desire to have a measure of intelligence that was independent from language, which was measured using other tools. Full-scale IQ (FSIQ) and verbal IQ (VIQ) both contain tasks that have verbal demands and as such, PIQ was chosen as a measure of IQ so as to eliminate the effect that the verbal demands would have on IQ estimation.

Studies investigating the relation between IT and IQ in young children have demonstrated a few points of interest to this discussion. First, some correlations between IT and PIQ have been lower (albeit significant) than correlations between IT and FSIQ or between IT and VIQ in young children (Nettelbeck & Young, 1989, 1990). In older samples, the opposite has been found. Nettelbeck's (2001) review of trends found in the IT – IQ literature indicated that the relation between IT and PIQ is often stronger than the relation between IT and VIQ. It is worth noting the sample sizes in these studies were larger and when correlations were run on subsets of 30 participants, the correlations dropped below a level of significance (Nettelbeck & Young, 1989, 1990). There may be slight differences between IQ tests for young children and those for adults, which may change the loadings of different tasks and explain why the relation between PIQ and IT threshold may be attenuated in younger children. It has been suggested that in children, tasks of verbal ability and tasks of IT are both impacted by fluid intelligence, which may explain the absence of a correlation between IT threshold and PIQ in this sample (Brand & Deary, 1982).

Maturation of IT

One relation of interest that has been supported in the literature and that we found to be significant in our sample was the correlation between IT and age. Despite a narrow age range (5.42 – 6.50 years), which reduces variability, a significant correlation was found between age and IT. This result suggests that the IT-age relation is quite strong. The regression run on predictors of IT demonstrated that age was a significant predictor of IT. The results of the regression suggested that as children age, their performance on the IT task improves at a rate of 14 ms/month. The results of this age analysis suggest that despite low variability, strong relations can be demonstrated in smaller samples.

How Effective is the Bird Task as a Measure of ATI?

The lack of predicted correlations between ATI and language, and ATI and age raise the possibility that the Bird Task is not an effective measure of ATI. As has been previously discussed, the Bird Task is a paradigm that requires the active participation of children. Although we made efforts to design the task in a way that it would be easier and more engaging than some other psychobehavioural ATI tasks used in the literature, the active response component, in and of itself, created a risk for confounds because of possible demands on cognitive factors such as attention, memory, motivation and learning.

In the Bird Task, children are required to hold both tone pairs in short-term memory and recall them for comparison purposes once both tone pairs are played. McArthur and Bishop (2004) used a three interval-two forced choice (3I-2AFC) paradigm to reduce confounds of memory and verbal labeling on a task of frequency discrimination. In 3I-2AFC paradigms, individuals hear three tones. Either the first or the

third tone is the target tone; the second tone is always the same in frequency as the target.

The remaining tone is different in frequency. The participant must identify whether the

first or the third tone is the same as the second tone. This task format reduces verbal

labeling because it doesn't require participants to associate labels (i.e., low or high) with

tones. That is, it reduces memory load through eliminating the absolute determination

about the stimuli (i.e., were the tones ordered low high or high low) after making the

relative judgment. Using a task with reduced memory and verbal labeling load ensures

that the score obtained better represents the auditory processing ability of those being

tested (McArthur & Bishop, 2004). A similar task to 3I-2AFC paradigms is the six

interval backward task (6I). In 6I paradigms, three tone pairs are used and participants

must decide whether tone pair two is the same as tone pair one or tone pair three. The 6I

paradigms seem to most reliably and most effectively measure auditory processing for

young children (Sutcliffe & Bishop, 2005). Based on the *temporal uncertainty account,*

children likely have trouble focusing on the target tone when it occurs. This explains why

certain formats of the task are more difficult for children. In the 6I format of the task,

children are provided with two beneficial opportunities to decide which pair sounds like

tone pair two. Children can use tone pair one and decide whether it is the same or

different than tone pair two without requiring tone pair three, but can use tone pair three

as another set of stimuli to verify that the right decision has been made (Sutcliffe &

Bishop, 2005). This information suggests that the 2I paradigm used for the Bird Task

may not have been the most reliable method for measuring ATI in 5-6 year old children.

Limitations and Future Directions

One limitation of this study was that the sample was intended to be a representative sample of 5 and 6-year-old children and be made up of children with a full range of abilities. Instead, the children who agreed to participate in this study were 26 children with typical development. No children with lower language and/or intelligence agreed to participate. Participants were recruited as part of a kindergarten screening validation study with the intention of recruiting children of all ability levels. The participant pool consisted of over 200 kindergarteners, some of whom were contacted for a follow-up visit to validate the language results of the screening study as well as participate in the experimental tasks for this study. Children who had performed at all levels on the screener were invited for this study. If we had been able to recruit some participants with lower ability levels, the variance in language and IQ scores would have been more dispersed and correlations may have been easier to identify (Deary et al., 1989).

Another limitation is that we have not conducted any investigations to determine whether the Bird task is a valid or reliable measure of ATI. This is problematic because the aims of this study were focused on ATI and its relation to a number of cognitive factors. The results of this study would have been more interpretable if we could identify with some degree of certainty that the Bird Task was measuring ATI.

A third potential limitation of this study is that our sample had a very narrow age range. The relations between ATI and age, and IT and age, which have been supported by much previous research, may be stronger across a wider range of ages. Stemming from the relation found by Smyth et al. (2014) between ATI and language in 8-13 year olds,

we had hoped to investigate whether this relation was stronger at a younger age. It is possible that the range chosen was too narrow and, if expanded, it would show the expected relation between ATI and age. On the other hand, we did find a significant relation between IT and age despite the narrow age range of our sample.

To further investigate the relations between ATI and language, ATI and other cognitive processes, and IT and IQ in children, it would be beneficial to continue recruiting participants to expand the size and variability of the sample. Children with lower language and intelligence scores and across a wider age range would enrich the sample, enabling a more thorough investigation into the relations of interest. Although significant correlations were not seen in the data collected thus far, there is ample support in the literature for these relations and it would be worth investigating further with a broader sample of abilities.

Another priority for future studies is to use a more reliable experimental task to measure ATI or to directly study the reliability and validity of the Bird Task. While the Bird Task may measure ATI, it has yet to be shown. Before using it in future studies, its validity and reliability need to be investigated. Another option would be to use an experimental task to measure ATI that has some existing evidence in support of its validity and reliability, such as one using a 6I-2AFC paradigm (Sutcliffe & Bishop, 2005).

In conclusion, despite failing to find significant correlations between auditory temporal integration and language, auditory temporal integration and inspection time and inspection time and intelligence, we cannot infer that the relations do not exist. Future research should be directed at including a more representative sample of the population

as a whole, so that the relations between these variables can be investigated more

thoroughly.

References

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders: DSM-5*. Arlington, VA.

Bailey, P. J., & Snowling, M. J. (2002). Auditory processing and the development of language and literacy. *British Medical Bulletin*, *63*, 135–146. doi:10.1093/bmb/63.1.135

Benasich, A. A., & Tallal, P. (2002). Infant discrimination of rapid auditory cues predicts later language impairment. *Behavioural Brain Research*, *136*(1), 31–49. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12385788

Bishop, D. V. M., Anderson, M., Reid, C., & Fox, A. M. (2011). Auditory development between 7 and 11 years: an event-related potential (ERP) study. *PloS One*, *6*(5), e18993. doi:10.1371/journal.pone.0018993

Bishop, D. V. M., & McArthur, G. M. (2005). Individual differences in auditory processing in specific language impairment: A follow-up study using event-related potentials and behavioural thresholds. *Cortex*, *41*(3), 327–341.

Boersma, P., & Weenink, D. (2014). *Praat: doing phonetics by computer* [Computer program]. Version 5.3.74, retrieved from http://www.praat.org/

Brand, C. ., & Deary, I. . (1982). Intelligence and "Inspection Time." In H. Eysenck (Ed.), *A Model for Intelligence* (pp. 133–150). Berlin: Springer-Verlag Berlin.

Burlingame, E., Sussman, H. M., Gillam, R. B., & Hay, J. F. (2005). An investigation of speech perception in children with specific language impairment on a continuum of formant transition duration. *Journal of Speech, Language, and Hearing Research*, *48*(4), 805–816. doi:10.1044/1092-4388(2005/056)

Burns, N. R., & Nettelbeck, T. (2003). Inspection time in the structure of cognitive abilities : Where does IT fit ? *Intelligence*, *31*, 237–255.

Carroll, J. B. (1991). No demonstration that g is not unitary, but there's more to the story: Comment on Kranzler and Jensen. *Intelligence*, *15*(4), 423–436. doi:10.1016/0160-2896(91)90004-W

CAT-ASVAB forms 1 & 2 (Technical Bulletin No. 1). (2006). Seaside, CA.

CAT-ASVAB forms 3 & 4 (Technical Bulletin No. 2). (2009). Seaside, CA.

CAT-ASVAB forms 5-9 (Technical Bulleting No. 3). (2008). Seaside, CA.

Clunies-Ross, K. L., Brydges, C. R., Nguyen, A. T., & Fox, A. M. (2015). Hemispheric asymmetries in auditory temporal integration: A study of event-related potentials. *Neuropsychologia*, *68*, 201–208. doi:10.1016/j.neuropsychologia.2015.01.018

Cowan, N. (1984). On short and long auditory stores. *Psychological Bulletin*, *96*(2), 341–370. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/6385047

Coyle, T. R., Pillow, D. R., Snyder, A. C., & Kochunov, P. (2011). Processing speed mediates the development of general intelligence (g) in adolescence. *Psychological Science*, *22*(10), 1265–1269. doi:10.1177/0956797611418243

Deary, I. J., Caryl, P. G., Egan, V., & Wigh, D. (1989). Visual and auditory inspection time: Their interrelationship and correlations with IQ in high ability subjects. *Personality and Individual Differences*, *10*(5), 525–533.

Dunn, D. M., & Dunn, L. M. (2007). Peabody Picture Vocabulary Test—Fourth Edition. San Antonio, TX: Pearson.

Evans, G., & Nettelbeck, T. (1993). Inspection time: A flash mask to reduce apparent movement effects. *Personality and Individual Differences*, *15*(1), 91–94.

Findlay, J. . (1978). Estimates on probability functions: A more virulent PEST. *Perception & Psychophysics*, *24*(2), 181–185. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/23636520

Fox, A. M., Anderson, M., Reid, C., Smith, T., & Bishop, D. V. M. (2010). Maturation of auditory temporal integration and inhibition assessed with event-related potentials (ERPs). *BMC Neuroscience*, *11*(49-64). doi:10.1186/1471-2202-11-49

Foyle, D. C., & Watson, C. S. (1984). Stimulus-based versus performance-based measurement of auditory backward recognition masking. *Perception & Psychophysics*, *36*(6), 515–522. doi:10.3758/BF03207511

Garaizar, P., Vadillo, M. a, López-de-Ipiña, D., & Matute, H. (2014). Measuring software timing errors in the presentation of visual stimuli in cognitive neuroscience experiments. *PloS One*, *9*(1), e85108. doi:10.1371/journal.pone.0085108

Grudnik, J. L., & Kranzler, J. H. (2001). Meta-analysis of the relationship between intelligence and inspection time. *Intelligence*, *29*(6), 523–535. doi:10.1016/S0160-2896(01)00078-2

Heath, S. M., Hogben, J. H., & Clark, C. D. (1999). Auditory temporal processing in disabled readers with and without oral language delay. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *40*(4), 637–647. doi:10.1017/S0021963099003947

Hill, P. R., Hogben, J. H., & Bishop, D. V. M. (2005). Auditory frequency discrimination in children with specific language impairment: A longitudinal study. *Journal of Speech, Language, and Hearing Research*, *48*(5), 1136–1146. doi:10.1044/1092-4388(2005/080)

Howell, D. C. (2010). *Statistical methods for psychology*. (J. Potter, R. Rosenberg, N. Albert, & A. Cohen, Eds.) (7th Editio.). Wadsworth, Cengage Learning.

Julesz, B., & Hirsh, I. J. (1978). Visual and auditory perception-an essay of comparison. In E. E. David & P. B. Denes (Eds.), *Human communication: A unified view* (pp. 283–340). Caledonia: McGraw-Hill Inc.

Kail, R. (1991). Developmental change in speed of processing during childhood and adolescence. *Psychological Bulletin*, *109*(3), 490–501. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/17988319

Kail, R. (1992). General slowing of information-processing by persons with mental retardation. *American Journal on Mental Retardation*, *97*, 333–341.

Kail, R. (1994). A method for studying the generalized slowing hypothesis in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*, *37*(2), 418–421.

Kail, R. (2000). Speed of information processing: Developmental change and links. *Journal of School Psychology*, *38*(1), 51–61.

Korpilahti, P., & Lang, H. A. (1994). Auditory ERP components and mismatch negativity in dysphasic children. *Electroencephalography and Clinical Neurophysiology*, *91*(4), 256–264. doi:10.1016/0013-4694(94)90189-9

Kranzler, J. H., & Jensen, A. R. (1991). The nature of psychometric g: Unitary process or a number of independent processes? *Intelligence*, *15*(4), 397–422. doi:10.1016/0160-2896(91)90003-V

Kuhl, P. K., Andruski, J. E., Chistovich, I. A., Chistovich, L. A., Kozhevnikova, E. V, Ryskina, V. L., … Lacerda, F. (1997). Cross-language analysis of phonetic units in

language addressed to infants. *Science*, *277*(5326), 684–686. Retrieved from

http://www.ncbi.nlm.nih.gov/pubmed/9235890

Kwok, E. (2013). *Auditory temporal processing in children with specific language impairment compared to same age controls*. Retreived from University of Western Ontario - Electronic Thesis and Dissertation Repository, Paper 1379.

Leonard, L. B. (2014). *Children with specific language impairment* (2nd ed.). Cambridge, Massachusetts: MIT Press.

Liberman, A. M., Cooper, F. S., Shankweiler, D., & Studdert-Kennedy, M. (1967). Perception of the speech code. *Psychological Reivew*, *74*(6), 431–461.

McArthur, G. M., & Bishop, D. V. M. (2001). Auditory perceptual processing in people with reading and oral language impairment: Current issues and recommendations. *Dyslexia*, *7*, 150–170.

McArthur, G. M., & Bishop, D. V. M. (2004). Frequency discrimination deficits in people with specific language impairment: reliability, validity and linguistic correlates. *Journal of Speech, Language, and Hearing Research*, *47*, 527–541.

McArthur, G. M., & Hogben, J. H. (2001). Auditory backward recognition masking in children with a specific language impairment and children with a specific reading disability. *The Journal of the Acoustical Society of America*, *109*(3), 1092–1100. doi:10.1121/1.1338559

Miller, C. A., Kail, R., Leonard, L. B., & Tomblin, J. B. (2001). Speed of processing in children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 44,* 416-433. doi:10.1044/1092-4388(2001/034)

Näätänen, R., & Winkler, I. (1999). The concept of auditory stimulus representation in cognitive neuroscience. *Psychological Bulletin*, *125*(6), 826–859.

Nettelbeck, T. (2001). Correlation between inspection time and psychometric abilities A personal interpretation. *Intelligence*, *29*, 459–474.

Nettelbeck, T., & Kirby, N. H. (1983). Measures of timed performance and intelligence. *Intelligence*, *7*(1), 39–52. doi:10.1016/0160-2896(83)90005-3

Nettelbeck, T., & Young, R. (1989). Inspection time and intelligence in 6-year-old children. *Personality and Individual Differences*, *10*, 605–614.

Nettelbeck, T., & Young, R. (1990). Inspection time and intelligence in 7-yr-old children: A follow-up. *Personality and Individual Differences*, *11*(12), 1283–1289.

Neville, H. J., Coffey, S. A., Holcomb, P. J., & Tallal, P. (1993). The neurobiology of sensory and language processing in language-impaired children. *Journal of Cognitive Neuroscience*, *5*(2), 235–53. doi:10.1162/jocn.1993.5.2.235

Oram Cardy, J. E., Flagg, E. J., Roberts, W., Brian, J., & Roberts, T. P. L. (2005). Magnetoencephalography identifies rapid temporal processing deficit in autism and language impairment. *NeuroReport*, *16*(4), 329–332.

Oram Cardy, J. E., Flagg, E. J., Roberts, W., & Roberts, T. P. L. (2008). Auditory evoked fields predict language ability and impairment in children. *International Journal of Psychophysiology*, *68*(2), 170–5. doi:10.1016/j.ijpsycho.2007.10.015

Oram Cardy, J. E., Tannock, R., Johnson, A. M., & Johnson, C. J. (2010). The contribution of processing impairments to SLI: insights from attention-deficit/hyperactivity disorder. *Journal of Communication Disorders*, *43*(2), 77–91. doi:10.1016/j.jcomdis.2009.09.003

P&P-ASVAB forms 23-27 (Technical Bulletin No. 4). (2012). Seaside, CA.

Petrill, S. A., Luo, D., Anne, L., & Detterman, D. K. (2001). Inspection time and the relationship among elementary cognitive tasks , general intelligence , and specific cognitive abilities. *Intelligence*, *29*, 487–496.

Plant, R. R., Hammond, N., & Turner, G. (2004). Self-validating presentation and response timing in cognitive paradigms: how and why? *Behavior Research Methods, Instruments, & Computers*, *36*(2), 291–303. doi:10.3758/BF03195575

Plant, R. R., & Turner, G. (2009). Millisecond precision psychological research in a world of commodity computers: new hardware, new problems? *Behavior Research Methods*, *41*(3), 598–614. doi:10.3758/BRM.41.3.598

Protopapas, A. (2014). From temporal processing to developmental language disorders : mind the gap. *Philosophical Transactions of the Royal Society B: Biological Sciences, 369*(1634), 20130090.

Rammsayer, T. H., & Brandler, S. (2007). Performance on temporal information processing as an index of general intelligence. *Intelligence*, *35*(2), 123–139. doi:10.1016/j.intell.2006.04.007

Sackett, P. R., & Yang, H. (2000). Correction for range restriction: an expanded typology. *The Journal of Applied Psychology*, *85*(1), 112–118. doi:10.1037/0021-9010.85.1.112

Schmidt, W. C. (2001). Presentation accuracy of Web animation methods. *Behavior Research Methods, Instruments, & Computers*, *33*(2), 187–200. doi:10.3758/BF03195365

Sheppard, L. D., & Vernon, P. A. (2008). Intelligence and speed of information-

processing: A review of 50 years of research. *Personality and Individual*

Differences, *44*(3), 535–551. doi:10.1016/j.paid.2007.09.015

Smyth, R. E., Archibald, L. M. D., Purcell, D., & Oram Cardy, J. (2014, June). *No*

difference in auditory temporal integration (ati) between children with language

impairment and typical development. Poster presented at the Symposium on

Research in Child Language Disorders, Madison, WI.

Stewart, N. (2006). Millisecond accuracy video display using OpenGL under Linux.

Behavior Research Methods, *38*(1), 142–145.

Sutcliffe, P., & Bishop, D. (2005). Psychophysical design influences frequency

discrimination performance in young children. *Journal of Experimental Child*

Psychology, *91*(3), 249–270. doi:10.1016/j.jecp.2005.03.004

Tallal, P. (1980). Auditory temporal perception, phonics, and reading disabilities in

children. *Brain and Language*, *9*(2), 182–198. doi:10.1121/1.2016007

Tallal, P. (2000). Experimental studies of language learning impairments: From research

to remediation. In D. V. M. Bishop and L. B. Leonard (Eds.), *Speech and language*

impairments in children: causes, characteristics, intervention and outcomes (pp.

131–155). Philadelphia, PA: Taylor & Francis Inc.

Tallal, P., Miller, S., & Fitch, R. H. (1993). Neurobiological basis of speech : A case for

the preeminence of temporal processing. *Annals of the New York Academy of*

Sciences, *682*(1), 27–47.

Tallal, P., & Piercy, M. (1973). Defects of non-verbal auditory perception in children with developmental aphasia. *Nature*, *241*(5390), 468–469. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/4705758

Tallal, P., & Stark, R. E. (1982). Perceptual/motor profiles of reading impaired children with or without concomitant oral language deficits. *Annals of Dyslexia*, *32*(1), 163–176. doi:10.1007/BF02647960

Tallal, P., Stark, R. E., & Mellits, E. D. (1985). Identification of language-impaired children on the basis of rapid perception and production skills. *Brain and Language*, *25*, 314–322.

Thorndike, E. L., Bregman, E. O., Cobb, M. V., & Woodyard, E. (1927). *The measurement of intelligence*. New York, New York: Teachers College, Columbia University.

Vickers, D., Nettelbeck, T., & Willson, R. J. (1972). Perceptual indices of performance: the measurement of "inspection time" and "noise" in the visual system. *Perception*, *1*(3), 263–295. Retrieved from http://www.perceptionweb.com/abstract.cgi?id=p010263

Vickers, D., & Smith, P. L. (1986). The rationale for the inspection time index. *Personality and Individual Differences*, *7*(5), 609–623.

Wang, W., Datta, H., & Sussman, E. (2005). The development of the length of the temporal window of integration for rapidly presented auditory information as indexed by MMN. *Clinical Neurophysiology*, *116*(7), 1695–1706. doi:10.1016/j.clinph.2005.03.008

Wechsler, D. (2002). *Wechsler Preschool and Primary Scale of Intelligence-Third Edition.* Toronto, ON: The Psychological Corporation.

Wetherill, G. B., & Levitt, H. (1965). Sequential estimation of points on a psychometric function. *The British Journal of Mathematical and Statistical Psychology*, *18*(1), 1–10.

Wiig, E., Secord, W., & Semel, E. (2004). *CELF Preschool 2: Clinical Evaluation of Language Fundamentals Preschool.* Toronto, ON: The Psychological Corporation.

Williams, S. E., Turley, C., Nettelbeck, T., & Burns, N. R. (2008). Inspection Time in Young Children. Journal of Neurobehavioral Experiments and Stimuli. Retrieved from http://www.neuroexpt.com/ex_files/expt_view?id=197

Williams, S. E., Turley, C., Nettelbeck, T., & Burns, N. R. (2009). A measure of inspection time in 4-year-old children: The Benny Bee IT task. *British Journal of Developmental Psychology*, *27*(3), 669–680. doi:10.1348/026151008X354573

Winkler, I., Czigler, I., Jaramillo, M., Paavilainen, P., & Näätänen, R. (1998). Temporal constraints of auditory event synthesis: evidence from ERPs. *Neuroreport*, *9*(3), 495–499. doi:10.1097/00001756-199802160-00025

Winkler, I., & Näätänen, R. (1992). Event-related potentials in auditory backward recognition masking: a new way to study the neurophysiological basis of sensory memory in humans. *Neuroscience Letters*, *140*(2), 239–42. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/1501786

Yabe, H., Tervaniemi, M., Reinikainen, K., & Näätänen, R. (1997). Temporal window of integration revealed by MMN to sound omission. *Neuroreport*, *8*(8), 1971–1974. doi:10.1097/00001756-199705260-00035

Yabe, H., Tervaniemi, M., Sinkkonen, J., Huotilainen, M., Ilmoniemi, R. J., & Näätänen, R. (1998). Temporal window of integration of auditory information in the human brain. *Psychophysiology*, *35*(5), 615–619. doi:10.1017/S0048577298000183

Appendices

Appendix A

Testing the Accuracy of Timing Reports in Visual Timing Tasks

Introduction

This article describes an independent way to test the accuracy of timing that is reported by computer programs used to carry out visual timing tasks when using any type of computer display. This article describes an example in which the timing accuracy test was performed using The Benny Bee Inspection Time task (Williams, Turley, Nettelbeck, & Burns, 2009), which is run in Neurobehavioral Systems stimulus-response software, Presentation (http://www.neurobs.com/).

Vickers and Smith (1986) defined inspection time (IT) as "the time required by a subject to make a single observation or inspection of the sensory input on which a discrimination of relative magnitude is based" (p. 609). IT thresholds are calculated based on the shortest amount of time the participant requires to make a correct decision about the stimuli in a specified percentage of trials. For example, in the Benny Bee IT Task, Benny the bee appears on one of two identical flowers and, after a certain amount of time, eight identical bees appear on each flower, acting as a mask. The mask is an identical image to overlay the stimulus that prevents processing following the display of the target stimuli (Nettelbeck & Young, 1989; Williams et al., 2009). The percentage of correct trials required varies depending on which specific paradigm is being used. In the case of the Benny Bee IT task, the threshold is the point at which the participant is 79% correct in making a decision (Williams et al., 2009). Understandably, the precision and

accuracy of the timing in these paradigms are crucial to the accurate calculation of the participant's IT threshold.

The Benny Bee IT task uses a 2 alternative forced choice, adaptive staircase procedure (Wetherill & Levitt, 1965; Williams et al., 2009). This procedure changes the time between trials by a certain period based on whether the previous response is correct or incorrect. The period is set by the display refresh rate that is estimated by the program running in Presentation. This article explains the process followed to test the timing accuracy of our program and display. It also provides steps for a generalized timing accuracy test, which can be used to test the timing accuracy of a visual paradigm using any display program and monitor combination.

To date, the visual timing properties of various display programs have been tested for error rates and some solutions have been offered. Garaizar, Vadillo, López-de-Ipiña and Matute (2014) performed timing tests using three types of software to determine which software programs have the most accurate timing properties in visual computer tasks. They tested the timing of popular, commercially available software (EPrime), popular, free software (DMDX) and free, multiplatform software (PsychoPy). To do this, Garaizar et al. (2014) used the Black Box Tool Kit (*BBTK,* Plant, Hammond, & Turner, 2004; Plant & Turner, 2009) to measure timing inaccuracies. The *BBTK* is a combination of software and hardware that uses a host computer and opto-detectors to measure the actual timing of visual and/or auditory stimuli versus the timing that is requested by the program. Other methods of timing measurement, namely a photo detector system and the operating system, Linux, were used to test the timing accuracy of the aforementioned software programs (Garaizar et al., 2014; Schmidt, 2001; Stewart, 2006). Garaizar et al.

found that there were certain times at which errors were more likely to occur within a test session, such as right before the monitor completed its vertical synchronization. They reported that errors in timing were related to the timing technology in the displays and the operating systems, but not necessarily related to the timing in the experimental paradigm software.

Schmidt (2001) investigated accuracy in the presentation of visual stimuli using internet-based programs with a photo detector system. Internet-based programs perform slightly differently than paradigms using local computer software because software and hardware are not as well controlled when the internet is being used to run the experiment. For example, when local computer software is used to run an experiment, the hardware and operating system can be accessed more directly, whereas when internet experiments are run, software and hardware are more difficult to control and hold constant due to the fact that the software is subject to effects from the internet, such as random delays in information transmission and the effects of mediating software on the process (Schmidt, 2001). Although Schmidt investigated the accuracy of internet experiments as opposed to experiments implemented using local software, his results indicated that the accuracy of all but one of the programs tested was affected by the speed of the system used in the test. These results suggest that it is important to perform a timing test using the specific system that will be used for the experiment because the accuracy changes with different systems.

The aims of the present study were to: 1) test the accuracy of the timing mechanism in a visual task by comparing the timing as requested by the task to the actual timing using readily available and inexpensive consumer hardware, and 2) provide an

independent way to test the timing accuracy of a visual computer task that is run on a cathode ray tube (CRT) monitor or another type of monitor.

Method

Materials

We used a Lenovo T440 computer with an Intel® Core ™ i7-4600U CPU @ 2.10 GHz 2.70 GHz running 64-bit Windows 7 Professional to perform the timing tests. The CRT display that was attached to the computer was an Elo Touchsystems monitor, model ET1725C-4UWE-3 (100-240V, 1.5A, 60/50Hz, P/N 454000-000). The consumer grade Fujifilm FinePix F600EXR camera was used to record high-speed video at 320 frames per second (fps) while mounted on a tripod and framing the CRT display. Default settings for 320 fps were used and individual frames were 320 x 240 pixels. We felt it was prudent to verify this consumer grade camera operated at the 320 fps specified in its documentation. A test circuit was constructed to flash a white light emitting diode (LED) with a known pattern so that the number of camera frames showing the periodically lit LED could be counted. The circuit lights the white signal LED for any input voltage greater than approximately 200 mV with switching times faster than the camera frame rate of 1/320 = 3.125 ms. Our test signal was generated by a computer sound card using MATLAB (Mathworks, MA) such that the LED would be periodically lit for 20 frames (62.5 ms) and unlit for 10 frames (31.25 ms) if the camera operated as documented. The camera saves video as a *.mov* file that was first transferred to computer and then individual sequential frames were extracted using the program Zeranoe FFmpeg (version 2014-03-20 git-19139d8, retrieved from http:// http://ffmpeg.zeranoe.com/builds/). After viewing and counting lit and unlit frames, we concluded the camera frame rate was

accurately 320 fps. The same manner of extracting and reviewing frames was also used to verify the timing of the Benny Bee IT task. The Benny Bee IT task was run using Neurobehavioral Systems Presentation (http://www.neurobs.com/) software.

Procedure

The Benny Bee IT task estimates the refresh rate prior to the start of each test session. This refresh rate estimation impacts the period by which the time between Benny the Bee appearing and his friends appearing changes with each trial. Prior to using this task in a study, we wanted to evaluate whether the times reported between Benny the Bee arriving and his friends arriving were accurate.

First, the camera was tested to ensure it was recording at a rate of 320 frames per second, as is described in the *Materials* section above. The camera was then set up using a tripod to record the Benny Bee Inspection Time task on the CRT monitor in videos of 30 seconds each. These videos were used to analyze the timing. The camera recorded 320 frames/second with a period of $((1/320)*1000)$ 3.125 ms/frame. The refresh rate on the monitor and software were both set to 85 Hz. The refresh period of the monitor $((1/85)*1000)$ was 11.76 ms. The monitor and Presentation software were set to the same refresh rate of 85 Hz.

To measure timing errors, the time between Benny the Bee appearing on the screen and the mask appearing on the screen as requested by the program was compared to the actual time between Benny appearing on the screen and the mask appearing on the screen by analyzing the high-speed video recordings of the task. The frame number in which Benny appeared was recorded and the frame in which his friends appeared was recorded for each trial. The difference in frame number between these two frames was

multiplied by the camera's frame period (3.125 ms) to give us the actual time between Benny arriving and his friends arriving. The actual time was then compared to the time difference requested by the program. In the end, we created a difference between the actual time and the requested time, and, if the difference was larger than one monitor period, it was an error that likely impacted the results of that trial.

Results

When the timing test to estimate refresh rate was run, the program calculated a period of 11.76 ms by averaging the delays of 100 test stimuli. This period was the time required to complete one vertical refresh of the monitor. In a test of 59 trials, 48 were recorded on video. Of these 48 recorded trials, there were no errors larger than one monitor period in this test. This suggests that, for the hardware and software employed here, the paradigm can run with a high level of accuracy. Errors in the timing were all smaller than the refresh rate (11.76 ms), as can be seen in Figure 2, and therefore, did not affect the accuracy of presentation.
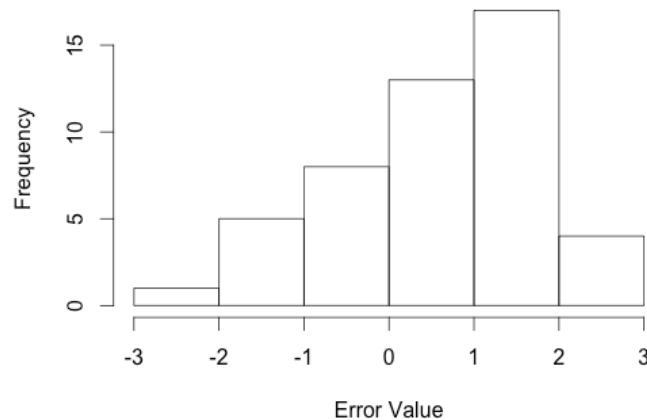

Figure 2. Distribution of timing error values.

Conclusion

This study demonstrated that the paradigm run in Presentation on our Lenovo laptop connected to the CRT monitor did not contain timing errors that affected the results. We verified this independently using a combination of hardware and software (i.e. Fujifilm FinePix camera, the test circuit, and Zeranoe FFmpeg). This study explains an independent procedure that can be used to test the accuracy of visual timing paradigms. It can be used as a test of accuracy for paradigms run in any software program on any operating system. The refresh rates of the display and software play large roles in the timing accuracy of the paradigm and this type of timing test captures this influence. This study offers a readily available, inexpensive, consumer hardware based alternative to previously reported timing tests that employ photo detectors or other hardware.

References

Garaizar, P., Vadillo, M. a, López-de-Ipiña, D., & Matute, H. (2014). Measuring software timing errors in the presentation of visual stimuli in cognitive neuroscience experiments. *PloS One*, *9*(1), e85108. doi:10.1371/journal.pone.0085108

Nettelbeck, T., & Young, R. (1989). Inspection time and intelligence in 6-year-old children. *Personality and Individual Differences*, *10*, 605–614.

Plant, R. R., Hammond, N., & Turner, G. (2004). Self-validating presentation and response timing in cognitive paradigms: how and why? *Behavior Research Methods, Instruments, & Computers : A Journal of the Psychonomic Society, Inc*, *36*(2), 291–303. doi:10.3758/BF03195575

Plant, R. R., & Turner, G. (2009). Millisecond precision psychological research in a world of commodity computers: new hardware, new problems? *Behavior Research Methods*, *41*(3), 598–614. doi:10.3758/BRM.41.3.598

R Core Team (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Schmidt, W. C. (2001). Presentation accuracy of Web animation methods. *Behavior Research Methods, Instruments, & Computers*, *33*(2), 187–200. doi:10.3758/BF03195365

Stewart, N. (2006). Millisecond accuracy video display using OpenGL under Linux. *Behavior Research Methods*, *38*(1), 142–145.

Vickers, D., & Smith, P. L. (1986). The rationale for the inspection time index. *Personality and Individual Differences*, *7*(5), 609–623.

Wetherill, G. B., & Levitt, H. (1965). Sequential estimation of points on a psychometric function. *The British Journal of Mathematical and Statistical Psychology*, *18*(1), 1–10.

Williams, S. E., Turley, C., Nettelbeck, T., & Burns, N. R. (2009). A measure of inspection time in 4-year-old children: The Benny Bee IT task. *British Journal of Developmental Psychology*, *27*(3), 669–680. doi:10.1348/026151008X354573

Appendix B

Western Research

Use of Human Participants - Initial Ethics Approval Notice

Principal Investigator: Dr. Lisa Archibald
File Number: 105151
Review Level: Delegated
Protocol Title: Validation of a Kindergarten Language Screening Measure
Department & Institution: Health Sciences\Communication Sciences & Disorders, Western University
Sponsor: Natural Sciences and Engineering Research Council

Ethics Approval Date: May 15, 2014 Expiry Date: March 29, 2015

Documents Reviewed & Approved & Documents Received for Information:

Document Name	Comments	Version Date
Instruments	PPVT-4 test form	
Instruments	CELF-P2 test form	
Western University Protocol	Revised Protocol _ April 24, 2014	2014/04/24
Instruments	Task Description _ April 24, 2014	2014/04/24
Instruments	WPPSISubtests_April24, 2014	2014/04/24
Letter of Information & Consent	RevisedLOI_April 24, 2014	2014/04/24
Assent		2014/05/09

This is to notify you that The University of Western Ontario Research Ethics Board for Non-Medical Research Involving Human Subjects (NMREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the applicable laws and regulations of Ontario has granted approval to the above named research study on the approval date noted above.

This approval shall remain valid until the expiry date noted above assuming timely and acceptable responses to the NMREB's periodic requests for surveillance and monitoring information.

Members of the NMREB who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussions related to, nor vote on, such studies when they are presented to the NMREB.

The Chair of the NMREB is Dr. Riley Hinson. The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941.

Ethics Officer to Contact for Further Information

Grace Kelly (grace.kelly@uwo.ca)	Vikki Tran (vikki.tran@uwo.ca)	Mina Mekhail (mmekhail@uwo.ca)	Erika Basile (ebasile@uwo.ca)

This is an official document. Please retain the original in your files.

Appendix C

Western
HealthSciences

Validation of a Kindergarten Language Screening Measure

Information about the Study
Your child is participating in our ongoing research study, Early Screening of Children's Learning. We are inviting you to participate in a companion study. The purpose of this second study is to investigate the effectiveness of the language measures included in our early screening tool in more detail. The study will take place either at Elborn College at Western University, or in your home. We are inviting children from our Early Screening study whose parents agreed to be contacted for further studies. Our aim is to recruit 30 children to the study.

Procedures
In this study, your child will complete one 45-minute research visit conducted by a trained research assistant. The visit will be scheduled at your convenience either at Elborn College at Western University, or in your home. At the visit, the study will be explained to your child in words that he or she understands, and your child will have the opportunity to agree to participate. During the visit, your child will be asked to do activities such as pointing to pictures, repeating sentences, and listening to sounds. The data from this research visit will be paired with your child's results on the screening tool completed as part of the companion study (Early Screening of Children's Learning).

Comfort and Safety
There are no known risks to participation in this study. There are also no direct benefits to your child for participating. The results of this study will help us to understand more about school learning in the early years. Participation in this study is voluntary. You or your child may refuse to participate, refuse to answer any questions or withdraw from the study at any time even after you have agreed to be in the study with no implications to your child's status or grades at school.

Confidentiality
All of the data collected will be kept confidential and will be used only for research purposes. Your name and the names of your child(ren), and the name of your child's school will never be mentioned in our reports of our results. The data will be restricted to our research group and will be destroyed within seven years of the completion of the study. You may also request the data be destroyed sooner by writing or telephoning Dr. Archibald (see contact information below). When we publish results of the study, your own name and your child's name will not be used. Representatives of the University of Western Ontario Non-Medical Research Ethics Board may contact you or require access to your study-related records to monitor the conduct of the research.

If you agree to allow your child to participate in this study, please complete the attached Consent Form and have your child return it to his/her teacher in the

Page 1 of 4

envelope provided. You can also indicate if you are willing to be contacted for future studies. The contact information you provide will be stored confidentially for 3 years.

Contact Information

If you have any questions about this study please contact:

Lisa Archibald, Ph.D
School of Communication Sciences and Disorders

Monica DaSilva, M.Sc.
Department of Psychology

Janis Cardy, Ph.D
School of Communication Sciences and Disorders

Rachael Smyth, M.Sc
School of Communication Sciences and Disorders

If you have questions about the conduct of this study or your rights as a participant in this research you may contact the Office of Research Ethics at 519-661-3036 or ethics@uwo.ca

This letter is yours to keep for future reference

Version date: April 24, 2014

Consent Form
Validation of a Kindergarten Language Screening Measure

I have read the Letter of Information, have had the nature of the study explained to me and I agree to allow my child to participate. All questions have been answered to my satisfaction.

_____
Child's name

Print your name in block letters: _____

Signed _____ Date _____
        (SIGN YOUR NAME)

Your relationship to the child _____

Please indicate if you wish to remain on our contact list for future investigations.

☐ Yes, I would like to be contacted

☐ No, I would not like to be contacted

Validation of a Kindergarten Language Screening Measure

If you would like a summary of the results of this study, please print your full address below. You may also include your email address if you prefer us to contact you electronically. The summary will be about all of the data as a whole. No individual results will be shared. Note that it may require up to a year to complete a study of this type.

_____

_____

_____

Email: _____

Curriculum Vitae

Name: Rachael Smyth

Post-secondary Education and Degrees:

University of Western Ontario
London, Ontario, Canada
2008-2012 B.H.Sc. Honours Specialization Health Sciences

The University of Western Ontario
London, Ontario, Canada
2013-2015 (expected) M.Sc. Health and Rehabilitation Sciences (Speech and Language Sciences)

Selected Experience

Graduate Research Assistant
Dr. Janis Oram Cardy, The University of Western Ontario
2013-Present

Research Assistant
Dr. Daniel Ansari & Dr. Heather Brown, The University of Western Ontario
2013-Present

Teaching Assistant
Dr. Janis Oram Cardy, The University of Western Ontario
2013, 2014

Teaching Assistant
Dr. Margaret Cheesman, The University of Western Ontario
2014

Publications:

1. Kwok, E. Y., Brown, H. M., **Smyth, R. E**., Oram Cardy, J. (2015). Meta-analysis of receptive and expressive language skills in Autism Spectrum Disorder. *Research in Autism Spectrum Disorders, 9,* 202-222. doi:10.1016/j.rasd.2014.10.008

2. Brown, H. M., Johnson, A. M., **Smyth, R. E.**, & Oram Cardy, J. (2014). Exploring the persuasive writing skills of students with high-functioning Autism Spectrum

Disorder. *Research in Autism Spectrum Disorders*, *8*, 1482-1499. doi:10.1016/j.rasd.2014.07.017

Peer Reviewed Conference Presentations:

1. **Smyth, R. E.**, Archibald, L., Purcell, D., & Oram Cardy, J. (2015, June). *Auditory temporal integration in children with language impairment compared to age- and language-matched controls.* Symposium on Research in Child Language Disorders. Madison, WI.

2. Kwok, E. Y. L., Archibald, L. M. D., Joanisse, M. F., Nicolson, R., **Smyth, R. E.**, & Oram Cardy, J. (2015, May). *Maturational differences in auditory event-related potentials according to presence versus absence of language impairment in children with autism spectrum disorder*. International Meeting for Autism Research. Salt Lake City, UT.

3. **Smyth, R. E.**, Archibald, L., Purcell, D., & Oram Cardy, J. (2014, June). *No difference in auditory temporal integration between children with language impairment and typical development*. Symposium on Research in Child Language Disorders. Madison, WI.

4. **Smyth, R. E.**, Kwok, E., Brown, H. M., & Oram Cardy, J. (2014, May). *A meta-analysis of receptive and expressive language in autism spectrum disorder*. Child Health Symposium. London, ON.

5. Brown, H. M., Oram Cardy, J., **Smyth, R. E.,** & Johnson, A. M. (2014, May). *Exploring the narrative writing skills of students with high-functioning autism spectrum disorders*. International Meeting for Autism Research. Atlanta, GA.

6. Kwok, E., Archibald, L. M. D., Brown, H. M., Joanisse, M., **Smyth, R. E.,** Stothers, M. E., & Cardy, J. (2013, June). *Auditory temporal integration in children with specific language impairment compared to same age controls*. Canada-Israel Symposium on Brain Plasticity, Learning, and Education. London, ON.