Children's Sentence Comprehension: The Influence of Working Memory on Lexical Retrieval During Complex Sentence Processing

A dissertation presented to

the faculty of

the College of Health Sciences and Professions of Ohio University

In partial fulfillment

of the requirements for the degree

Doctor of Philosophy

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August 2016

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This dissertation titled

Children's Sentence Comprehension: The Influence of Working Memory on Lexical Retrieval During Complex Sentence Processing

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Abstract

FINNEY, MIANISHA C., Ph.D., August 2016, Speech-Language Science <u>Children's Sentence Comprehension: The Influence of Working Memory on Lexical</u> <u>Retrieval During Complex Sentence Processing</u>

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Background: Models of adult sentence comprehension are emerging that suggest object relative (OR) sentence processing is subserved by memory abilities. Though the developmental literature lacks similar models of comprehension, investigations of children's cognitive abilities and sentence comprehension suggest that working memory capacity (WMc) and focus attention switching are related to children's sentence comprehension.

Typically developing children (as young as 6 years old) have demonstrated the ability to reactivate NP1 at the syntactically relevant gap location (verb offset). Importantly, Roberts, Marinis, Felser, and Clahsen (2007) found that WMc appears to play a role in children's ability to reactivate NP1 at the gap, leading authors to suggest that perhaps children with lower WMc need more time to reactivate and integrate a dislocated NP constituent during sentence processing. Extending the work of Roberts et al., this study investigated the influence of two memory mechanisms, working memory and attention switching, on lexical reactivation (NP1). Two sentence locations were investigated: (a) the syntactic gap, and (b) the post-gap (500 msec after the gap), a reasonable temporal point from estimates in the adult literature that should reflect the

possible delayed NP1 reactivation in children (delay defined as "not immediate" reactivation).

Aims: The two primary aims were to investigate the contributions of WMc and attention switching on NP1 reactivation time at (a) the syntactic gap (Gap) and (b) 500 msec after the syntactic gap (Post-Gap) during children's OR sentence processing.

Methods: Typically developing children, 9-11 years of age, completed three experimental tasks: a working memory capacity task (WMc), an attentional focus switching task, and a cross-modal picture priming task to capture NP1 reactivation during sentence processing.

Results and Conclusion: GLM modeling suggested that WMc and attention switching both contributed to speeded NP1 reactivation times. The findings agree with the emerging developmental language literature by showing that WMc appears to play a role in memory retrieval during OR sentence processing. Importantly, focus switching was found to be critically important in supporting memory retrieval during OR comprehension. Children's ability to momentarily switch their focus of attention away from the current demands of ongoing sentence processing to memory retrieval facilitated the speeded reactivation of a prior constituent (NP1).

Dedication

This work is dedicated to Joshua for his belief in art, exploration, and authenticity, and to Mary and Patrick for building me a world with many bridges.

Acknowledgments

This project was completed with the support, guidance, and expertise of many people. At this time, I wish to extend my heartfelt thanks to those individuals.

It gives me immense pleasure to express my sincere gratitude to my advisor, Dr. James Montgomery, for his untiring effort, support, and patience during the course of my studies. Dr. Montgomery's belief in developing an incremental, forward-thinking, research program and his attention to details have guided me through this program and helped to make this a better study. I am honored to have received so much of his time and attention. I am fortunate to have him as a mentor. Thank you.

A special thank you is extended to the members my committee, Dr. Joann Benigno, Dr. Chao-Yang Lee, and Dr. Alexander Sergeev, who have offered valuable guidance during this study and throughout my graduate program. They bring unique areas of expertise, coupled with the ability to give supportive and constructive feedback.

I would also like to thank my lab colleagues, Dr. Beula Magimairaj, for being a patient peer mentor and an extraordinary friend, and Ms. Yazmin Ahmad Rusli, for bringing her enthusiasm to Ohio and for collaborating in the lab.

A special thanks is also extended to the participants in this study and their families, whose generous gift of time and energy (and enthusiasm for science), formed the building blocks for this study.

Lastly, I would to thank the American Speech-Language Hearing Association and Ohio University's: Graduate Senate, College of Health Sciences and Professions, and the Division of Communication Sciences and Disorders for helping to fund my dissertation.

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Chapter 1: Introduction

Working memory refers to [a set of mental processes] holding a small amount of information in the mind, readily accessible for a short time to help an individual comprehend language and solve problems. As such, it is not just any topic, but potentially the key mechanism that organizes and represents one's conscious experience as [adult] human beings. (Cowan et al., 2005)

Understanding the intersection of working memory (WM) and complex sentence processing in children is limited. Few studies have explored the issue and even fewer have examined the issue from within an integrated framework of memory. WM capacity (WMc), broadly defined as the amount of activated long-term memory representations in focal attention at any given moment while simultaneous processing is occurring (Cowan, 1995), is the only WM mechanism examined with any regularity as it relates to children's sentence comprehension (Booth, MacWhinney, & Harasaki, 2000; Roberts, Marinis, Felser, & Clahsen, 2007; Weighall & Altmann, 2011). However, WM also incorporates other aspects, including controlled attention (Cowan, 1995, 1999; Cowan et al., 2005; Cowan, Nugent, Elliott, Ponomarev, & Saults, 1999). One controlled attention mechanism is focus switching (Cowan, 1995, 1999; Cowan et al., 2005, 1999; Conway, Kane, & Engle, 2003; Daneman & Carpenter, 1980; Engle, Kane, & Tuholski, 1999; Kyllonen & Christal, 1990; Turner & Engle, 1989). The proposed study is designed to expand the current developmental sentence processing literature by investigating the potential influence of two mechanisms of WM, WMc and attention switching, on children's real-time complex sentence processing. Results of this study will provide new

and important information about how and when potential WM abilities influence children's sentence processing, with a special emphasis on children's noun phrase 1 (NP1) reactivation.

Complex sentences like object relative (OR) structures are noncanonical in nature; they violate the typical or canonical subject-verb-object word order of English in which the first noun phrase (NP1) is generally the agent and the second noun phrase (NP2) is the patient (*The new girl in school kissed the shy boy*). For example, the following OR sentence is noncanonical: *The shy boy that the new girl in school kissed ran away*, because NP1 functions as patient and NP2 as agent. The OR sentence above thus requires the child to maintain two unintegrated NPs in memory (NP1 *the shy boy*, NP2 *the new girl*) until hearing the embedded VP *kissed*. Immediately upon hearing *kissed*, the child must reactivate NP1 from memory. At this point, the VP is able to assign the proper thematic role of agent to NP2 and patient to NP1.

During OR sentence processing, as listeners construct the syntactic-semantic meaning of a sentence, WM presumably is required. Storage is needed to maintain two unintegrated noun phrases (NP1, NP2) in memory until encountering the embedded verb phrase (VP). At this point, NP1 must be reactivated from memory and reintegrated into ongoing processing at the syntactic gap (just after the verb). We hypothesize that NP1 reactivation is mediated, at least in part, by children's ability to switch their attention from on-going sentence processing (e.g., processing the embedded verb phrase and material downstream from the verb phrase) to the memory storage, so NP1can be reactivated and the proper thematic roles can be assigned to each NP.

Finney, Montgomery, Gillam, & Evans (2014) completed a study to examine the roles of WMc and attention focus switching on children's OR sentence processing. This study used an adapted agent selection task to assess real-time sentence comprehension. The method combined the traditional agent selection task (i.e., selecting the agent of the sentence after sentence offset) (Dick, Wulfeck, Krupa-Kwiatkowski, Bates, 2004) with the cross-modal picture priming (CMPP) paradigm that assesses children's ability to reactivate NP1 at the verb offset (Love, 2007; Love & Swinney, 1996, Nicol, Swinney, Love, & Hald, 2006; Roberts et al., 2007). Typically developing children, 7-11 years old, heard OR sentences and were shown a picture of the agent and a picture of the patient of the sentence immediately following the verb phrase (at the syntactic gap). Children selected the agent as quickly as possible. Results showed that, after accounting for age, both WMc and the ability to switch attentional focus significantly contributed to accurate OR comprehension. Furthermore, children with low WMc and low attention switching ability were significantly less accurate and slower at OR comprehension than children with higher WM abilities. Finney et al. (2014) suggested that individual differences in WMc and attention switching affect children's OR sentence processing.

The Finney et al. (2014) study contributed important new information about the roles of both WMc and attention switching to children's OR sentence processing, as well as important information about individual differences in these abilities affecting sentence comprehension. However, given the focus and design of their study, they did not directly investigate NP1 reactivation during OR processing. Because the method they used was a

hybrid of the agent selection and CMPP paradigms, the influence of memory abilities on NP1 reactivation was not specifically assessed.

Accordingly, this study directly investigated NP1 reactivation during children's OR sentence processing. The primary aims were to investigate the contributions of WMc and attention switching on: (a) NP1 reaction time, and (b) NP1 reactivation time (the priming effect demonstrated during the CMPP paradigms). Results of this research contributed new and important information about the complex sentence processing abilities of typically developing children.

Chapter 2: Literature Review

A Linguistic Description of Object Relative Sentence Processing

Because of their processing challenge, OR sentences have occupied a centerpiece in both the adult comprehension literature (Gordon, Hendrick, & Johnson, 2004; Gordon, Hendrick, & Levine, 2002; King & Kutas, 1995) and the childhood literature (Love, 2007; Roberts et al., 2007). OR sentences involve wh-movement of a NP from the object position to a nonargument position and movement across clausal boundaries. To recover an SVO representation of an OR (Carnie, 2006; Chomsky, 1995) a syntactic movement operation is performed to establish what is called a filler-gap dependency, i.e., "move" NP1 (referred to as the filler) to a phonologically empty NP position, or trace (referred to as the gap). During processing, NP1 (filler) "moves" to a post-verb slot, or gap (ti). To understand the OR sentence, The boy_i that the girl had kissed _{ti} on the nose ran away, NP1 (The boy) must be "moved" from its fronted object position to its post-verb canonical position (the girl had kissed ti the boy). The trace position is linked to the first NP through co-indexing (i). It is at this point that the proper thematic roles are assigned by the embedded verb. Reintegration of NP1 at the gap represents the establishment of a "filler-gap" dependency. In this way, OR sentences involve a syntactic dependency between the moved element and the position from which it moved (Carnie, 2006; Chomsky, 1995).

Real-time studies of adults' OR sentence comprehension reveal that comprehenders automatically reactivate the filler (NP1) immediately upon encountering the gap. Importantly, it is the fronted object NP that tends to be reactivated, not other NPs appearing before the gap. Such NP reactivation has been demonstrated using a variety of paradigms, including, for example, event-related potentials (ERP; Garnsey, Tanenhaus, & Chapman, 1989; Hestvik, Bradley, & Bradley, 2012; Hestvik, Maxfield, Schwartz, & Shafter, 2007) and cross-modal priming (Nicol, & Pickering, 1993; Swinney, Zurif, Prather, & Love, 1996).

The cross-modal picture priming (CMPP) paradigm is an established method used to study the time course of OR sentences processing (Love, 2007; Love & Swinney, 1996, 1998; Nagel, Shapiro, & Nawy, 1994; Nicol, & Pickering, 1993; Nicol, & Swinney, 1989; Nicol et al., 2006; Roberts et al., 2007; Swinney et al., 1996). This method allows researchers to determine at what point during processing a filler-gap dependency is established by examining the reactivation of a prior constituent (NP1) from memory. Participants listen to sentences and at some point during the sentence (e.g., gap (ti), or upstream or downstream from the gap) participants see a picture. They are asked to make a simple classification decision about the target picture as quickly as possible (e.g., object in the picture is living or not living). Target pictures minimally can be "related" (i.e., picture of NP1) or "unrelated" (i.e., *not* a picture of NP1, but controlled for various lexical properties). When the picture is presented at the gap (just after the embedded VP), the time to make a decision is significantly faster when the target picture is NP1 as opposed to any other type of prime picture (Love, 2007).

The priming advantage for NP1 picture reflects the immediate reactivation of NP1 from WM (Love, 2007, Swinney & Prather, 1989). That NP1 is reactivated at the gap has been taken as evidence of syntactic movement and for the idea that syntactic gaps form

part of the basic syntactic processing apparatus of adults and children (Love, 2007; Love & Swinney, 1996, 1998; Nagel et al., 1994; Nicol, & Pickering, 1993; Nicol, & Swinney, 1989; Nicol et al., 2006; Roberts et al., 2007; Swinney et al., 1996).

Children's ability to reactivate NP1 during OR processing has only begun to be examined, especially using the CMPP paradigm. Results of a few recent studies show children as young as 5-7 years old are able to reactivate NP1 during OR sentence processing (Love, 2007; Roberts et al., 2007). Such results have been taken as evidence that young children, like adults, are equipped with a robust syntactic processing apparatus.

A Memory Perspective on Object Relative Sentence Processing

Adult literature as a backdrop to children's processing. That memory is an important determinant in complex sentence comprehension has been posited for many years (Kimball, 1973; Miller & Isard, 1964). A variety of metrics of sentence complexity have been proposed regarding the presumed memory load imposed on comprehenders by complex structures, including the number of intervening discourse referents (Gibson, 1998), the number of partially processed dependencies (Lewis, 1996), and the number of embeddings (Miller & Isard, 1964). Regardless of the metric studied, most of the research investigating the intersection of WM and complex sentence comprehension has focused on the role of working memory storage capacity (WMc) (Chen, Gibson, & Wolf, 2005; Gibson, 1998; Just & Carpenter, 1992; King & Just, 1991).

One approach that has been used to evaluate this intersection is an individual differences approach. The hypothesis for this approach is that syntactic complexity

should interact significantly with memory ability, i.e., with the comprehension of complex sentences showing greater disruption in low-WMc individuals (as a group).

Generally, relative to individuals with reduced WMc, those with larger capacities tend to show better complex sentence comprehension. King and Just (1991) have argued that low-WMc individuals have much greater difficulty than high-WMc individuals processing complex sentences. MacDonald, Just, and Carpenter (1992) have also claimed that adults with reduced WMc are more negatively affected by syntactic ambiguity than individuals with greater WMc. Using an ERP paradigm, King and Kutas (1995) reported group differences (in a left anterior negative wave) between good and poor readers as the participants processed OR clauses, with the poor readers showing slower event-related potentials. These authors argued that the poor readers' slower potentials were attributable to their reduced WM capacity.

Hestvik et al. (2012), also using an ERP method and an individual differences approach, showed that low WMc individuals (compared with higher WMc individuals) failed to show immediate reactivation of the NP1 at the gap, thereby being significantly slower to establish a filler-gap dependency during OR sentence processing. Importantly, however, the low-WMc individuals demonstrated lexical reactivation; though slower than their high-WMc counterparts, they were not lacking lexical reactivation. These findings suggest that complex sentence processing may be influenced by memory mechanisms other than just storage capacity.

Current formulations of complex sentence processing conceptualize comprehension from a broader, more integrated memory perspective (Gordon, Hendrick,

Johnson, & Lee, 2006; Lewis, & Vasishth, 2005; Lewis, Vasishth, & Van Dyke, 2006; McElree, 2000, 2001; McElree, Foraker, & Dyer, 2003; Van Dyke, 2007; Van Dyke & McElree, 2006, 2011, Young & Lewis, 1999). In recent years, the adult sentence processing literature has reflected new and important advances in our understanding of complex sentence processing. These advances derive from researchers building models of sentence processing that are explicitly informed and constrained by a number of independently motivated principles of human memory (Berman, Jonides, & Lewis, 2009; Gibson, 1998; Gordon et al., 2002, 2006; Lewis et al., 2006; McElree, 2001; McElree et al., 2003; Van Dyke, 2007; Van Dyke & Lewis, 2003; Van Dyke & McElree, 2006, 2011). Memory mechanisms incorporated in these frameworks include: (a) a sharply limited attentional focus (i.e., limited capacity); (b) item activation decay; and (c) rapid item retrieval.

Overview of working memory. Working memory is comprised of several interrelated memory mechanisms. The following briefly reviews several key concepts. WM capacity (WMc) is broadly defined as *the amount* of long-term memory representations activated in focal attention at any given moment while simultaneous processing is occurring (Baddeley, 1996). According to Cowan et al. (2005), only a small bit of information can occupy this focus of attention (WMc) at any given moment (also see Cowan, 1997). Controlled attention mechanisms are responsible for coordinating and controlling the different activities within the focus of attention, such as allocating mental energy to different levels of a task, focus switching between processing and memory, and updating moment-to moment-comprehension (Baddeley, 1996; Conway et al., 2003;

Cowan, 1995, 1999; Cowan et al., 2005, 1999; Daneman & Carpenter, 1980; Engle et al., 1999; Kyllonen & Christal, 1990; Portrat, Camos, & Barrouillet, 2009; Turner & Engle, 1989). Focus switching is suggested to be an important cognitive ability supporting mental processes such as sentence comprehension. Focus switching is the ability to change/maintain the contents of WM by rapidly switching attention between the processing part of the task to the reactivation of items held in peripheral activation. (Barrouillet, Gavens, Vergauwe, Gaillard, & Camos, 2009; Conlin, Gathercole, & Adams, 2005; Portrat et al., 2009).

Overview of memory-based model of sentence processing. Lewis and colleagues offer proposals of noncanonical sentence comprehension that assume comprehension is subject to and constrained by sharply limited attentional focus and rapid retrieval of a stored constituent (NP1) from WM. In their model, WM retrieval is subject to interference and activation decay (Lewis et al., 2006; McElree et al., 2003; Van Dyke, 2008; Van Dyke & Lewis, 2003; Van Dyke & McElree, 2006). The model consists of three principle components: (a) long-term declarative memory which holds multiple levels of lexical content; (b) procedural Memory that is devoted to grammatical knowledge, which is stored in procedural form as a set of rapid and automatic sentence parsing production rules responsible for deriving intermediate structures; and, (c) lexical retrieval and attentional buffers that are responsible for temporarily holding and retrieving an element that has already been activated and is awaiting integration with new material. The current state of each of the buffers constitutes WM, since relatively little information can occupy a buffer at any point.

According to the model, comprehension of OR sentences (e.g., *The shy boy that the new girl in school kissed ran away*) would be described as follows. A listener would access lexical and syntactic information of the first several words from declarative memory, and then store in STM (activated state) the words and any developing syntactic expectation. Based on the syntactic prediction and contents held in activation, a WMbased production rule sets cues to retrieve a constituent held in WM. If its contents include the first two NPs (e.g., NP1 *the shy boy*, NP2 *the new girl*) at the point the VP (e.g., *kissed*) is encountered, the production rule sets retrieval cues to favor NP1 over NP2 to be reactivated. Retrieval of a constituent from WM depends on level of activation of each lexical item, which reflects distance between the item and retrieval site. Because NP1 is accessed via a content-addressable, associative retrieval process, it is subject to similarity-based interference. This interference should increase if there is significant overlap in the syntactic and semantic cues between NP1 and NP2 in the developing sentence context.

In sum, emerging experimental findings in adult literature suggest the following about the role of memory mechanisms in sentence processing. The memory mechanisms most critical to comprehension include: (a) a controlled limited focus of attention (including the ability to switch attention away from language processing to WM retrieval); (b) fast access to item information (lexical retrieval); (c) similarity-based retrieval interference (retrieval interference); and, (d) fluctuating activation as a function of decay and retrieval strategy. It is also important to emphasize that some memory mechanisms, though involved, do not seem to play an important role in adult sentence processing and comprehension. For example, limited focus of attention (WMc) appears to have minimal influence on complex sentence comprehension. Adult comprehenders appear to have sufficient memory capacity to hold two to three unintegrated constituents in mind prior to integrating them into a developing structure (Hestvik et al., 2012; Lewis et al., 2006). In addition, Van Dyke and Lewis (2003) argued that activation decay (e.g., forgetting of NP1) exerts minimal influence on the first pass processing of a sentence during which the comprehender builds initial sentence structure and meaning. Decay, however, is a factor after first-pass processing if a comprehender needs to revise the structural analysis or interpretation of a given sentence constituent, with the constituent decaying during the revision process.

Applicability of the adult model to children's sentence processing. Overall, Lewis et al. (2006) offer an appealing framework for adult sentence comprehension. However, their model derives from normal adult behavioral data and assumes fully developed and intact cognitive mechanisms. Research with typically developing children implicates cognitive mechanisms in noncanonical sentence comprehension that are not implicated in adults. For instance, comprehension of verbal-be passive sentences (e.g., *the boy was kissed by the girl*) invite WMc and processing speed (Montgomery, Magimairaj, & O'Malley, 2008) and OR sentences instantiate both WMc (Finney et al., 2014, Roberts et al., 2007) and phonological short term memory (pSTM) (Booth et al., 2000). The Lewis et al. (2006) model needs modification to be sensitive to children. As mentioned, pSTM and WM are assumed to play no appreciative role in adult sentence comprehension, but both participate in children's comprehension. In addition, the Lewis model does not explicitly include a processing speed factor or the broader construct of controlled attention (e.g., attentional focus, focus switching), yet these are implicated in children's sentence comprehension/receptive language performance (Finney et al., 2014, Montgomery, 2000; Montgomery & Evans, 2009). Developmental models of WM suggest that WM entails several mechanisms, including pSTM storage, WM storage (ability to store information while processing), processing speed, controlled attention, and retrieval (Bayliss, Jarrold, Baddeley, Gunn, & Leigh, 2005; Conlin et al., 2005; Towse, Hitch, & Hutton, 1998, 2002). Perhaps the cognitive mechanisms supporting children's sentence processing are similar to those supporting adult comprehension, but are weighted differently than adults. Or it may be that children rely on a different subset of mechanisms for sentence processing.

Developmental literature. Theoretically and empirically integrated frameworks describing/explaining children's complex sentence processing from a memory perspective do not exist. Systematic developmental research similar to that occurring in the adult literature is sorely needed. The following section will review what is currently known about the influence of working memory on children's OR sentence processing.

Direct investigation into the intersection of WM and online OR sentence processing and comprehension is limited. Booth et al. (2000), using an individual differences approach, examined the influence of memory storage on 8- to 11-year-old children's auditory processing of OR, SR and SVO sentences, with the primary dependent variables being speed of sentence processing and accuracy of comprehension based on a post-sentence comprehension probe. Results showed that, relative to children with higher WMc, those with reduced WMc were poorer to comprehend the OR structures.

Roberts et al. (2007), using an individual differences approach, appear to be the first to directly examine the relation of WMc and OR processing in children (and adults). The aim of the study was to determine whether children (5-7 years old) with lower WMc are less able to reactivate NP1 at the gap relative to children with higher WMc. All of the participants completed a conventional WM span task as an index of WM storage capacity. They also completed a cross-modal picture priming (CMPP) task. Participants listened to OR (and fillers) sentences in which key NPs corresponding to the agent (the lobster) and patient (the camel) were animals ("Bob fed the camel to which the pink lobster showed his new computer game at his office on Monday morning"). A picture of either the fronted NP (camel) or a control picture (e.g., picture of a nonanimate object) was presented at one of two locations during the sentence, at the gap position or 500 msec earlier than gap (control position). Prior to this task, participants were trained to make a classification decision as to whether the prime picture they will see during the sentence is animate/alive or inanimate/not alive. Participants touched the word "Yes" for animal prime pictures (animate/alive) and "No" for object prime pictures (inanimate/not alive), with the assumption that processing times for the fronted NP1 (actual patient picture) should be significantly faster than those for control prime pictures at the gap site. Results showed that the children (and adults) with reduced WMc showed no processing time advantage for the fronted NP1 pictures at the gap, whereas the children (and adults) with higher WMc did. A comparison of child groups (WM, low vs. high) was not reported. The results were interpreted to suggest that, in contrast to higher WMc children, lower WMc children may need more time to reactivate and integrate a dislocated NP constituent in a developing structure. This possibility motivates one of the main aims of the present study, as the current experimental design incorporates a post-gap position, which theoretically represents "delayed" NP1 reactivation, at least relative to the adult literature and two childhood studies.

One of the only other studies exploring the contribution of WMc to children's OR processing was conducted by Finney et al. (2014). Importantly, however, these investigators also examined the contribution of a second memory mechanism, attentional focus switching. Designed to replicate/extend findings from Roberts et al. (2007), the study explicitly examined the relation between WMc and OR comprehension. Attentional focus switching was included for two reasons. First, the developmental memory literature has recently begun to indicate that attentional focus switching is a crucial memory mechanism related to children's WM performance (Cowan, Morey, AuBuchon, Zwilling, & Gilchrist, 2010; Kane, Bleckley, Conway, & Engle, 2001; Magimairaj & Montgomery, 2012a, 2012b; Portrat et al., 2008; Unsworth & Engle, 2008). Second, the adult sentence processing literature indicates that NP1 reactivation from memory is a critically important factor subserving complex sentence processing. Finney and colleagues hypothesized the ability to switch the focus of attention should be an important memory

mechanism subserving children's ability to reactivate NP1 from WM during OR comprehension. Specifically, children need to be able to momentarily switch their attentional focus away from ongoing sentence processing (e.g., processing the embedded VP) to WM so they may reactivate NP1 immediately upon encountering the gap. The results indicated that whereas WMc is involved in OR comprehension, attentional focus switching is an especially important WM mechanism supporting OR comprehension.

Motivation for the Study

Broader and more integrated memory-based models of adult sentence comprehension have emerged over recent years, leading to significant advances in understanding adult sentence processing. The developmental literature lacks similar models of comprehension. This dissertation designed to begin to address this gap in the developmental literature. The next paragraphs summarize the basis for the current study, followed by a brief review the theoretical assumptions governing complex sentence comprehension.

For OR sentences, the developmental literature suggests that children's comprehension is related to WMc (Booth et al., 2000; Finney et al., 2014). In addition, attentional focus switching appears to be an especially important WM mechanism supporting OR comprehension, perhaps by subserving children's ability to reactivate NP1 from WM during OR comprehension (Finney et al., 2014).

Examination of NP1 reactivation during OR sentence comprehension has been studied using cross-modal picture priming (CMPP) tasks. Children as young as 6 years old demonstrated NP1 reactivation at the syntactic gap location (Love, 2007; Roberts et al., 2007). Importantly, WMc appeared to play a role in children's ability to immediately reactivate NP1 at the gap, leading authors to suggest that perhaps children with lower WMc need more time to reactivate and integrate a dislocated NP constituent in a developing structure (Roberts et al., 2007).

Two questions left open by this study (Roberts et al., 2007) were: (a) how delayed are low WMc subjects at NP1 reactivation (as their observations would also be consistent with a complete lack of reactivation), and (b) are WM mechanisms other than storage important to successful reactivation during OR sentences processing. A complicating factor of the Roberts et al. data is that they eliminated a number of children who failed to reach a 90% correct on post-sentence questions. Such a procedure may have restricted the range of variability in performance in the group, obscuring the role that memory may have played in the children's speed of NP1 reactivation, i.e., overestimated the speed of reactivation.

This potential overestimation represents an important motivation for the current study to examine whether the time course of NP1 reactivation is actually slower than that reported by Roberts et al. (2007), motivating the decision to include a post-gap NP1 reactivation location in the study design. As mentioned earlier, Hestvik et al. (2012) examined the influence of WMc on the time course of adults' OR processing using an event-related potentials paradigm. They found that compared with higher WM adults, low WMc adults have an onset latency delay of about 200 msec in brain responses to violations of syntactic expectancies after the gap site, thus providing a measure of the delay (in adults) hypothesized by Roberts and colleagues. The effect of WMc (and other possible WM mechanisms) on the time course of children's OR processing remains unclear.

Motivated by this gap in the literature, the current study examined the influence two memory mechanisms, WM capacity (WMc) and attention focus switching, in a developing model of online OR sentence processing/comprehension.

The present study extended the work of Roberts et al. (2007) in two important ways. First, we included two independent and theoretically relevant WM mechanisms to explore their contribution to children's NP1 reactivation at the syntactic gap. Second, we extended the time course of NP1 reactivation time to 500 msec after the gap, which we believe was a reasonable temporal point from estimates in the adult literature that should reflect delayed NP1 reactivation in children, i.e., "delay" being defined as not "immediate" reactivation. This study investigated online processing to better understanding the influence of memory as comprehension unfolds in real time.

Predictions about the role of these memory mechanisms were based on the following broad assumptions governing sentence comprehension. First, children must be able to construct, remember, and integrate various intermediate linguistic representations (e.g., NPs, VPs, filler-gap dependency) from incoming lexical material into a final sentence representation of "who did what to whom." Second, each incoming word presumably occupies children's limited focus of attention momentarily as they glean its structural properties and semantic meaning, and integrate the word into a developing sentence representation. Third, comprehension entails both WMc and memory retrieval. Storage capacity (i.e., limited focus of attention) involves children retaining two unintegrated NPs (NP1, NP2) in memory until encountering the embedded VP/gap (*The shy boy that the new girl in school kissed* [*GAP*] *ran away*). At this point, children must reactivate NP1 to establish a filler-gap dependency between NP1and the VP, allowing the VP to assign a proper thematic role to each NP. Fourth, memory retrieval is at least in part supported by children's ability to switch their focus of attention momentarily away from ongoing sentence processing to memory in order to reactivate NP1.

The memory framework describing/explaining adult sentence processing has been critical in guiding this effort to better understand children's sentence processing. This work shares the same overarching goal as in the adult literature: develop a model of sentence processing that includes a range of theoretically- and empirically-motivated memory principals.

Aims

The goal of this study was to systematically expand the work already begun in the developmental literature (Finney et al., 2014, Roberts et al., 2007). Accordingly, this study employed a cross-modal picture priming (CMPP) paradigm to directly investigate NP1 reactivation during children's OR sentence processing.

The primary aims were to investigate: (a) the contributions of WMc and attention switching on the speed of NP1 reactivation, and (b) whether WMc and attention switching abilities influence the *advantage* for NP1 reactivation (i.e., evidence of syntactic priming; Love & Swinney, 1996) during the time course of sentence processing. Three experimental tasks were used: a working memory capacity task (WMc), an attentional focus switching task (Att Switching), and a CMPP task to capture NP1 reactivation during sentence processing.

During sentence processing, two theoretically relevant sentence locations were examined, the gap (verb offset) and post-gap (500 msec post verb offset, effectively, after gap processing has occurred in adults). Target pictures presented at each location were related animal (animal mentioned in NP1) or an unrelated animal (control).

Four experimental dependent measures were captured: (a) Gap RT (NP1 reactivation time at the syntactic gap); and (b) Post-Gap RT (NP1 reactivation time 500 msec after the syntactic gap); the Gap RT measure was consistent with what other developmental researchers have used (Love, 2007; Roberts et al., 2007), the Post-Gap RT was used to examine the time course of children's NP1 reactivation; (c) Gap Priming (RT difference between the related and unrelated prime pictures at the gap); and, (d) Post-Gap Priming (RT difference between the related and unrelated prime pictures at the post-gap). The RT 'difference' represented a priming advantage of the related prime over the unrelated prime, and was novel to this study.

Possible Outcomes and Interpretation

Speed of lexical activation (NP1). The first two sets of possible outcomes use reaction time as the dependent variables (Gap RT and Post-Gap RT).

Speed of NP1 activation at the gap. If both WMc and focal attention switching contribute to children's *immediate* reactivation of NP1, then we might expect that both WMc and attention switching should account for unique/significant amounts of variance in NP1 reactivation time at the gap. If neither WMc nor attention switching contributes to

children's *immediate* NP1 reactivation, then we might predict neither variable to account for any unique/significant variance in NP1 reactivation time at the gap.

Speed of NP1 activation at the post-gap. If children, overall, are 'somewhat' *delayed* in reactivating NP1 (i.e., reactivation occurs approximately 500 msec after syntactic gap) and both WMc and focal attention switching contribute to children's *delayed* NP1 reactivation, then we might expect that both WMc and attention switching should account for unique/significant portions of variance in the speed of NP1 reactivation at the post-gap.

Alternatively, WMc and focal attention switching might not account for any unique/significant portion of variance in NP1 reactivation time: (a) if neither predictor contributes to the speed of children's (*delayed*) NP1 reactivation, or (b) if children, overall, are *severely delayed* in reactivating NP1 relative to the syntactic gap (i.e., predictors are involved but reactivation occurs later than 500 msec after syntactic gap).

Advantage for NP1 reactivation. The next two sets of possible outcomes reflect WM's influence during assumed syntactic priming and use *reaction time advantage* as the dependent variables (Gap Prime and Post-Gap Prime).

Advantage for NP1 reactivation at the gap. If both WMc and focal attention switching contribute to children's *immediate* advantage for reactivating NP1 (difference scores), then we might expect that both WMc and attention switching should account for unique/significant amounts of variance in NP1 priming at the gap. If neither WMc nor attention switching contribute to children's *immediate* advantage for reactivating NP1, then we might predict neither variable to account for any unique/significant variance in NP1 priming at the gap.

Advantage for NP1 reactivation at the post-gap. If children, overall, are 'somewhat' *delayed* in reactivating NP1 (500 msec after syntactic gap) and both WMc and focal attention switching contribute to children's *delayed* NP1 reactivation, then we might expect that both WMc and attention switching should account for unique/significant portions of variance in the reaction time advantage of NP1 at the postgap.

Alternatively, WMc and focal attention switching might not account for any unique/significant portion of variance in the advantage of NP1 at the post-gap: (a) if neither predictor contributes to the speed of children's (*delayed*; 500 msec) NP1 reactivation, or (b) if children, overall, are *severely delayed* in reactivating NP1 relative to the syntactic gap (i.e., predictors are involved but the priming advantage of NP1 occurs later than 500 msec post syntactic gap).

Chapter 3: Methods

Participants

This study yielded cognitive-behavioral data from 55 children between the ages of 9 and 11 years (9;0-11;11) with normal developmental history and language development. The sample included 27 girls and 28 boys, with a mean age of 10.6 years (M = 126 months, SD = 11 months, range = 108-143 months). Though children are developing syntactic abilities throughout childhood, this age range was selected to represent a unified group. The range was motivated on three grounds: (a) findings from Dick et al. (2004) indicate significant developmental improvement in the interpretation of complex sentences during the 9th year of life, (b) children in this age range are able to comprehend complex OR sentences with good reliability (Dick et al., 2004; Finney et al., 2014; Montgomery, Evans, Gillam, Sergeev, & Finney, 2016), and (c) as a group, children's sentence comprehension in this age range differ from younger children (6;0-8;11; Dick et al., 2004; Montgomery et al., 2016) and older children (12;0-14;11; Dick et al., 2004).

Children were recruited from across Athens County through community flyers, university emails, and Ohio University-sponsored educational programs for children (e.g., Kids on Campus). All the children were English-speaking and had normal medical, developmental, and language history, and no neurological impairment or psychological disturbance (e.g., autism, bi-polar disorder), based on parent report.

Standardized language and cognitive assessments, as well as parent reports, were completed at time of participation. Sixty-six children were enrolled in the study; 55 of

those children met inclusionary criteria. To participate in the study, children needed to demonstrate normal-range nonverbal IQ at or above 85 (Leiter International Performance Scale-Revised; Roid & Miller, 1997), normal-range hearing sensitivity (500Hz, 1kHz, 2kHz, 4kHz; American National Standards Institute, 2010), normal or corrected vision, and normal-range language (above -1 *SD*) as measured by a composite score that included: (a) the Clinical Evaluation of Language Fundamentals-4 (CELF-4; Semel, Wiig, & Secord, 2003), *Linguistic concepts and following directions* subtest and *Recalling sentences* subtest, and (b) the Comprehensive Receptive Expressive Vocabulary Test (CREVT-2, Wallace & Hammill, 2002). Each of the standardized language tests has good internal reliability (.84-.95) and internal validity (.60-.82). Table 1 displays summary cognitive and language data for the 55 included participants.

Table 1

Variables	Mean	SD	Range	
Age in months	124.1	10.8	108-143	
Nonverbal IO				
Nonverbal IQ Sequential order	0.0	26	6 15	
Sequential order	9.9	2.0	0-15	
Patterns	11.2	2.3	5-15	
CREVT				
Receptive	107.0	10.0	87-125	
Expressive	102.1	11.0	75-122	
CELF-4				
RS	10.8	2.2	6-15	
C&FD	10.7	2.3	5-16	

Descriptive Statistics of Inclusionary Criteria (n = 55; 27 female, 28 male)

Note. Nonverbal IQ = Leiter International Performance Scale. CREVT = Comprehensive Expressive-Receptive Vocabulary Test-Revised. CELF-4 = Clinical Evaluation of Language Fundamentals (4th ed.): *Recalling Sentences* and *Concepts and Following Directions*.

General Procedures

Each child, seen individually in a quiet lab, completed 3 testing sessions. Each

session lasted between 1-2 hours with multiple rest breaks (session1: ~2 hours; session 2-

3: \sim 1 hour). See Table 2 for presentation order of tasks.
Table 2

Session 1	Session 2	Session 3
Questionaire: No Hx Hearing WNL Leiter (RM & SO)		
Motor (1) CMPP (1, 2, 3)	Motor (2) CMPP (2, 3, 1)	Motor (3) CMPP (3, 1, 2)
CREVT-2 CELF-4	WMc Att Switching	

Presentation Order for Inclusionary and Experimental Tasks

Note. WMc = working memory capacity task, indexed by Auditory Working Memory Subtest of the Woodcock-Johnson III. Att Switching = attention switching task. Motor = baseline motor speed task. CMPP = sentence processing task; cross-modal picture priming. Three sets of CMPP task presented in counterbalanced order to equal number of participants. Inclusionary criteria: Questionnaire = answered by parents before experimental sessions; no history of language or psychological diagnoses. Hearing = WNL(within normal limits). Leiter = Nonverbal IQ; Leiter International Performance Scale (reported as full scale IQ). CREVT-2 = Comprehensive Expressive-Receptive Vocabulary Test-Revised. CELF-4 = Clinical Evaluation of Language Fundamentals (4th ed.): Subtests: *Recalling Sentences* and *Concepts and Following Directions*.

Session 1 began with the administration of the standardized test measures,

followed by the start of the experimental tasks. The standardized tests were administered in a fixed order. Sessions 2 and 3 were devoted to completing the remaining experimental tasks. Three different counterbalanced orders of the CMPP were created (more detail presented below in Sentence Processing Task design). To record the accuracy and speed of the children's responses as well as ensure a random order of presentation of the trials and position of the correct answer, presentation of the stimuli was controlled using E- Prime software (Schneider, Eschmann, & Zuccolotto, 2002) running on a laboratory laptop connected to a 17" Elo Touch Screen monitor.

Children sat at a table in front of a touch screen. To maintain consistency in interpreting reaction time data, children placed their arm in a comfortable position on the table so that the fingers of their dominant hand rested on a red dot located in the center of the bottom edge of the monitor, just below the touch screen. Children were instructed to leave their fingers on the dot until they were ready to touch the screen. Both response accuracy and speed were emphasized in speeded tasks. Prior to experimental trials in each task, children saw demonstration items and completed practice trials to ensure they understood the tasks. The children were able to complete the practice trials and no child was excluded due to difficulty understanding or completing the tasks. Stimuli were presented binaurally under noise reduction headphones at a comfortable listening level determined by the child. Each child received a toy of his/ her choice upon completion of each experimental visit.

Experimental Tasks

Working memory capacity. To index working memory storage (i.e., ability to store at least two items pertinent to sentence processing such as NP1 and NP2), children completed the Auditory Working Memory Subtest of the Woodcock-Johnson III NU Test of Cognitive Abilities (Woodcock, McGrew, & Mather, 2001). This is a psychometrically strong standardized index of WMc in which children were presented a random series of words and digits and asked to repeat the words in serial order followed by the digits in

serial order. The task is strongly correlated with children's OR comprehension (.88) (Montgomery, Evans, & Gillam, in press).

Procedure. Children were told that they will hear a man saying some words and numbers and that these items were all mixed up (e.g., cat, 1, 6, butter). They were instructed to listen carefully and first repeat the words they heard in the order they heard them (e.g., cat, butter), followed by the digits in the order they heard them (e.g., 1, 6) (see Appendix A for a transcription of instructions and score sheet).

Trials were presented in blocks of increasing item length, starting with a two item recall. Three trials were presented for each block/item length. Experiment was stopped when child made an error on all three trials in a block. Reliability of item transcription and scoring for this task has been shown to be 100% (Montgomery et al., in press).

Dependent variable. The primary dependent variable indexing WM capacity was absolute span scores, reflecting the highest block for which each child is able to correctly produce at least two of the three trials (range: 2-6) (Conway et al., 2005).

Attentional focus switching. The attention focus switching task (Magimairaj & Montgomery, 2012a, 2012b, 2013), used by Finney et al. (2014), was based on the Garavan paradigm in which participants must switch their focus of attention between two different running memory counts as they update and maintain those counts (Garavan, 1998; Garavan, Ross, Li, & Stein, 2000; Unsworth & Engle, 2008). It is proposed that the memory items are maintained in WM in serial fashion and only one item can occupy the focus of attention at any given moment. The children were presented sets that included both high and low tones and asked to keep a running/updated count of each tone.

Task design and stimuli. Auditory stimuli consisted of a high tone (4 kHz; 500 msec) and a low tone (250 Hz; 500 msec). Each trial consisted of 7-11 tones, with four trials at each sequence length. The task consisted of four blocks of five trials each (20 test trials total). Within a trial, stimuli followed a predetermined order. A randomized sequence length was used across trials. Finally, the task has been shown to be a reliable index of children's attention focus switching and to be age sensitive in children 7 to 11 years of age. The switching task has good reliability (r = .83; Magimairaj & Montgomery, 2012a, 2013), is age sensitive (r = .48), and is significantly related to OR comprehension (Finney et al., 2014).

One third of the total presentations in each trial were switch presentations and the other two thirds non-switch. On nonswitch trials, there is no need to switch attention from one tone to the other to update the count for that particular tone; the child only needs to increase the count for that stimulus by one. On switch presentations, the child must switch attention from the current tone to the previous (different) tone, thus holding both tones in the focus of attention to update the count of each tone type. Switch trials incur greater "switch cost" than nonswitch trials, in terms of longer response times and less accurate updating (Finney et al., 2014; Magimairaj & Montgomery, 2012a).

Procedure. Each child sat in front of a computer monitor and a keyboard. The child was instructed that he/she would hear a series of tones, one after another, and that they needed to press the space bar to hear each tone. The child was asked to be as fast and accurate as possible. Each trial began with a fixation point on the screen for 150, 300, or 600 msec (random across trials) followed by a tone (Unsworth & Engle, 2008). After

each tone, the child updated both counts (i.e., high tones, low tones). For example, if the child already heard two high tones and three low tones and then heard a low tone, he/she would say, "two high, four low." The computer recorded response time (msec) for each tone (switch, nonswitch). At the end of a trial, the screen turned green and the child verbally reported the total number of high and low tones heard. Examiner recorded total count into computer (see Appendix A for a transcription of instructions and score sheet).

Dependent variable. The primary dependent variable was attention switching response times within accurate trials (msec; Finney et al., 2014). Switch response times were averaged across trials in which total counts (both high-low tone) were recalled correctly.

Baseline motor speed. The motor task was used as an index of child's motor planning and execution speed (Dick et al., 2004; Montgomery & Leonard, 2006; Montgomery et al., 2016). This task will be used to adjust the children NP1 reactivation times.

Stimuli and procedure. Children were told that they would first hear a tone (2k Hz, 500 msec) and then see a cross appear in one of the boxes. They were instructed to touch the cross as quickly as possible as soon as it appeared. The task comprised 30 trials. The tone and cross were separated by an interstimulus interval varying between 500-1500 msec. The cross appeared in each box randomly across the trials and an equal number of times (see Appendix A for a transcription of instructions and score sheet).

Dependent variable. The primary dependent variable was mean response time across three sessions (RT), measure in milliseconds.

Sentence processing task: Assessing lexical reactivation. A cross-modal picture priming (CMPP) task was used to examine lexical reactivation of noun phrase 1 (NP1) during OR sentence processing. Because the CMPP task asks listeners to make a timed classification judgment (while listening to a sentence), it is an excellent paradigm to explore the relation of NP1 reactivation and memory mechanisms involved in sentence processing. This is due to the fact that it implicitly taps NP1 reactivation in sentence processing and does not introduce any confounding explicit memory demands (e.g., verbal rehearsal) during sentence processing (Berman et al., 2009).

Procedures. Children were told to carefully listen to a man saying some sentences and instructed that they would be questioned about the sentences from time to time. They were also told that at some point during each sentence, they would see a picture appear at the top of the computer screen. They were instructed to touch as quickly as possible *the circle*, if the picture was of a living thing, and *the square*, if the picture was of a nonliving thing. They were to assume a response ready position with the fingers of their dominant hand resting on a fixation point located in the middle of the frame just below the touch monitor. On the bottom of the touch screen to the left was a circle that contained the word words "Living" and to the right a box that contains the words "Not Living." Prior to hearing the experimental items, the children completed a training phase where they learned to touch "circle" for living things and "square" for nonliving things. They were required to perform with 100% accuracy during each phase prior to moving on to the experimental items. Two demonstration items that contained sentences (judgment

task while listening to sentence) and five practice trials also preceded experimental trials (see Appendix A for a transcription of instructions and score sheet).

Sentence stimuli. The experimental OR sentences were modeled after those used in Finney et al. (2014) and Love (2007). A total of 105 sentences were presented to each participant in each session (visits) (See Appendix A for full list of sentential materials). Thirty of these sentences constituted 'experimental' sentences (presented twice), 32 constituted 'filler' sentences. An additional five practice sentences were presented each session that were different from sentences presented in experiment. The filler and practice sentences were constructed such that 30 sentences contained a subject relative clause but similar to that structure in the experimental sentences. The other 15 were compound sentences matched lexically for word frequency, imageability, and age of acquisition. The purpose of using these latter constructions was to eliminate expectancy strategies based on sentence form and length.

All sentences contained two animal NPs. No animal in the experimental sentences was repeated in the filler sentences. Each animal name had a maximum age of acquisition rating of 4.5 years (Coltheart, 1981; Cortese & Khanna, 2008; Fenson et al., 1993; Gilhooley & Logie, 1980). Both NPs also were controlled for imageability (> 500), concreteness (> 500), and familiarity (> 500) on a scale ranging from 100-700. Each embedded verb in the sentence was also familiar to 7- to 11-year-old children (Moe, Hopkins, & Rush, 1982) and controlled for imageability (> 450) (Coltheart, 1981; Cortese & Fugett, 2004; Gilhooly & Logie, 1980; Toglia & Battig, 1978). These controls

maximized the likelihood that the Ns and Vs in the sentences are highly familiar to all the children, thereby minimizing lexical factors contributing to NP1 reactivation.

All of the sentences were semantically reversible. Each animal name appeared as NP1 in half of the sentences and as NP2 in the other half. The embedded verbs were neutral regarding which animal would typically perform the action on the other. That is, each animal had "comparable" probability of performing the action on the other. Using neutral verbs allowed for a more clear focus on whether WM affects children's NP1 reactivation, unconfounded by semantic/pragmatic cues. Finally, the images of the related animals (NP1) and unrelated (control) were color drawings standardized for name and image agreement, familiarity (for 7- to 11-year-old children), and visual complexity (Rossion & Pourtois, 2004).

As noted, 2 kinds of filler sentences were created, SR fillers and compound sentences. All fillers were constructed following the same constraints used to construct the test OR sentences. See Table 3 for an example of experimental sentences and conditions (see Appendix B for full set of sentences). Table 3

Target type		Target picture presentation location
		Gap
NP1	(# cow)	The <i>cow</i> that the horse had kissed # outside the barn was noisy
Control	(# pig)	The cow that the horse had kissed # outside the barn was noisy
		Post-Gap
NP1	(# cow)	The <i>cow</i> that the horse had kissed outside the # barn was noisy
Control	(# pig)	The cow that the horse had kissed outside the # barn was noisy

Cross Modal Picture Priming Task

Note. Gap targets presented at offset of verb phrase. Post-gap targets presented exactly 500 msec after the offset of verb-phrase.

Target picture location. To investigate the influence of working memory abilities on NP1 reactivation, two probe locations were examined. Probe location 1 was presented at the syntactic gap, a point of verb offset. Probe location 2 (post-gap) was a point 500 msec after verb offset (effectively, after gap processing has occurred in adults).

Target type. To assess priming during sentence processing, two target picture types were created, one representing NP1 and a control. Target Pictures were related animal (NP1) or an unrelated animal (control). These were presented at different probe locations while the participants were listening to the sentences.

The assumption was that just after the verb, the previously hear word (NP1) is reactivated. The occurrence of the verb (the prime) just prior to presentation of the NP1 visual target, results in speeded processing of the target (compared to an unrelated control), a result that is termed priming (Love, 2007; Meyer, Schvaneveldt, & Ruddy,

1974; Neely, 1991; Roberts et al., 2007). Thus, difference scores (NP1 vs. control) were interpreted as a priming effect, reflecting lexical activation.

Ensuring children's sentence comprehension. Children completed a postsentence comprehension check on 20% of the sentences. Immediately after the offset of the sentence (and following the child's response), each children was asked a simple Y/N comprehension question with the focus on encouraging continued listening. This postsentence comprehension check was intended to ensure that children comprehend the meaning of the sentence (also reactivating NP1 to establish a filler-gap dependency), while also monitoring the screen for the presentation of the visual probe. The sentence immediately following a comprehension question was always a filler item to decrease possible cognitive load effects.

Presentation of experiment. The experiment employed a matched-sentence design, in which sentence presentation vary on two conditions: Probe location (2: gap, post-gap) and Target Type (NP1 animal or control animal). Participants heard each experimental sentence twice during each session, once with the related and once with the unrelated target picture. Importantly, participants never saw any one picture more than one time in any one of the three sessions in which they participated. Sessions were schedule a minimum of two days apart to minimize repetition effects.

Experimental OR sentences and filler sentences (SRs and compound sentences) were all presented in random order. The two sentence conditions, Probe Locations (2) and Target Type (2) did not constitute separate presentation conditions. Conditions were intermixed; during each session children were presented trails representing all conditions.

However, positions were counterbalanced (e.g., session 1: NP1 at gap, control at postgap; session 2: NP1 at post-gap, control at gap). The main reason for this design was that random presentation across sentence and conditions should prevent children from developing a rhythm or expectancy in processing any given sentence type, Probe Location, or Target Type. Three sentence sets were created, with each set comprising a random order of 105 sentences. Each participant experienced these sessions in a randomly assigned (fully counterbalanced) order to eliminate repetition effects across the overall experiment.

Dependent variable. The preliminary dependent variables were processing times for the NP1and unrelated picture targets in the OR sentences. The PC-internal clock started at picture onset. The clock stopped as soon as the child touched a picture. The child had 5 s to respond or the trial timed out and the trial was scored as incorrect. The computer automatically calculated and stored children's response times.

Four experimental dependent measures were captured: (a) Gap RT (NP1 reactivation time at the syntactic gap); and (b) Post-Gap RT (NP1 reactivation time 500 msec after the syntactic gap); the Gap RT measure was consistent with what other developmental researchers have used (Love, 2007; Roberts et al., 2007), (c) the Post-Gap RT was used to examine the time course of children's NP1 reactivation. A third dependent variable was Gap Priming (RT difference between the related and unrelated prime pictures at the gap); and, (d) Post-Gap Priming (RT difference' represented a priming a time pictures at the post-gap). The RT "difference" represented a priming

advantage of the related target picture over the unrelated target picture, and is novel to this study.

To control for intersubject variability, each subject's final mean RT measures (Gap RT, Post-Gap RT) were computed by subtracting subject's basic motor speed. Priming advantage variables (difference scores) were within subject measures that intrinsically controlled for inter-subject variability.

Data Preparation

Prior to the analysis of CMPP response times (RT), data was examined for outlying responses. Outliers were identified and eliminated from each subject's data set (Fazio, 1990). No subject was excluded based on outlying data. Rather, data points were replaced with each subject's mean RT. An outlier was defined as any RT falling \pm 2.5 SD from a child's mean RT for both NP1 targets and unrelated control pictures targets. The procedure entailed: (a) first calculating a mean RT for each child, (b) identifying all outliers and then eliminating all outliers from each child's data set, and finally, (c) after outliers are removed and replaced by an appropriate mean RT, a new mean RT was calculated (Fazio, 1990). This procedure yielded a complete data set for each child. Mean RT were used in all of the following analyses.

Chapter 4: Results

Review of Variables

To investigate the influence of WMc and attention switching on noun phrase 1 (NP1) reactivation, three primary experimental tasks were used: an overall working memory capacity task (WMc), an attentional focus switching task (Att Switching), and a cross-modal picture priming (CMPP) task to capture NP1 reactivation times.

During the CMPP sentences, two specific online probe locations were examined: *Gap* (offset of verb phrase) and *Post-Gap* (500 msec after verb phrase offset). Experimental target pictures presented at both probe locations were either: related animal (*NP1*) or an unrelated animal (*control*).

Four experimental dependent measures were captured: (a) Gap RT (NP1 reactivation time at the syntactic gap); and (b) Post-Gap RT (NP1 reactivation time 500 msec after the syntactic gap); (c) Gap Priming (RT difference between NP1 and conrol pictures at the gap); and (d) Post-Gap Priming (RT difference between NP1 and control pictures at the post-gap).

Preliminary Analyses

Diagnostic measures such as histogram of errors, studentized residuals, and Cook's distance were used to examine for cases that might fall far from the regression equation. There were no outliers/influential cases. These findings indicated that the assumptions for the model were satisfied and the conclusions obtained from the model could be endorsed. Collinearity statistics (Tolerance and Variance Inflation Factor) indicated that there was no multicollinearity. **Sentence Processing Task.** First, children were highly accurate in responding "Yes" or "No" to the prime pictures in all of the sentences (99.4% correct). Second, data for the post-trial comprehension probe questions indicated that the children were paying attention to the sentences while making the "Yes/No" classification decision (96% correct). See Table 4 for descriptive statistics of all experimental measures and age.

Table 4

Variables	Mean	SD	Range	Skewness	Kurtosis
СМРР					
Gap RT	391.2	187.0	124-1055	1.611	3.397
Post-Gap RT	367.0	162.5	100-980	1.144	2.530
Gap Priming	28.2	117.9	-282-426	.922	3.082
Post-Gap Priming	35.1	103.0	-186-415	.902	2.345
WMc	4.0	0.9	2-6	504	.315
Att Switching	2926.0	838.1	1405-5152	.618	.305
Age	124.1	10.8	108-143	.151	-1.158

Descriptive Statistics of All Experimental Measures and Age (n = 55)

Note. CMPP = cross-modal picture priming task. Gap RT and Post-Gap RT = response times for NP1 lexical classification decisions at each sentence location (msec). Gap Priming and Post-Gap Priming = difference in reaction times for control picture vs. NP1 at each location (msec). WMc = working memory capacity span score. Att Switching = attention switching response time for accurate trials (msec) controlling for general motor RT (msec).

Examination of target type and probe location. Three initial analyses were

performed to investigate whether children, overall, demonstrated a syntactically driven

time advantage at the gap and post-gap sentence locations. First, to determine whether

response times differed between NP1 and the control target, two paired-sampled *t* tests were conducted at the gap and then the post-gap. Gap: The results indicated that the mean RT for NP1 at the Gap (M = 391.2, SD = 187.0) did not differ from the mean RT for control target at the Gap (M = 419.4, SD = 230.7), t(54) = 1.775, p = .082, r = .23, suggesting that children, as a group, did not consistently demonstrate a syntactical priming advantage at the gap. Post-Gap: The results indicated that the mean RT for NP1 at the Post-Gap (M = 367.0, SD = 162.5) was faster than the mean RT for control target at the Post-Gap (M = 402.1, SD = 202.4). This difference, 35.1 msec, was significant t(54) = 2.526, p = .015, represented a medium-sized effect, r = .33, and suggested that children, as a group, demonstrated a *delayed* priming advantage (NP1 reactivation) at the post-gap. See Figure 1 for boxplots displaying reaction times for NP1 and Control target pictures at the Gap and Post-Gap.



Figure 1. Boxplots displaying reaction times for NP1 and control target pictures at the gap (left) and post-gap (right).

Second, to examine whether, overall, the NP1 response times at Post-Gap differed from the Gap, a paired-sampled t test was conducted comparing Post-Gap RT and Gap RT. The results indicated that the mean RT for NP1 at the Post-Gap (M = 367.0, SD =162.5) was faster than the mean RT for NP1 at the Gap (M = 391.2, SD = 187.0). This difference, 24.2 msec, was significant t(54) = 2.31, p = .025, and represented a mediumsized effect, r = .30.

Third, to examine whether, overall, the advantage seen at the Post-Gap differed from the Gap, a paired-sampled *t* test was conducted comparing Gap-Prime and Post-Gap difference scores. The results indicated that the time advantage for NP1 at the Gap (M = 28.2, SD = 117.8) did not differ from the time advantage for NP1 at the Post-Gap (M = 35.1, SD = 103.0), t(54) = .416, p = .697.

Primary Analyses

Correlation analyses. Correlation coefficients were computed among the experimental measures and age. Results of the correlation analyses presented in Table 5 revealed that age was statistically correlated with both of the predictor variables (WMc, and switching), but correlations were nonsignificant with all four of the dependent experimental variables. WMc and attention switching were significantly correlated with each other, and both significantly correlated with three of the four dependent experimental measures. Lastly, a pattern was indicated within the dependent variables. The response time measures at both locations (Gap RT, Post-Gap RT) were strongly correlated. The difference score measures at both locations (Gap Priming, Post-Gap Priming) were also moderately correlated. Correlations for response time and difference score measures were nonsignificant.

Partial correlation coefficients were then computed among experimental measures, controlling for age in months. The partial correlations are reported in the second half of Table 5. Five partial correlations were significant. The two response time measures (Gap RT, Post-Gap RT) remained significantly correlated. The two difference score measures (Gap Priming, Post-Gap Priming) remained significantly correlated. Lastly, attention switching remained significantly correlated with Gap RT, Post-Gap RT, and Post-Gap Priming, but not with Gap Priming. Table 5

V	ariables	1	2	3	4	5	6	7		
			Bivariate correlations							
1	Age									
2	WMc	.426**								
3	Att Switching	376**	289*							
4	Gap RT	153	276*	.358**						
5	Post-Gap RT	199	313*	.334*	.911**					
6	Gap Priming	223	301*	.262	.099	.250				
7	Post-Gap Priming	247	112	.386**	.250	.119	.388**			
			Dout	-1 <i>m</i> -1-	tions cont	nallin a fa				
2			Paru	ai correia	tions cont	roning ic	or age			
2										
3	Att Switching		153							
4	Gap RT		235	.328*						
5	Post-Gap RT		257	.286*	.909**					
6	Gap Priming		234	.197	.067	.216				
7	Post-Gap Priming		008	.327*	.221	.073	.352**			

Bivariate and Partial Correlations between the Experimental Measures and Age (n = 55)

Note. Age in months. WMc = working memory capacity. Att Switching = attention switching RT for accurate trials. Gap RT and Post-Gap RT = response times for NP1 lexical classification decisions at each sentence location (msec). Gap Priming and Post-Gap Priming = difference in reaction times for control picture vs. NP1 at each location (msec).

*Significant at $\alpha = .05$ (2 tailed). **Significant at $\alpha = .01$ (2 tailed).

General linear modeling (GLM) analyses. Four sets of GLM analyses were run.

The first two sets examined the influence of WMc and attention switching on NP1

reactivation time at the two theoretically relevant sentence locations, at the gap (Gap RT)

and the post-gap (Post-Gap RT). This measure reflects how fast each child was able to

switch his/her attention away from auditory sentence processing and activate the

(previously encountered) noun. A third and fourth set of analyses examined the influence

of WMc and attention switching on the response time *advantage for NP1* over the control target (Gap Priming, Post-Gap Priming). These "advantage" measures (control target-NP1 target; msec) were interpreted as lexical *priming* effects and reflected the speed advantage of NP1 gained during parallel auditory sentence processing at the two theoretically relevant sentence locations (Love, 2007; Roberts et al., 2007). Because age did not correlate with any of the dependent measures, it was not included in the modeling.

Predicting speed of NP1 reactivation at the gap. GLM was used for model estimation, with NP1 response time at the Gap as the dependent variable. The predictor variables were WMc and attention switching. Results of a univariate GLM revealed that the two predictors jointly explained 16% of the variance in NP1 response time at the Gap, $F(2, 52) = 4.972, p = .011, Adjusted R^2 = .128$. Table 6 displays the GLM results.

Multiple regression analyses were next conducted to examine how much individual variance WMc and attention switching accounted for in children's NP1 reactivation speed, with WMc entered first followed by attention switching. WMc accounted for a significant 7.6% of variance, $R^2 = .076$, $\beta = -.276$, F(1, 53) = 4.358, p =.042, r = .276. Attention switching accounted for an additional 8.5% of unique variance over and above that accounted for by WMc, $\Delta R^2 = .085$, $\beta = .304$, F(2, 52) = 4.972, p =.026, r = .401. Table 7 displays a summary of the multiple regression results.

Table 6

Variables in the model	В	95% confiden	F	р			
		Lower bound	Upper bound				
WM capacity	-39.842	-96.309	16.625	2.005	.163		
Attention switching	.068	.008	.127	5.236	.026		
<i>Note.</i> $F(2, 52) = 4.972, R^2 = .16, p = .011.$							

General Linear Model Predicting Gap RT (n = 55)

Table 7

Hierarchical	Regression	Predicting	Sneed of NP1	Reactivation at	the Gar
	1.00.000000				ine oup

Model (R^2)	Variable	β	ΔR^2	ΔF	(df1, df2)	р
$ \begin{array}{c} 1 \\ (R^2 = .08) \\ (\text{Adj } R^2 = .06) \end{array} $	WMc	276	.076*	4.358*	1, 53	.042
2 ($R^2 = .16$) (Adj $R^2 = .13$)	WMc Att Switching	188 .304	.085*	5.236*	2, 52	.026

Note. WMc = working memory capacity. Att Switching = attention switching RT for accurate trials. *Significant at q = 05 (2 tailed) **Significant at q = 01 (2 tailed)

*Significant at $\alpha = .05$ (2 tailed). **Significant at $\alpha = .01$ (2 tailed).

Predicting speed of NP1 reactivation at post-gap. GLM was used for model estimation, with NP1 response time at the Post-Gap as the dependent variable. The predictor variables were WMc and attention switching. Results of a univariate GLM revealed that the two predictors jointly explained 16.3% of the variance in NP1 response

time at the Post-Gap, F(2, 52) = 5.055, p = .010, *Adjusted* $R^2 = .131$. Table 8 displays the GLM results.

Multiple regression analyses were next conducted to examine how much individual variance WMc and attention switching accounted for in children's NP1 reactivation speed at the Post-Gap, with WMc entered first followed by attention switching. WMc accounted for a significant 9.8% of variance, $R^2 = .098$, $\beta = -.313$, F(1, 53) = 5.754, p = .020. Attention Switching accounted for an additional 6.5% of unique variance over and above that accounted for by WMc, $\Delta R^2 = .065$, $\beta = .266$, F(2, 52) = 4.028, p = .050. Table 9 displays a summary of the multiple regression results.

Table 8

В	95% confidence interval		F	р
	Lower bound	Upper bound		
-43.492	-92.488	5.504	3.173	.081
.052	.000	.103	4.028	.050
	<i>B</i> -43.492 .052	B 95% confiden Lower bound	B 95% confidence interval Lower bound Upper bound -43.492 -92.488 5.504 .052 .000 .103	B 95% confidence interval F Lower bound Upper bound - -43.492 -92.488 5.504 3.173 .052 .000 .103 4.028

General Linear Model Predicting Post-Gap RT (n = 55)

Note. $F(2, 52) = 5.055, R^2 = .16, p = .010.$

Table 9

Model (R^2)	Variable	β	ΔR^2	ΔF	(df1, df2)	р
$1 (R^{2} = .10) (Adj R^{2} = .08)$	WMc	313	.098*	5.754*	1, 53	.020
2 ($R^2 = .16$) (Adj $R^2 = .13$)	WMc Att Switching	236 .266	.065*	4.028*	2, 52	.050

Hierarchical Regression Predicting Speed of NP1 Reactivation at the Post-Gap

Note. WMc = working memory capacity. Att Switching = attention switching RT for accurate trials.

*Significant at $\alpha = .05$ (2 tailed). **Significant at $\alpha = .01$ (2 tailed).

Predicting priming advantage for NP1 Reactivation at the gap. GLM was used for model estimation, with Gap Priming as the dependent variable (difference score = control RT - NP1 RT). The predictor variables were WMc and attention switching. Results of a univariate GLM revealed that the two predictors jointly explained 12.4% of the variance in Gap Priming, F(2, 52) = 3.689, p = .032, *Adjusted* $R^2 = .091$. Table 10 displays the GLM results.

Multiple regression analyses were next conducted to examine how much individual variance WMc and attention switching accounted for an advantage in NP1 reactivation speed (Gap Priming), with WMc entered first, followed by attention switching. WMc accounted for a significant 9.1% of variance, $R^2 = .091$, $\beta = -.301$, F(1, 53) = 5.296, p = .025. After accounting for WMc ability, attention switching did not account for a significant proportion of the variation in response time advantage, $\Delta R^2 =$.033, β = .191, F(2, 52) = 1.985, p = .165. Table 11 displays a summary of the multiple regression results.

Table 10

General Linear Model Predicting Priming Advantage at the Gap $(n = 55)$								
Variables in the model	В	95% confider	F	р				
		Lower bound	Upper bound					
WM capacity	-32.903	-69.250	3.444	3.300	.075			
Attention switching	.027	011	.065	1.985	.165			
<i>Note</i> . $F(2, 52) = 3.698, R^2 = .124, p = .032.$								

Table 11

Hierarchical Regression Predicting Priming Advantage at the Gap

Model (R^2)	Variable	β	ΔR^2	ΔF	(df1, df2)	р
$ \begin{array}{c} 1 \\ (R^2 = .09) \\ (\text{Adj } R^2 = .03) \end{array} $	WMc	301	.091*	5.296*	1, 53	.042
$2 (R^2 = .124) (Adj R^2 = .09)$	WMc Att Switching	246 .191	.033	1.985	2, 52	.165

Note. WMc = working memory capacity. Att Switching = attention switching RT for accurate trials.

*Significant at $\alpha = .05$ (2 tailed). **Significant at $\alpha = .01$ (2 tailed).

Predicting priming advantage for NP1 reactivation at the post-gap. GLM was used for model estimation, with Post-Gap Priming as the dependent variable (difference score = control RT - NP1 RT). The predictor variables were WMc and attention switching. The predictor variables were WMc and attention switching. Results of a univariate GLM revealed that the two predictors jointly explained 14.9% of the variance in Post-Gap Priming, F(2, 52) = 4.555, p = .015, *Adjusted* $R^2 = .116$. Table 12 displays the GLM results.

Multiple regression analyses were next conducted to examine how much individual variance WMc and attention switching accounted an advantage in NP1 reactivation speed, with WMc entered first, followed by attention switching. Alone, WMc did not account for a significant proportion of the variation in response time advantage, $R^2 = .013$, $\beta = -.112$, F(1, 53) = 0.678, p = .414. Attention Switching accounted for an additional 14% of unique variance over and above that accounted for by WMc, $\Delta R^2 = .136$, $\beta = .386$, F(2, 52) = 8.338, p = .006. Table 13 displays a summary of the multiple regression results.

Table 12

Variables in the model	В	95% confiden	F	р			
		Lower bound	Upper bound				
WM capacity	102	-31.430	31.266	0.000	.995		
Attention switching	.047	.014	.080	8.338	.006		
<i>Note.</i> $F(2, 52) = 4.555, R^2 = .149, p = .015$							

General Linear Model Predicting Priming Advantage at the Post-Gap (n = 55)

Table 13

Hierarchical	<i>Regression</i>	Predicting	Priming A	dvantage at t	he Post-Gap
				0	

Model (R^2)	Variable	β	ΔR^2	ΔF	(df1, df2)	р
$1 (R^2 = .08) (Adj R^2 = .06)$	WMc	112	.013	0.678	1, 53	.414
$2 (R^2 = .16) (Adj R^2 = .13)$	WMc Att Switching	001 .386	.136**	8.338**	2, 52	.006

Note. WMc = working memory capacity. Att Switching = attention switching RT for accurate trials.

*Significant at $\alpha = .05$ (2 tailed). **Significant at $\alpha = .01$ (2 tailed).

Chapter 5: Discussion

The purpose of the present study was to test a model of object relative (OR) sentence processing in 9- to 11-year-old children for which both WMc and attention focus switching were predicted to be significant contributors. Predictions were based on the assumption that children's sentence comprehension entails both WMc and memory retrieval (Finney et al., 2014). Working memory storage capacity (i.e., limited focus of attention) is needed to retain two unintegrated noun phrases (NP1, NP2) in memory until encountering the embedded verb/gap, and attention switching is needed to support the memory retrieval of NP1 to establish a filler-gap dependency, allowing the verb to assign a proper thematic role to each NP.

This study was motivated by findings from Roberts et al. (2007), who found that typically developing children with reduced WMc showed no processing time advantage for the fronted NP pictures at the gap. The authors suggested that, in contrast to higher WMc children, lower WMc children may need more time to reactivate a dislocated NP constituent in a developing structure. A question left open by Roberts et al.'s study was: how delayed? Using an event-related potentials paradigm, Hestvik and colleagues (2012) found that compared with higher WM adults, low WMc adults have an onset latency delay of about 200+ msec in brain responses to violations of syntactic expectancies after the gap site.

The current study extended this work of in two important ways. First, we included two independent and theoretically relevant WM mechanisms to explore their contribution to children's NP1 reactivation at the syntactic gap. Second, like Roberts et al. (2007), we used a cross-modal picture priming (CMPP) paradigm, but we extended the time course of NP1 reactivation time to 500 msec after the gap. From estimates in the adult literature, we believed this was a reasonable temporal point that should reflect delayed NP1 reactivation in children, but discourage residual activation confounds. "Delay" was defined as not "immediate" reactivation at the syntactic gap.

Three experimental tasks were used: a working memory capacity task, an attentional focus switching task, and a CMPP task to capture NP1 reactivation during sentence processing. For the CMPP task : four experimental dependent measures were captured: (a) NP1 response time at the syntactic gap; and (b) NP1 response time 500 msec after the syntactic gap; (c) RT difference between the NP1 and the control target pictures at the gap; and (d) RT difference between the NP1 and the control target pictures at the post-gap. The RT 'difference' score represented the priming advantage of the NP1 target over the unrelated target picture, and was novel to this study.

The model was tested using general linear modeling (GLM). We predicted WMc and attention switching each would make a unique/ significant contribution to children's NP1 reactivation time. We also anticipated that WMc and attention switching abilities contribute to children's syntactic priming advantage during the time course of NP1 reactivation. Our predictions were largely supported.

Overall, the children performed each of the experimental tasks with little difficulty. On the standardized working memory capacity task (WMc), the children performed in the normal range (M = 4.0, SD = 0.9). Likewise, the children performed well on the attention switching task, achieving 76% switching accuracy overall. The

children also yielded good performance on the sentence processing task (CMPP): children were highly accurate in responding "Yes" or "No" to the prime pictures in all of the sentences (99.4% correct). Second, data for the posttrial comprehension probe questions indicated that the children were paying attention to the sentences while making the "Yes/No" classification decision (96% correct). Finally, children's WMc and attention switching ability were related, and each was related to three of the four sentence processing measures. Because age was not related with any of the dependent measures, it was not included in the modeling.

Preliminary evidence of NP1 reactivation. Results from preliminary analyses produced three important findings. First, typically developing children, as a group, showed no timing advantage for immediate NP1 reactivation (at the syntactic gap). This finding contradicts past research that demonstrated that children as young as 6 years of age show NP1 reactivation at the gap (Love, 2007; Roberts et al., 2007). Second, as a group, children demonstrated delayed NP1 reactivation, evidenced by a reaction time advantage at the post-gap location and comparatively faster NP1 reactivation times at the delayed location relative to the syntactic gap. Hestvik et al. (2012) found that adults with less working memory ability had delayed NP1 reactivation. Together these findings suggest that, as a group, children with developing WM abilities (like adults with less WMc) may have delayed NP1 reactivation that is closer to 500 msec after verb offset. Lastly, substantial variation in overall priming advantage for immediate and delayed activation suggests that the time course for NP1 reactivation appears to differ across

children. We predicted that WMc and attention switching would help explain variation in children's OR sentence processing.

Contributions of WMc and Attention Switching to Children's Sentence Processing

Using general linear modeling, four models of OR sentence processing were tested, representing the speed and retrieval advantage for NP1 at both the syntactic gap and 500 msec post-gap. Together, WMc and attention switching significantly contributed to each model. These findings support the claim that children's sentence comprehension and sentence processing, as indexed by NP1 reactivation, are generally supported by WMc and attention switching (Finney et al., 2014, Roberts et al., 2007). The following discussion takes a closer look at the unique contributions of each WM mechanism at the two probe locations (gap and post-gap)..

Contributions of WMc and attention switching to rapid NP1 activation.

Results of OR sentence comprehension modeling indicated that, while WMc is involved, attention switching is the only mechanism uniquely contributing to NP1 reactivation speed in the full model. Although WMc alone contributed to children's sentence processing, attention switching ability predicted how fast children were able to switch their attention away from auditory sentence processing and reactivate the (previously encountered) noun. These findings are consistent with the literature. Like adults (Gordon, Hendrick, & Johnson, 2001; Gordon et al., 2002, 2004; Lewis et al., 2006; Van Dyke, 2007; Van Dyke & McElree, 2006, 2011), children have the capacity to hold two unintegrated NPs in memory during sentence processing (Roberts et al., 2007), but limited focus of attention (WMc) appears to play a minor role (Hestvik et al., 2012;

Lewis et al., 2006) in explaining differences in NP1 reactivation times. Also similar to adults and the emerging developmental literature (Love, 2007; Roberts et al., 2007), children have the ability to reactivate NP1 immediately upon or shortly after encountering the embedded VP, allowing them to integrate it with the VP to build a filler-gap dependency.

Contributions of WMc and attention switching to priming advantage of NP1. Regarding the time course of NP1 reactivation, WMc and attention switching together are involved in both *immediate* and *delayed* NP1 reactivation. However, results of the modeling indicate that WMc and attention switching uniquely contribute to different temporal points during sentence processing.

While neither WMc nor attention switching uniquely explained NP1reactivation in the full model, alone, WMc contributed to children's *immediate* NP1reactivation. Attention switching ability did not contribute to NP1 reactivation at the gap. These findings suggest that the priming advantage for NP1 at the syntactic gap is mediated by how much information a child can hold in the focus of attention (Roberts et al., 2007). It follows that children with more WMc resources are not switching away from ongoing sentence processing to reactivating NP1; so much as they are able to keep NP1 in some heightened state of activation. Some researchers have argued that increases in WM capacity may also be driven by changes in attentional control. As children grow older they become better at rapidly switching their attention between the processing part of the task and maintaining items activated in short term memory (Barrouillet et al., 2009; Conlin et al., 2005; Portrat et al., 2009). The development of this ability may explain differences between adult and child literatures regarding the role of WMc. Though WMc is involved in adult sentence processing, it plays a minimal role in explaining adult's sentence comprehension (Hestvik et al., 2012; Lewis et al., 2006). The present findings are in line with emerging development literature (Finney et al. 2014; Roberts et al., 2007) and suggest that WMc is involved in children's complex sentence comprehension.

Results also indicated that, for *delayed* NP1 reactivation, attention switching, but not WMc, contributed to a NP1 reactivation advantage at the post-gap location. Though WMc was not involved in NP1 reactivation at post-gap, it is highly doubtful that children had insufficient storage capacity to support memory retrieval at this point in the sentence. Recall that children's NP1 reactivation was assessed immediately after word 7 (+500 msec). The present findings, interestingly, appear to mirror those in the adult literature that suggest WMc (limited focus of attention) may not be the major determinant of children's NP1 reactivation for sentences involving a short dependency.

If WMc was not a major factor, attention switching was. The finding suggests that *slightly delayed* NP1 reactivation is mediated by children's ability to switch their attention away from auditory sentence processing and reactivate the (previously encountered) noun.

In sum, these findings suggest that varying subsets of WM mechanisms contribute to sentence processing at different temporal intervals during sentence comprehension. An advantage for NP1 reactivation at the gap is related to children's WMc; their ability to hold two NP in activated memory. However, only 500 milliseconds later during sentence processing, children no longer relying on their WMc ability, but rely on their attention switching ability. This is further evidence that for children, normal processing of syntactic cues trigging memory retrieval may be slightly delayed.

Limitations and Future Directions

The present study has set the foundation for future research by adding new information to an emerging model of children's complex sentence processing and uncovering important questions yet unanswered.

Interpretation of the time course. Our interpretation of the results point to the following: although the time course for NP1 reactivation appears to differ across children, as a group, children have delayed NP1 reactivation that is constrained by their attention switching ability. This was supported by preliminary analysis indicating that (as a group) children demonstrated priming advantages at the post-gap time interval, not the gap (interpreted from a significant difference score, Love, 2007, Roberts et al., 2007). Also, during later (post-gap) sentence processing, children relied on their attention switching ability, not WMc, to support NP1 reactivation. That children overall may show a slight delay in NP1 reactivation is supported by literature which demonstrated a group difference; children were slower to reactivate NP1 than adults (Roberts et al., 2007).

An alternative interpretation to "delayed reactivation" is that the post-gap may simply reflect residual reactivation from the gap, not a delay as defined by the adult literature or by just one child study. It is reasonable to assume that, of the two temporal points examined, the post-gap may best capture the varying times. For some children, the gap may represent residual activation from lexical retrieval at the gap. For others it may the onset of reactivation (and anywhere in between). In addition, the design of our shorter sentences (created to parallel a comprehension task), may have contributed to continued lexical activation from the original NP1 presentation at the beginning of the sentence. This "continued activation" interpretation is supported by our findings that suggest children's speed of NP1 reactivation at the gap and post-gap sentence locations were similar. Also recall that although priming occurred at the post-gap site, the advantage/difference scores between the gap and post-gap location were also similar; NP1 reactivation appears to differ across children. Future studies with the CMPP paradigm and using multiple temporal points and/or increasing the verbal stimuli between NP1 and the gap, would provide valuable information to the emerging developmental model of sentence processing.

The above discussion also raises the issue of individual variation; the time course for NP1 reactivation appears to differ across children. Roberts et al. (2007) found that at least some of the children in that study were able to demonstrate NP1 reactivation at the gap (children with higher WMc). Our study also demonstrated that WMc was involved with an immediate timing advantage for reactivating NP1 at the GAP, but as a group NP1 reactivation was supported by attention switching at the post-gap. Perhaps the design of the study was unable to capture the variability of NP1 patterns across children. Future studies using the CMPP paradigm may benefit from using an individual differences approach by breaking the children up into ability groups (e.g., hi-lo memory groups) to better examine potential performance patterns.

Another explanation of 'delayed' NP1 reactivation is the influence of similaritybased retrieval interference. See Other Possible Constraints below for further discussion. The cross-modal picture priming task. This study used the cross-modal picture priming (CMPP) paradigm to test a model of NP1 reaction for which two WM measures were predicted to be significant contributors. The CMPP is an established design used to study NP1 reactivation; however it may not be suited to examine the influence WM on the time course of lexical reactivation during children's sentence processing.

First, for the CMPP to be effective, a good temporal prediction point is needed. Without a specific temporal prediction, use of the CMPP method would require sampling reactivation at multiple down-stream syntactic positions, which would be a resource intensive endeavor given the large subject samples, small effect size, repeated measures, and multiple sessions required for a single position. In addition, even with a good prediction, it is possible that subject variability may confound the data.

Our study employed two probe positions based on theoretically relevant temporal points in the sentence, the gap and 500 msec after the gap. The second point was based on estimates from the adult literature (Hestvik et al., 2012) and we believed was a reasonable temporal point that should reflect delayed NP1 reactivation in children, but discourage residual activation confounds from the gap. However, as stated earlier, based on our results, we believe it is possible our post-gap may have reflected residual reactivation from the gap. Perhaps the CMPP is insensitive to modeling the actual time course of NP1 reactivation in children. A better way to model (GLM) the time course of NP1 reactivation may be to use event-related potential (ERP). This is a measured brain response that is the direct result of a specific sensory, cognitive, or motor event, and has been found to be effective in detecting patterns of adult sentence processing across time (Hestvik et al., 2012). An EPR paradigm would provide much opportunity for testing findings from the adult models of sentence processing and emerging evidence from the developmental literature. In addition, using an ERP paradigm would solve the working memory confound discussed above, as it only requires subjects to listen to a sentence.

A second concern is that variability in WM may have influenced the task measurement itself. As stated, one benefit of the cross-modal picture priming task (CMPP) is that it implicitly taps NP1 reactivation in sentence processing in that it does not require any confounding explicit memory demands (e.g., verbal rehearsal) during sentence processing (Berman et al., 2009). However, the CMPP is a dual-attention task, and the premise of the CMPP method is that trials are only valid in so far as the subjects are paying equal attention to stimuli in both modalities. Paying equal attention to two stimulus streams raises the baseline amount of working memory that has to be allocated during the task. This raises the possibility that if a subject has low verbal memory capacity, he or she may in fact not be able to pay equal attention to both stimulus stream in every trial, focusing more on either the auditory stimuli or the picture stimuli. If so, it could be that lower WM subjects fail to show priming because they are unable to comply with dual task demands. This may also explain variation in post sentence question performance. Future studies exploring additional methods for measuring the effect of working memory resources on processing of filler-gap constructions (where the task itself does not add extra working memory demands) would offer a clearer, potentially less confounded, window into the role of WM.

Other potential constraints. As noted earlier, the adult sentence processing literature has made significant advances in recent years in understanding complex sentence comprehension. These advances are the result of researchers building models of sentence comprehension that are explicitly informed by various independently motivated principles mechanisms of human memory (Berman et al., 2009; Gibson, 1998; Gordon et al., 2002, 2006; Lewis et al., 2006; McElree et al., 2003; Van Dyke, 2007; Van Dyke & McElree, 2006, 2011). Memory mechanisms incorporated in these frameworks include: (a) a controlled limited focus of attention (WMc), (b) fast access to item information (lexical retrieval), (c) similarity-based retrieval interference (retrieval interference), and (d) fluctuating activation as a function of decay and retrieval strategy.

It is also important to emphasize that some memory mechanisms, though involved, do not seem to play an important role in explaining differences in adult sentence comprehension, including: limited focus of attention (WMc) (Hestvik et al., 2012; Lewis et al., 2006) and item activation decay, i.e., forgetting of NP1 before reactivation/retrieval is required (Lewis et al., 2006; Van Dyke & Lewis, 2003). While other mechanisms are appear to have a strong influence on adult comprehension. Importantly, retrieval interference (cue overload) shows strong effects in adults. Little is known about the influence these mechanisms have on children's processing.

Item retrieval: Role of activation decay. The current study was not designed to address several WM mechanisms incorporated in the adult model of sentence processing. Activation delay (the effect of increased temporal interval between NP1 and the gap on reactivation) was not investigated. The sentences in our study were relatively short,
compared to other studies (the task was designed to parallel a comprehension task). Longer and varied sentence stimuli would likely engage decay of activation, especially for children with limited WMc and decreased attention switching skills.

Item retrieval: Role of similarity-based interference. Similarity-based retrieval interference is emerging as a powerful explanation of poor complex sentence comprehension in adults (Gordon et al., 2001, 2004, 2006; Lewis et al., 2006; McElree et al., 2003; Van Dyke & McElree, 2006, 2011). It is thought that retrieval interference causes cue overload whereby the cues needed to retrieve or recover an item from memory (e.g., NP1) are closely associated with other items (e.g., NP2 and any other NPs) in memory. It is thought that retrieval interference causes cue overload whereby the cues needed to retrieve or recover an item from memory (e.g., NP1) are closely associated with other items (e.g., NP1) are closely associated with other NPs) in memory.

Although the current study was not designed to investigate similarity-based retrieval interference, it is possible that our results reflect interference. The OR sentence stimuli (designed to parallel a comprehension task) were created with embedded VPs that were as semantically/pragmatically neutral as possible in terms of which NP performed the action; in each sentence, both animals shared anatomical and/or environmental similarities. This design feature may have created significant retrieval competition between NP1 and NP2 (e.g., cow, horse). In effect, interference may be another alternative explanation for the overall 'delayed' NP1 reactivation demonstrated by children. Accordingly, we might expect that children with less WM abilities (being able to hold more information and efficiently switch focus) would be susceptible to retrieval interference and cue overload. Investigation of cue-dependent retrieval interference in children's sentence comprehension clearly is an important line of future study.

Item retrieval: Role of language knowledge. Bates and colleagues (Bates & MacWhinney, 1987, 1989; Bates et al., 1984) proposed the Competition Model, an interactive activation model, as an account of cross-linguistic differences in children's sentence processing. The model assumes that the listener interprets the meaning of a sentence by calculating the probabilistic value of multiple linguistic cues in a sentence such as word order, morphology and semantic characteristics (e.g., animacy). The listener's final interpretation of the sentence is based on the coalition of linguistic cues having the highest likelihoods. Three key constructs–cue validity, cue strength, and cue cost–are included in the model. Developmentally, the competition model posits that children learn these coalitions of cue-function mappings implicitly from their input language and adjust the weights of the different mappings over time with increased exposure to their native language.

The present study did not investigate children's knowledge as a potential explanation of NP1 reactivation. However, it is likely to be involved. For example, it is reasonable to assume that stable lexical representations reinforce encoding and retrieval during sentence processing. Future research examining the role of language knowledge (e.g., vocabulary, syntactic) in children's NP1 reactivation would provide valuable information to a memory-based model of sentence processing.

Lastly, this study was conducted only with typically developing children. Children with specific language impairment (SLI) demonstrate significant receptive and/or expressive language deficits in the presence of normal-range hearing and nonverbal IQ. Many of these same children also show marked limitations in a variety of working memory (WM) abilities. Future studies with children with SLI would contribute to the knowledge base on the intersection of memory ability and language impairment.

In sum, an emerging developmental model of sentence processing would benefit from studies that considered the following expansions. Future studies with the CMPP paradigm might consider multiple temporal post-gap points and increasing the verbal stimuli between NP1 and the gap to decrease the potential effect of continued activation (vs. reactivation). Also, to better examine potential performance patterns in NP1 reactivation, researchers may consider using an individual differences approach by breaking the children into ability groups (e.g., hi-lo memory groups). That said, we believe exploring additional/different methods for measuring the effect of working memory resources on NP1 reactivation will be beneficial. For example, a better way to model the time course of NP1 reactivation may be to use event-related potential (ERP). An EPR paradigm would provide an opportunity to examine the time course of NP1 reactivation in greater detail and would solve the potential WM confound. In addition, future studies that examine activation decay and retrieval interference (by varying the sentence stimuli) would provide valuable information regarding other WM constraints on children's sentence processing and comprehension. We also believe that research examining the role of language knowledge (e.g., vocabulary, syntactic) in children's NP1 reactivation would provide valuable information to a memory-based model of sentence

processing. Finally, we hope to see future studies including children with language impairment.

Theoretical and Clinical Implications

Theoretically and empirically motivated frameworks describing children's complex sentence processing from a memory perspective do not exist. Results of this study have several important impacts: (a) they add new/important information to the child language and psychology literatures regarding the influence of a two memory mechanisms constraining language comprehension, and (b) they add developmentallysensitive information to a model of sentence processing that is just emerging in the adult language literature. Lastly, these results may provide critical data against which the cognitive processing of children with language difficulties may be compared. Better understanding the nature of auditory comprehension problems is crucial, not only because of its impact on general language development and academic success, but also because it represents the single best predictor of reading comprehension in children with language impairment. Broader and deeper understanding of the memory abilities underlying auditory sentence comprehension may provide important insight into which memory abilities might be appropriate targets for intervention, with the intent of directly boosting auditory sentence comprehension and indirectly boosting reading comprehension.

Conclusion

Overall, the present findings add new and important information to the developmental language literature by indicating that WMc and attention switching support quick NP1 reactivation and are related to an NP1 retrieval advantage (over other lexical items in memory). The findings of this study agree with the emerging developmental language literature by showing that WMc plays a role in memory retrieval during OR sentence processing. In addition, these findings provide experimental evidence of the importance of an attention focus switching mechanism supporting children's sentence processing and comprehension hypothesized by Finney and colleagues (2014).

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Appendix A: Glossary

Independent Variables

- Att switching (focus attention switching): mean reaction time (msec) for the switch tones in accurate attention switching task trials, measured by the "Hi-Lo" attention switching task (Finney et al., 2014; Magimairaj & Montgomery, 2013).
- WMc (working memory storage capacity): WM Span, highest list length with at least 2/3 trials recalled accurately, measured by the Auditory Working Memory Subtest of the Woodcock-Johnson III NU Test of Cognitive Abilities (Woodcock, McGrew, & Mather, 2001).

Dependent Variables (Cross-modal picture priming task: CMPP)

- Gap RT: mean response time (msec) for NP1 reactivation at verb offset (CMPP).
- **Post Gap RT**: mean response time (msec) for NP1 reactivation 500 msec after verb offset (CMPP).
- **Gap Advantage**: reactivation advantage (msec) for NP1 (over other lexical items) at the Gap. This is a difference score: control target picture RT NP1 target RT.
- **Post-Gap Advantage**: reactivation advantage (msec) for NP1 (over other lexical items) at the Post-Gap. This is a difference score: control picture RT NP1 RT.

Terms

attention: the controller of cognitive processes (executive functions), including working memory (Baddeley, 2000). The attentional focus is limited (Cowan et al., 2005)and the focus of attention can only "hold onto" one thing at a time (Oberauer, 2009).

attention switching: the ability to effectively switch between ongoing processing and storage during cognitive tasks to integrate information.

cross-modal picture priming task (CMPP): dual task paradigm used to implicitly examine noun phrase 1 reactivation (no explicit memory directives; Love & Swinney, 1996).

Gap and Post-Gap: *Gap*: verb offset; the point in the sentence where noun phrase 1 is reactivated to establish filler-gap dependency (to regain canonical word) order during sentence processing (Chomsky, 1995). *Post-Gap*: 500 msec after verb offset, employed to examine the time course (and possible delay; Hestvik et al., 2012) of NP1 reactivation.

noun phrase1 (NP1): the first noun in a sentence. In object relative sentences, NP1 is the recipient of the main verb in the sentence, the direct object.

object relative sentence (OR): "complex" sentences that have a direct object as the subject, e.g. *The boy that the girl kissed*. More specifically, OR sentences involve syntactic wh-"movement" of a phrase (*the boy*) from the canonical object position (e.g., *The girl kissed the boy*) to a fronted position. Listeners come to understand these sentences via regaining canonical order (Chomsky, 1995).

response time (RT): response time in milliseconds to stimuli presented in an experimental task.

working memory (WM): A [set of mental processes] holding a small amount of information in the mind, readily accessible for a short time to help an individual comprehend language and solve problems (Cowan et al., 2005).

working memory storage capacity (WMc): the amount of information that can be stored (held in an active state) during concurrent processing (Cowan et al., 2005, 2010).

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Appendix B: Experimental Task Score Sheets

Auditory Working Memory Task: Woodcock Johnson-3

Subject ID Code:

Examiner: Start audio recording now

Instructions: You're going to hear some names of things like animals or food, and some numbers. You will hear 1 beep and that tells you to get ready to listen to the words and numbers. You will only hear the lists one time so you will need to listen very hard. Then I want you to say the words first in the same order you heard them and then say the numbers in the same order you heard them. When you hear 2 beeps and see me point to you, that means repeat what you heard. Try to say the words and numbers back to me as soon as you can; don't wait too long because the next list will be coming pretty soon. When you hear the 1 beep again, that tells you the next list is going to start. I'll go first. Remember, we say the words first in the order we heard them and then say the numbers in the order we heard them.

Procedures:

1) Examiner writes down a # above each word (1, 2, 3) & each digit (1, 2, 3) to reflect child's serial order recall of each grouping of items.

2) Examiner writes down any word or digit intrusion error in the position it occurs in the word and/or digit group (draw a line to its position in the list) & indicate its serial order by writing a # above the error.

3) Strike thru any word or digit that is not produced.

Examiner Live Voice Demo: 2 Cat **Response:** Cat 2 ("See how I started with the word Cat then said the # 2?)

Online Scoring Rules (per trial):

+ = all words recalled in serial order **1st** THEN all digits recalled in serial order **2nd** -- = neither words nor digits recalled in serial order **OR** digits recalled before words (perfect recall is irrelevant)

Accept responses as correct if they are:

- 1) phonologically-similar sounding to or rhyme with the target word and/or
- 2) misarticulated versions of the target word

STOP RULE: STOP when child misses all 3 trials at any given list length (i.e., a – score is given on all trials)

Examiner to Child: *Ok now it's your turn. Remember, tell me the words 1st THEN say the numbers.*

Begin Testing

Child Practice 1: 9, apple 2-Item Test Lists T1 shoe, 6 T2 5, bird T3 2, meat

Child Practice 2: 1 cat milk

3-Item Test Lists

T1 8, sweater, 5 *T2* frog, 2, hat *T3* 7, fruit, house

4-Item Test Lists

T1 3, bread, 1, lion *T2* coat, 5, juice, 9 *T3* 8, horse, sock, 2

5-Item Test Lists

T1 4, orange, 1, bear, 7 *T2* belt, 3, 6, butter, 8 *T3* 9, rabbit, 5, 4, dress

6-Item Test Lists

T1 cow, 1, cake, 3, shirt, 6 *T2* 7, snake, soup, 2, 9, glove *T3* 8, pants, 3, mouse, 1, egg

7-Item Test Lists

T1 chair, 4, 7, cap, sugar, 6, 5 *T2* 2, spider, 9, bed, 3, skirt, 1 *T3* cracker, 5, 8, pig, door, 6, button

8-Item Test Lists

T1 4, salt, fox, 7, stove, 2, 9, boot *T2* cookie, 1, turtle, 5, table, 6, mitten, 3 *T3* carrot, 8, clock, 4, 9, corn, bird, 2 (apple) (9) (+ / --) **Correct Response Score** (shoe) (6) (bird) (5) (meat) (2) (cat milk) (1) (+ / --)

Correct Response Score

(sweater) (8 5) (frog hat) (2) (fruit house) (7)

(+ / --)

Correct Response Score

(bread lion) (3 1) (coat juice) (5 9) (horse sock) (8 2)

(+ / --)

Correct Response Score (orange bear) (4 1 7) (belt butter) (3 6 8) (rabbit dress) (9 5 4)

(+ / --)

Correct Response Score

(cow cake shirt) (1 3 6) (snake soup glove) (7 2 9) (pants mouse egg) (8 3 1)

(+ / --)

Correct Response Score

(chair cap sugar) (4 7 6 5) (spider bed skirt) (2 9 3 1) (cracker pig door button) (5 8 6) (+/--) **Correct Response Score** (salt fox stove boot) (4 7 2 9)

(cookie turtle table mitten) (1 5 6 3) (carrot clock corn bird) (8 4 9 2)

Examiner: Save Subject's audio file in Subject Data & Task Data Folders

DV1: WMspan

DV2: Total number of trials correct_____

(longest list with perfect serial order recall on 2 out of 3 trials) (Total number of trials correct across entire test)

Subject ID Code: _____ Age: ____ Gender: ____

Instructions:

- A. Can you count from 1 to 11? Go.
- **B.** Now you're going to see and hear two numbers and I want you to add them to make a new, bigger number. For example, if the numbers were '2 + 1' that would be '3.' Now you try a few.
- *C.* Now you're going to play a listening game where you will hear and count some beeps. You will hear two kinds of beeps - a high beep and a low beep. Even though you will hear many beeps, you will only hear one beep at a time, NOT a whole bunch at one time. As you hear the beeps you need to keep count of them in your mind and remember how many Hi-beeps you hear <u>AND</u> how many Low-beeps you hear.

You will rest your fingers on this little dot here. To hear each beep you will press this little spacebar key and bring them back to the dot. Right after you hear the beep you will say 'X Hi' 'X-Lo'. I want you to push the spacebar as fast as you can to hear the next beep but only <u>after</u> you tell me how many Hi and Low beeps you've heard.

You will know when you've heard the last beep because the screen will go green. When you see that, you tell me how many High beeps you heard and then how many Low beeps you heard. You can tell me in any order you want. Now, remember try to be as correct and as fast as you can be. Last thing, I don't want you to use your fingers to count. Just count out loud to me.

Procedures:

- 1) Examiner sits next to child
- 2) Child has keyboard in front of him/her & pushes spacebar to deliver each tone
- Examiner (a) types on both the child's score sheet AND on the green screen child's verbal report of # Hi & # Lo tones <u>and</u> (b) writes down on score sheet +/-- in Accuracy column on score sheet
- 4) Examiner also notes on score sheet when he/she reversed the Hi # & Lo # reported by child on any trial (e.g., typed on the green screen the # for Lo tones in the Hi tones slot & visa versa). The score sheet will be used to modify those trials in the .edat file where the examiner has reversed the values reported by the child

Examiner Demo:

- A. First, this is what the High beep sounds like (examiner pushes spacebar)
- **B.** *This is what the Low beep sounds like* (examiner pushes spacebar).
- Ok, now let me show you how to do this.

Trial 1: 1-Hi, 6-Low

Child Practice: Ok, you try a few practice.

Examiner: provide encouragement and general praise

Practice Set	Child Response
Trial 1: 1-Hi, 6-Low	
Trial 2: 8-Hi, 1-Low	
Trial 3: 2-Hi, 6-Low	

Block	Trial	Total Tones	Total Switches	Frequency	High Tones	Low Tones	Accuracy (+//0) (2/1/0)
1	1	7	2	L	1	6	
	2	9	2	L	8	1	
	3	11	3	L	6	5	
	4	8	3	Н	2	6	
	5	10	5	Н	5	5	
2	1	9	5	Н	6	3	
	2	11	6	Н	7	4	
	3	10	3	L	3	7	
	4	7	4	Н	4	3	
	5	8	2	L	2	6	
3	1	11	3	L	3	8	
	2	8	4	Н	4	4	
	3	7	2	L	1	6	
	4	10	3	L	8	2	
	5	9	5	Н	4	5	
4	1	8	2	L	1	7	
	2	11	6	Н	8	3	
	3	7	4	Н	5	2	
	4	9	2	L	7	2	
	5	10	5	Н	4	6	
					To	tal Points:	/40

WM Task: Attentional Switching Experimental Trials

Examiner:

- 1. Change any trials in .edat file that you Noted on child's score sheet where you reversed the child's verbal report of the # of Hi tones & # of Lo tones on the computer screen. Go to *biganswer.RESP* & *smanswer.RESP* columns in .edat file to make corrections.
- 2. Save Subject's .edat & .txt files & audio file in Subject Data & Task Data Folders

Basic Motor Speed Ta	Session #:	Session #:		
Subject ID Code:	Date:	Age:	Gender:	

Instructions: This is a little speed game. You're going to rest your fingers on this little red dot. Then you will see a cross show up in one of these squares. When you see a cross I want you to move your fingers off the red dot and touch the cross as fast as you can. You will first hear a beep though and that will tell you to get ready to touch the cross.

Administration: Examiner may need to provide general encouragement to "*keep going*", "*remember be as fast as you can*" and/or to "*stay focused*."

Examiner: Mark the box the child touches

I	DEMO			PRACTICE				
Demo 1	+			Prac 1	+			
Demo 2			+	Prac 2		+		
				Prac 3	+			
				Prac 4		+		
				Prac 5			+	
TES	ST ITEMS	5						
1	+			16		+		
2			+	17		+		
3	+			18			+	
4		+		19		+		
5		+		20			+	
6			+	21	+			
7		+		22		+		
8			+	23	+			
9	+			24			+	
10		+		25	+			
11	+			26			+	
12			+	27		+		
13	+			28	+			
14			+	29			+	
15	+			30	+			

Instructions:

In this game, you are going to see pictures appear on the screen. You will tell me if these things are living or nonliving (are they alive or NOT alive).. Before we begin, take a look at the pictures below: Can you point to the pictures that are living? Can you point to the pictures that are nonliving? Instructions 2:

So, you are going to see pictures appear on the screen ---ONE AT A TIME. You will tell me if each picture is living or NOT living, by touching the circle OR the square at the bottom of the screen. The circle means living; the square means not living.

(Examiner points back and forth while labeling: 'living /not living')

Try to be as fast as you can... Before you see the picture, I want you to put your fingers on this red dot. The picture will appear in the center of the screen, so keep your eyes on the blue 'cross'. As soon as you know if the picture is living or not living, move your fingers off the red dot as fast as you can and stick them on the circle OR the square. Even if you are not sure of the answer, you still need to make a guess.

(Speakers are used here rather than earphones to support training explanations.)

Examiner Demo1:

OK, let me show you how it's done. I'm resting my finger on the red dot and I'll keep them here until I know if the picture I see is: Living ('then I'll touch the circle") or NOT living ('then I'll touch the square"). Remember, I'm going to do this as fast as I can.

Practice Trials1: Ok, you try some practice. Remember keep your fingers on the dot until you are ready to make a decision. When you know if the picture is living or not living, touch the center of that block as fast as you can...

(Examiner may need to remind child to keep fingers on dot if s/he removes them before the pictures appear.

(Examiner circles the answer the child touches.)

Examiner Demo2:

Ok, now we are going to add a sentence to the game. You are going to hear a sentence and ALSO see a picture appear on the screen. You will have two jobs. First, you will tell me if each picture is living or NOT living, by touching the circle OR the square at the bottom of the screen as fast as you can. Second, I will need to listen carefully to the sentence, because I may ask you a question about the sentence after it is over. Let me show you how to do this. Before you hear the sentence I want you to put your fingers on this red dot. During the sentence, you will see a picture appear on the screen (Point to 'blue plus'). As soon as you know if the picture is living or not living, move your fingers off the red dot as fast as you can and stick them on the circle OR the square. Sometimes I will ask you a question about the sentence you heard.

(Examiner: remember to give example question)

Practice Trials2:

Ok, now you try some practice. Remember keep your fingers on the dot until you are ready to make a decision. When you know if the picture is living or not living, touch the circle OR the square as fast as you can.

(Press any key to continue)

<u>Administration and Scoring</u>: Administer entire task and record it directly onto the computer in an CMPP subject file. For each trial, record child's picture choice (answer is in **bold** and **[bracketed]: [A]** = Left; **[B]** = Right). Leave blank those not recalled. Computer records RT.

#	Code	Image	#	Resp	Responses Sentence Question CorrectAr r r r		CorrectAnswe r	+/o
1	demo	lamp		а	[B]			
2	demo	grasshopper		[A]	b			
1	prac	peacock		[A]	b			
2	prac	grasshopper		[A]	b			
3	prac	chick		[A]	b			
4	prac	helicopter		а	[B]			
5	prac	crown		а	[B]			
6	prac	bread		а	[B]			
7	prac	purse		а	[B]			
8	prac	bell		а	[B]			
9	prac	pot		а	[B]			
10	prac	grasshopper		[A]	b			
11	prac	flag		а	[B]			
12	prac	coat		а	[B]			
13	prac	chick		[A]	b			
14	prac	cake		а	[B]			
15	prac	peacock		[A]	b			
16	prac	desk		а	[B]			
1	demo	cup	1	а	[B]	Was this ant sleeping?	No	
2	demo	grasshopper	2	[A]	b			
1	prac	stove	1	а	[B]	Did this rabbit go to school?	No	
2	prac	chick	2	[A]	b			
3	prac	clock	3	а	[B]	Was this duckling was happy?	Yes	
4	prac	bike	4	а	[B]			
5	prac	peacock	5	[A]	b			

#	Code	Image	#	Res	ponses	Sentence Question	Corre	ctAnswer	+/o
1	fil	book	1	а	[B]				
2	OR	snail	2	[A]	b	Was this snail noisy?	Yes	01	
3	fil	couch	3	а	[B]	Did this monkey go into the pond?	Yes	f1	
4	fil	broom	4	а	[B]				
5	C_OR	raccoon	5	[A]	b				
6	OR	owl	6	[A]	b				
7	OR	pig	7	[A]	b				
8	fil	bed	8	а	[B]				
9	SR	kettle	9	а	[B]	Was this bird sad?	No	f2	
10	SR	glasses	10	а	[B]				
11	OR	аре	11	[A]	b				
12	OR	fish	12	[A]	b				
13	fil	knife	13	а	[B]				
14	OR	frog	14	[A]	b				
15	fil	shoe	15	а	[B]	Did this bull stomped his feet?	Yes	f3	
16	fil	brush	16	а	[B]				
17	OR	dog	17	[A]	b				
18	fil	dress	18	а	[B]				
19	OR	swan	19	[A]	b				
20	C_OR	lobster	20	[A]	b				
21	C_OR	bat	21	[A]	b				
22	fil	shirt	22	а	[B]				
23	fil	hat	23	а	[B]				
24	OR	bird	24	[A]	b				
25	OR	skunk	25	[A]	b	Was this skunk swimming?	No	o2	
26	fil	chair	26	а	[B]				
27	OR	toad	27	[A]	b				
28	fil	bowl	28	а	[B]				
29	OR	seal	29	[A]	b				
30	OR	dove	30	[A]	b				
31	C_OR	lion	31	[A]	b	Was this pig cheerful?	Yes	c1	
32	fil	spoon	32	а	[B]				
33	OR	duck	33	[A]	b				
34	fil	truck	34	а	[B]				
35	OR	horse	35	[A]	b				

#	Code	Image	#	Res	ponses	Sentence Question	CorrectAnswer		+/o
36	fil	plane	36	а	[B]	Were they in this kitchen?	No	f4	
37	fil	key	37	а	[B]				
38	C_OR	zebra	38	[A]	b				
39	OR	crab	39	[A]	b				
40	OR	rat	40	[A]	b	Was this rat thirsty?	Yes	03	
41	fil	belt	41	а	[B]				
42	OR	goat	42	[A]	b				
43	OR	bear	43	[A]	b				
44	fil	ball	44	а	[B]				
45	OR	fox	45	[A]	b				
46	fil	glove	46	а	[B]				
47	C_OR	squirrel	47	[A]	b				
48	OR	hen	48	[A]	b				
49	fil	fork	49	а	[B]	Did they live in this barn?	Yes	f5	
50	fil	boat	50	а	[B]				
51	OR	cow	51	[A]	b	Was this cow big?	No	o4	
52	fil	ring	52	а	[B]				
53	C_OR	tiger	53	[A]	b				
54	C_OR	rooster	54	[A]	b				
55	OR	cat	55	[A]	b				
56	fil	car	56	а	[B]				
57	OR	deer	57	[A]	b				
58	OR	snake	58	[A]	b				
59	SR	anchor	59	а	[B]				
60	fil	wheel	60	а	[B]	Were they frightened?	Yes	f6	
		BREAK ?????				BREAK ?????			
61	fil	drum	61	а	[B]				
62	OR	goose	62	[A]	b	Was this goose happy?	No	05	
63	fil	box	63	а	[B]	Did this rooster have yellow eyes?	Yes	f7	
64	fil	sock	64	а	[B]				
65	OR	whale	65	[A]	b				
66	OR	hawk	66	[A]	b				
67	fil	boot	67	а	[B]				ļ
68	C_OR	spider	68	[A]	b				
69	OR	sheep	69	[A]	b				
70	OR	mule	70	[A]	b				

#	Code	Image	#	Resp	onses	Sentence Question	CorrectAnswer		+/o
71	fil	kite	71	а	[B]	Did this puppy drool?	Yes	f8	
72	fil	door	72	а	[B]				
73	C_OR	seahorse	73	[A]	b				
74	C_OR	elephant	74	[A]	b				
75	C_OR	monkey	75	[A]	b	Was this seal mean?	No	c2	
76	SR	axe	76	а	[B]				
77	C_OR	penguin	77	[A]	b				
78	SR	basket	78	[A]	[B]	Was this fox excited?	No	f9	
79	SR	guitar	79	а	[B]				
80	C_OR	giraffe	80	[A]	b				
81	C_OR	fly	81	[A]	b				
82	C_OR	kangaroo	82	[A]	b	Was this crab hungry?	Yes	c3	
83	SR	refrigerator	83	а	[B]				
84	C_OR	rabbit	84	[A]	b				
85	C_OR	leopard	85	[A]	b				
86	SR	window	86	а	[B]	Was this snake quiet?	No	f10	
87	SR	candle	87	а	[B]				
88	C_OR	butterfly	88	[A]	b				
89	C_OR	turtle	89	[A]	b				
90	C_OR	rhino	90	[A]	b	Was the hen lazy?	Yes	c4	
91	SR	umbrella	91	а	[B]				
92	C_OR	caterpillar	92	[A]	b				
93	SR	toothbrush	93	а	[B]				
94	SR	trumpet	94	а	[B]				
95	C_OR	panda	95	[A]	b				
96	C_OR	beetle	96	[A]	b				
97	C_OR	alligator	97	[A]	b				
98	SR	wagon	98	а	[B]				
99	C_OR	camel	99	[A]	b				
100	C_OR	ostrich	100	[A]	b	Was the whale worried?	Yes	c5	
101	SR	stove	101	а	[B]				
102	C_OR	bee	102	[A]	b				
103	SR	lock	103	а	[B]				
104	C_OR	crow	104	[A]	b				
105	C_OR	ant	105	[A]	b				

Appendix C: CMPP Sentence Stimuli, Durations, and Target Probe Onset Times

I.

a) **OR:** related target (NP1_animate) presented at gap position in OR experimental sentences

b) **OR:** related target (NP1_animate) presented at post-gap position in OR experimental sentences

II.

c) C_OR: (control) unrelated target (NOT NP1_animate) presented at gap position in OR experimental sentences

e) **C_OR:** (control) unrelated target (NOT NP1_animate) presented at post-gap position in OR experimental sentences

III.

f) SR: foil target (nonanimate) presented in SR sentences (at NP2 offset and 500 msec after NP2 offset)

g) fil: foil target (nonanimate) presented in filler sentences (at 50% and 75% total duration)

SENTENCE	CODE	DURATION	GAP	POST_GAP
				(GAP + 500ms)
The ant noticed the spider while climbing through the window	demo _1	2974	1524	2024
The turtle that had watched the squirrel splashed in the river	demo _2	3114	1977	2477
The rabbit that had washed the monkey went home for dinner	pract_1	3088	1892	2392
The wolf that the camel had pushed through the door was tired	pract _2	3290	1906	2406
The duckling that had called the lamb in the field was happy	pract _3	3154	1804	2304
The bee that the ant had pinched dreamed about flowers	pract _4	3311	1848	2348
The tiger that had followed the lion into the woods was sad	pract _5	3460	1889	2389
			Gap	(GAP + 500ms)
			verb offset	
The snail that the crab had kissed outside the barn was noisy	OR_1	3641	1917	2417
The owl that the rat had pulled through the field was happy	OR_2	3314	1862	2362
The pig that the goat had chased over the fence was cheerful	OR_3	3320	1780	2280
The ape that the bear had pinched in the garden was worried	OR_4	3287	1837	2337
The fish that the snake had touched by the beach was angry	OR_5	3173	1779	2279
The frog that the hen had washed behind the barn was cheerful	OR_6	3519	1915	2415

The dog that the cow had tripped in the road was silly	OR_7	2834	1650	2150
The swan that the cat had pushed through the school was tired	OR_8	3491	1942	2442
The bird that the deer had bumped into the tree was hungry	OR_9	3236	1677	2177
The skunk that the fox had licked near the window was thirsty	OR_10	3288	1760	2260
The toad that the goose had bathed beside the house was little	OR_11	3349	1844	2344
The seal that the whale had splashed by the beach was friendly	OR_12	3440	2087	2587
The dove that the hawk had hugged beside the school was dirty	OR_13	3483	1866	2366
The duck that the sheep had scratched by the window was lazy	OR_14	3194	1815	2315
The horse that the mule had grabbed near the lake was sleepy	OR_15	3362	1865	2365
The crab that the snail had washed by the river was hungry	OR_16	3241	2014	2514
The rat that the owl had scratched by the lake was thirsty	OR_17	3252	1892	2392
The goat that the pig had bumped under the stairs was noisy	OR_18	3398	1690	2190
The bear that the ape had squeezed in the garden was friendly	OR_19	3227	1890	2390
The fox that the skunk had grabbed near the pond was dirty	OR_20	3221	1873	2373
The hen that the frog had tripped down the stairs was lazy	OR_21	3277	1810	2310
The cow that the dog had squeezed near the house was little	OR_22	3085	1830	2330
The cat that the swan had bathed below the nest was tired	OR_23	3622	1925	2425
The deer that the bird had touched in the field was cheerful	OR_24	3106	1699	2199
The snake that the fish had chased around the pond was silly	OR_25	3316	1825	2325
The goose that the toad had splashed near the river was angry	OR_26	3231	1939	2439
The whale that the seal had licked under the tree was worried	OR_27	3410	1813	2313
The hawk that the dove had kissed inside the nest was cheerful	OR_28	3550	1745	2245
The sheep that the duck had pushed over the fence was happy	OR_29	3094	1740	2240
The mule that the horse had pulled down the road was sleepy	OR_30	3249	1830	2330
			NP2 offset	NP2 + 500ms
The rat that had pinched the skunk in the field was angry	SR_1	3254	1832	2332
The cat that had pulled the fox through the field was happy	SR_2	3090	1815	2315
The duck that had washed the goat by the river was cheerful	SR_3	3068	1671	2171

The hear that had ninched the ane under the stairs was little	SR 4	3103	1646	2146
The fish that had fouched the snail beside the house was anony	SR 5	3372	1776	2140
The hawk that had chased the ben around the pond was cheerful	SR 6	3353	1683	2183
The horse that had snlashed the cow by the beach was sleepy	SR 7	3340	1802	2100
The owen that had existenced the owl by the lake was tired		2265	1032	2332
	3K_0	3305	1916	2410
The dog that had pushed the deer over the fence was worried	SR_9	3186	1654	2154
The skunk that had grabbed the rat in the garden was friendly	SR_10	3145	1776	2276
The toad that had squeezed the crab near the house was lazy	SR_11	3405	1957	2457
The seal that had licked the whale near the window was thirsty	SR_12	3312	1738	2238
The frog that had bathed the bird inside the nest was dirty	SR_13	3408	1793	2293
The pig that had bumped the sheep into the tree was hungry	SR_14	3190	1762	2262
The dove that had tripped the hawk in the road was hungry	SR_15	2915	1686	2186
		100	50%	75%
The bull that had stared at the chicken in the field stomped his feet 15	fil_1	3794	1897	2846
The eagle watched the zebra in the field fall into the ditch 16	fil_2	3639	1820	2729
The turtle hid from the fox before laying its eggs 13	fil_3	3299	1650	2474
The monkey carried the rabbit into the pond to go swimming 16	fil_4	3224	1612	2418
The ant and the spider stayed under the rock all morning 14	fil_5	3158	1579	2369
The ant and the spider stayed under the rock all morning 14 The lion that had roared at the camel walked beside the river 16	fil_5 fil_6	3158 3469	1579 1735	2369 2602
The ant and the spider stayed under the rock all morning 14 The lion that had roared at the camel walked beside the river 16 The donkey snorted at the rooster before scratching at the door 16	fil_5 fil_6 fil_7	3158 3469 3684	1579 1735 1842	2369 2602 2763
The ant and the spider stayed under the rock all morning 14 The lion that had roared at the camel walked beside the river 16 The donkey snorted at the rooster before scratching at the door 16 The kitten that had seen the eagle ran into the woods 14	fil_5 fil_6 fil_7 fil_8	3158 3469 3684 3329	1579 1735 1842 1665	2369 2602 2763 2497
The ant and the spider stayed under the rock all morning 14 The lion that had roared at the camel walked beside the river 16 The donkey snorted at the rooster before scratching at the door 16 The kitten that had seen the eagle ran into the woods 14 The rooster looked at the tiger before cleaning its feathers 15	fil_5 fil_6 fil_7 fil_8 fil_9	3158 3469 3684 3329 3263	1579 1735 1842 1665 1632	2369 2602 2763 2497 2447
The ant and the spider stayed under the rock all morning 14 The lion that had roared at the camel walked beside the river 16 The donkey snorted at the rooster before scratching at the door 16 The kitten that had seen the eagle ran into the woods 14 The rooster looked at the tiger before cleaning its feathers 15 The puppy that watched the squirrel from the house was playful 14	fil_5 fil_6 fil_7 fil_8 fil_9 fil_10	3158 3469 3684 3329 3263 3129	1579 1735 1842 1665 1632 1565	2369 2602 2763 2497 2447 2347
The ant and the spider stayed under the rock all morning 14 The lion that had roared at the camel walked beside the river 16 The donkey snorted at the rooster before scratching at the door 16 The kitten that had seen the eagle ran into the woods 14 The rooster looked at the tiger before cleaning its feathers 15 The puppy that watched the squirrel from the house was playful 14 The tiger that had watched the lion in the jungle slept in the sun 17	fil_5 fil_6 fil_7 fil_8 fil_9 fil_10 fil_11	3158 3469 3684 3329 3263 3129 3859	1579 1735 1842 1665 1632 1565 1930	2369 2602 2763 2497 2447 2347 2894
The ant and the spider stayed under the rock all morning 14 The lion that had roared at the camel walked beside the river 16 The donkey snorted at the rooster before scratching at the door 16 The kitten that had seen the eagle ran into the woods 14 The rooster looked at the tiger before cleaning its feathers 15 The puppy that watched the squirrel from the house was playful 14 The tiger that had watched the lion in the jungle slept in the sun 17 The kitten ordered the mouse in the cage to do a somersault 16	fil_5 fil_6 fil_7 fil_8 fil_9 fil_10 fil_11 fil_12	3158 3469 3684 3329 3263 3129 3859 3430	1579 1735 1842 1665 1632 1565 1930 1715	2369 2602 2763 2497 2447 2347 2894 2573
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The spider had seen the lion beside the pond drink water 15	fil_16	3751	1876	2813
The zebra that had stomped through the fields flattened all the plants 14	fil_17	3729	1865	2797
The rooster asked the chicken in the field not to eat all the seeds 16	fil_18	3744	1872	2808
The tiger that had knocked over the monkey was angry 15	fil_19	2805	1403	2104
The lamb and the calf that had been in the field now lived in the barn 16	fil_20	3860	1930	2895
The donkey and the bull that had eaten all the hay were full 15	fil_21	3281	1641	2461
The wolf asked the rooster with yellow eyes to sing a new song 15	fil_22	3774	1887	2831
The camel that sat beside the pond chewed on an apple 14	fil_23	3249	1625	2437
The mouse and the squirrel that had circled the barn were frightened 15	fil_24	3356	1678	2517
The beetle had asked the fly to find some food for dinner 13	fil_25	3104	1552	2328
The spider listened for the eagle after hanging from the window 17	fil_26	3540	1770	2655
The puppy that had drooled on the toy crawled across the room 15	fil_27	3515	1758	2636
The beetle and the ant that had played near the lake were tired 15	fil_28	3239	1620	2429
The rabbit asked the turtle in the lake not to throw stones 14	fil_29	3303	1652	2477
The monkey waved to the zebra before climbing up the tree 15	fil_30	3354	1677	2516



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