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THE INFLUENCE OF ATTENTIONAL CONTROL ON HEMISPHERIC PROCESSING OF PREDICTIVE INFERENCES

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THE INFLUENCE OF ATTENTIONAL CONTROL
ON HEMISPHERIC PROCESSING OF PREDICTIVE INFERENCES

A Thesis

Presented in

Partial Fulfillment of the
Requirements for the Degree of
Master of Arts

BY

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Abstract

This study investigates the effects of attentional control on the hemispheric processing of predictive inferences during reading. Participants read texts that were either strongly or weakly constrained towards a predictive inference and performed a lexical decision task to inference-related target words presented to the right or left visual field—hemisphere. Facilitation for strongly constrained predictive inferences was greater than facilitation for weakly constrained predictive inferences in both hemispheres. Readers with high attentional control showed significant facilitation for strongly constrained inferences in the both hemispheres, but only showed significant facilitation for weakly constrained inferences in the left hemisphere. Readers with low attentional control did not show significant facilitation in any of the conditions. These results suggest that readers with high attentional control may have an advantage for generating predictive inferences during reading, a skill which could contribute to improved situation model construction and comprehension compared to readers with low attentional control.

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BIOGRAPHY

The author was born in the Philippines on November 3rd, 1989. He graduated from Holland High School in Holland, Michigan in 2007. He earned a Bachelor of Arts degree in Psychology from DePaul University in 2011.

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INTRODUCTION

Successful reading comprehension relies on the ability to generate connections (i.e., inferences) about information presented in a text. Previous research has shown that certain types of inferences (e.g., coherence or bridging inferences) are necessary for understanding a text as they establish connections between what the reader is currently processing and information that they have encountered previously in a text (Graesser, Singer, & Trabasso, 1994). For example, in the passage “The man threw the vase against the wall. It cost over \$100 to replace,” the reader must refer back to the first sentence to understand that the vase broke. By contrast, predictive inferences (i.e., predictions about what will occur next in a text) are often considered to be elaborative and optional (Allbritton, 2004; Casteel, 2007). For example, after reading the sentence, “The couple were just pronounced as man and wife” one will likely make a prediction that the couple will kiss, but this prediction may not be necessary to comprehend subsequent information in the text. Thus, predictive inferences are not as crucial to text comprehension as bridging or coherence inferences.

Despite being optional during text comprehension, research has shown that predictive inferences can help readers build situation models (i.e., mental representations of the situations conveyed by words and sentences in a text) (Zwaan, Magliano, & Graesser, 1995; Zwaan & Radvansky, 1998) and improve comprehension (Fincher-Kiefer, 1993). Further, research has shown that predictive inferences can lead to easier processing of future text events (van den Broek, 1990). However, generating predictive inferences is costly in terms of cognitive processing and thus requires ample resources in working memory (i.e., the ability to store and process information simultaneously), which

may not be available to all readers during text comprehension (Baddeley, 1983; Linderholm, 2002; Virtue, van den Broek, & Linderholm, 2006). Specifically, research has suggested that readers with low working memory capacity (WMC) rarely make predictive inferences during reading, which suggests that predictive inferences may only be available to readers with access to a certain amount of working memory resources (Linderholm, 2002). Thus, working memory contributes to predictive inference generation during reading.

The availability of predictive inferences during reading has also been shown to vary based on the level of causal constraint (i.e., the likelihood that future events will take place) in a text. Readers are less likely to generate predictive inferences after reading weakly constrained texts versus strongly constrained texts (Linderholm, 2002; Virtue, et al., 2006). For example, compared to the previous example of the couple being pronounced husband and wife (i.e., a strongly constrained text), a reader would be less likely to generate the predictive inference that the two characters would kiss if they had been presented with the sentence “The students had just been announced as college graduates” (i.e., a weakly constrained text) (Virtue et al., 2006). In sum, causal constraint can influence the likelihood that a reader will generate a predictive inference during reading.

The neural mechanisms that underlie predictive inference generation have also been shown to vary based on textual constraint and working memory capacity. Specifically, high working memory capacity readers have been shown to exhibit greater facilitation for strongly constrained inferences than weakly constrained inferences in both hemispheres while low working memory capacity readers show the same pattern in the

left hemisphere but show higher facilitation for weakly constrained inferences than for strongly constrained inferences in the right hemisphere (Virtue et al., 2006). These findings suggest that readers with low working memory capacity are less likely to inhibit weakly constrained predictions in the right hemisphere than readers with high working memory capacity.

Recent research has identified attentional control (i.e., the ability to fixate attention on a task and resist interference from task-irrelevant stimuli) as a crucial element of working memory (Unsworth & Spillers, 2010; McVay & Kane, 2012). Attentional control—which can be measured using a go/no-go task called the Sustained Attention to Response Task (SART)—influences goal-maintenance processes (i.e., processes that guide attention toward task-relevant information) during reading by facilitating access to information in a text while minimizing interference from distractions (e.g., environmental interference, habitual behaviors, task irrelevant thoughts) (Braver, Gray, & Burgess, 2007; McVay & Kane, 2012). While research has provided insights into influence of WMC on predictive inference generation, research has yet to investigate the specific role that attentional control could play in this process. Investigating this topic can provide a better understanding of the attention-specific mechanisms that underlie previously observed differences in predictive inference generation as a factor of WMC. Specifically, comparing findings from investigations of WMC and predictive inference generation with findings from an investigation of attentional control and predictive inference generation could provide insight into the specific influence that attentional control has on a reader’s ability to make predictions about what will occur next in a text. Thus, the present study investigates how attentional

control affects predictive inference generation in the hemispheres during reading as a function of textual constraint.

The following sections provide a theoretical overview for the present study, including a discussion of predictive inferences and a review of previous research on hemispheric processing of predictive inferences. This is followed by a discussion of previous research on the influence of textual constraint and working memory on predictive inference generation and a review of relevant research on the effects of attentional control on text comprehension in the hemispheres during reading.

Attributional Research

Predictive Inferences

Broadly speaking, inferences can be divided into two primary categories: backward inferences and forward inferences (Fincher-Kiefer, 1995; Virtue et al., 2006a). Bridging inferences (i.e., backward inferences) allow readers to connect new information in a text with information mentioned earlier in a text (van den Broek, 1990; Virtue et al., 2006a). For example, in the passage, “The man threw the vase against the wall. It cost over one hundred dollars to replace,” the second sentence creates a coherence break (i.e., an interruption to the logical flow of the narrative) and, thus, a bridging inference is necessary to understand that the vase mentioned in the first sentence was broken after it was thrown against the wall. Bridging inferences allow readers to combine background knowledge (e.g., knowing what happens to fragile objects when they are thrown against hard surfaces) with contextual information (e.g., the fact that the vase had to be replaced) to resolve contradictions created by coherence breaks and, thus, to understand what is occurring in a text (Graessar, Singer, & Trabasso, 1994; Beeman, Bowden, &

Gernsbacher, 2000). Thus, backward inferences are necessary for comprehension because they allow readers to draw connections between the information that they are currently reading and the information that was previously mentioned to create a more detailed representation of a text.

Predictive inferences (i.e., forward inferences) allow readers to anticipate what will happen next in a text (van den Broek, 1990). For example, after reading the sentence, “The minister just pronounced the couple husband and wife,” it is likely that a reader will infer, based on their background knowledge of wedding ceremonies, that the couple will kiss (Virtue et al., 2006). According to the Construction-Integration model (Kintsch, 1988), readers generate inferences by making connections between multiple events and ideas in a text and integrating those connections with their background knowledge to construct a macro-level representation of a text (i.e., situation model). This model suggests that readers automatically activate predictive inferences during reading to comprehend a text.

Some research has provided support for the Construction-Integration model with regard to inferences by showing the advantages that predictive inference generation provides for text comprehension. For example, predictive inferences can lead to easier processing of future text events by allowing readers to anticipate what will happen next and proceed more quickly to subsequent text events when those predictions are confirmed (van den Broek, 1990). Predictive inferences have also been found to help readers make causal connections between events in a text (Fincher-Kiefer, 1993). Specifically, predictive inferences have been shown to improve readers’ ability to construct situation models of narratives during reading, which leads to improved comprehension of a text

(Fincher-Kiefer, 1993). Further, some research has suggested that certain types of predictive inferences (e.g., high-predictability inferences) are necessary for text comprehension (Klin, Murray, Levine, & Guzman, 1999). Thus, predictive inferences may provide important advantages to readers during text comprehension.

However, research has been inconclusive as to whether or not readers routinely and automatically generate predictive inferences during reading (Campion, 2004). The Minimalist Hypothesis posits that only locally coherent (i.e., sentence level) inferences, which are necessary for comprehension, are routinely activated during text comprehension (McKoon & Ratcliff, 1992). A related theory called the Constructionist Theory, posits that globally coherent (i.e., inferences that contribute to a reader's overall understanding of a text) are also activated automatically during reading (Graessar, Singer, & Trabasso, 1993). Several studies have provided support for the Minimalist Hypothesis and Constructionist Theory with regard to predictive inference generation by showing that predictive inferences are not routinely activated during reading, despite being available under certain optimal conditions (e.g. when story context strongly supports predictive inference generation) (Weingarten, Guzman, Levine, & Klin, 2003; Campion, 2004; Casteel, 2007). As a result, predictive inferences are often considered to be optional and elaborative rather than automatic and critical for comprehension.

Predictive inferences have also been shown to be cognitively demanding (Linderholm, 2002). That is, predicting future text events requires cognitive resources that go above and beyond simply encoding and processing current text events. As such, predictive inferences tend to be generated more often by readers who score highly on measures of reading comprehension (e.g., the Nelson Denny Reading Test) than by

readers who score poorly on measures of reading comprehension (Murray & Burke, 2003). According to the Causal Inference Process model, predictive inference generation relies on the interplay between activation of explicitly stated and associated concepts in long-term memory being transferred into working memory (van den Broek, 1994). Thus, predictive inferences require a minimum amount of activation of inference-related concepts to be successfully generated.

In sum, predictive inferences allow readers to make predictions about future text events and have been shown to improve comprehension, but readers do not routinely generate predictive inferences during reading. Further, research has shown that predictive inferences are cognitively demanding and that the ability to generate predictive inferences during reading varies based on reading skill. To better understand the processes that underlie predictive inference generation, research has investigated how predictive inferences are processed in each hemisphere of the brain.

Inferential Processing in the Hemispheres

Research on the hemispheric processing of predictive inferences has provided insight into the specific neural mechanisms that underlie inferential processing in the brain. Specifically, research has provided support for the right hemisphere's role in inferential processing during reading. Brownell, Potter, Bihrlé, & Gardner (1986) found that patients with right hemisphere lesions were severely impaired in their ability to draw inferences. Specifically, right-hemisphere-damaged patients were unable to successfully answer true or false questions about information that was not explicitly mentioned in a text (i.e., information requiring a bridging inference) despite being able to correctly answer questions about explicitly stated information (Brownell et al., 1986). Subsequent

research, which used lexical decision tasks to test inference generation in right hemisphere-damaged patients after they read narratives containing multiple passages, also found evidence to support the right hemisphere's role in inferential processing (Beeman, 1993). These early investigations suggested that neurological structures in the right hemisphere were crucial for inferring information during text processing.

Subsequent studies have provided a more nuanced understanding of the right hemisphere's role in predictive inference processing. For instance, research on healthy participants has indicated that the right hemisphere is more sensitive to priming predictive (i.e., forward) inferences while the left hemisphere is more sensitive to priming coherence (i.e. bridging/backward) inferences (Beeman, Bowden, & Gernsbacher, 2000). Patients with right hemisphere damage have been shown to be less able to maintain predictive inferences over time than healthy individuals (Lehman-Blake & Tompkins, 2001). Further, patients with right hemisphere brain damage have been found to display difficulty generating predictive inferences based on contextual details compared to individuals without brain damage (Lehman-Blake & Lesniewicz, 2005). For example, when presented with the sentence "The man threw the vase against the wall," patients with right hemisphere damage are less likely than healthy participants to use the sentence context to activate the correct inference meaning (i.e., BREAK). fMRI studies have shown that while predictive inferences are constructed in the left inferior frontal gyrus, the right lingual gyrus is responsible for integrating predictive inferences into a reader's representation of a text (Jin, Liu, Fang, Zhang, & Lin, 2009). Taken together, these findings suggest that the right hemisphere is involved in the processing of predictive inferences during reading.

Textual Constraint

One factor that has been shown to influence the hemispheric processing of predictive inferences is textual constraint. Research has shown that the level of textual constraint—that is, how strongly text events point to a particular word or event—can affect activation in the cerebral hemispheres during inference generation (Virtue, van den Broek, & Linderholm, 2006a). Specifically, both hemispheres have been found to facilitate the process of generating strongly constrained inferences (Virtue et al., 2006). However, the right hemisphere has been found to display a distinct advantage for processing weakly constrained inferences (Virtue et al., 2006). For example, activation for the inference “kiss” is more likely to occur in the right hemisphere after reading the sentence “The students had just been announced as college graduates” than in the left hemisphere (Virtue et al., 2006). In sum, while both hemispheres have been found to facilitate strongly constrained inferences, research suggests that the right hemisphere is uniquely involved in the processing of weakly constrained inferences.

Beeman’s Fine Coarse Semantic Coding theory provides an explanation for patterns of hemispheric activity observed during inferential processing at varying levels of constraint (Beeman, Friedman, Grafman, Perez, Diamond, & Lindsay, 1994). This theory proposes that the left hemisphere—which contains more densely-packed neural structures than the right hemisphere—specializes in activating a limited set of strongly related associations (i.e., fine semantic coding) that are closely related to a given word during reading (Beeman et al., 1994). In contrast, the right hemisphere—which contains more loosely packed neural structures than the left hemisphere—specializes in the generation of broad, loosely correlated associations during reading (i.e., coarse coding)

(Beeman et al., 1994; Beeman, Bowden, & Gernsbacher, 2000). For example, after being presented with the word “bee,” the left hemisphere would be more likely to generate closely-related semantic associations such as “honey” or “sting,” whereas the right hemisphere would be more likely to generate loosely related semantic associations such as “pollen” or “fly” (Beeman, Bowden, & Gernsbacher, 2000). Thus, the right hemisphere’s role in facilitating weakly constrained inferences is likely a product of its advantage for coarse coding of distantly related associations. As such, weakly constrained (i.e., coarsely associated) predictive inferences rely more on the looser neural connections of the right hemisphere than strongly constrained predictive inferences.

Working Memory Capacity

Along with textual constraint, another factor that has been found to influence the generation and hemispheric processing of predictive inferences is working memory capacity. One of the most widely studied factors that influences inference generation during reading is working memory capacity (WMC) (i.e., the ability to store and manipulate multiple pieces of information at the same time) (Baddeley, 1983). Early research investigating the connection between inference processing and WMC found that individuals with high WMCs exhibited faster generation of bridging inferences and more efficient access to relevant knowledge than individuals with low WMCs (Singer & Ritchot, 1996). Researchers posited that the elevated inference and comprehension levels observed in high WMC readers were a result of a qualitatively different reading style that was better suited for efficiently integrating world knowledge and constructing situational models during reading (Dixon, LeFevre, & Twilley, 1988; Singer & Ritchot, 1996). In sum, differences in WMC have been found to explain much of the variance in readers’

ability to successfully generate inferences during reading.

Research has also investigated the mechanisms involved with these WMC-related differences in reading comprehension. Daneman & Carpenter (1983) found that individuals with low WMC have pronounced difficulties with integrating information (i.e., making connections between text events) and resolving lexical ambiguity (i.e., deciding on the appropriate interpretation of a word meaning when multiple interpretations are available) during reading. According to the Capacity Constrained Comprehension (CCC) theory, cognitively demanding reading tasks (e.g., reading a sentence that contains a complex structure or generating a predictive inference) require a certain amount of available cognitive resources in order to be successfully comprehended (Just & Carpenter, 1992). With regard to predictive inferences, research has supported the CCC theory by showing that often only readers with high WMC possess enough available cognitive resources to activate inference-related concepts from LTM whereas low WMC readers do not (Linderholm, 2002). Thus, WMC can directly affect a reader's ability to successfully generate predictive inferences during reading by influencing whether or not a reader has enough expendable cognitive resources available to activate the concepts necessary to generate a specific inference.

Further research has investigated how inferential processing is manifested in the hemispheres of individuals with high and low WMC. Virtue, van den Broek, & Linderholm (2006) had participants read texts that promoted strongly or weakly constrained inferences and performed a lexical decision task (i.e., word/non-word judgment) in response to inference-related and neutral target words presented to either the right visual field-left hemisphere (RVF-LH) or the left visual field-right hemisphere

(LVF-RH). With regard to predictive inferences, their results indicated that readers with high WMC showed greater facilitation (i.e., response time to inference-related target words compared to neutral words) for strongly constrained inferences than for weakly constrained inferences in the both the left and right hemisphere (Virtue et al., 2006a). Conversely, low WMC readers exhibited an identical pattern in the left hemisphere but showed greater facilitation for weakly constrained inferences in the right hemisphere (Virtue et al., 2006). The researchers interpreted this hemispheric asymmetry as indicating a deficit in inhibiting the activation of less constrained and less contextually relevant potential outcomes on the part of low WMC readers (Virtue et al., 2006). In sum, research has shown that WMC influences reading comprehension and predictive inference generation in the hemispheres as a function of textual constraint.

Attentional Control

Subsequent research has attempted to disentangle the mechanisms that underlie WMC and has suggested that one of its key components is attentional control (Unsworth & Spillers, 2010; McVay & Kane, 2012). The ability to keep one's attention fixated on a task and resist interference from task-irrelevant stimuli has been found to reflect individual differences in WMC (Borella, Ludwig, Fagot, & De Ribaupierre, 2011; Levinson, Smallwood, & Davidson, 2012). According to the Executive-Attention view of WMC, the relation between WMC and reading comprehension is driven by overlapping, domain-general attentional-control mechanisms (Engle & Kane, 2004). That is, the attentional control mechanisms that are used for sustaining attention are thought to be the same regardless of the task or stimulus (Engle & Kane, 2004). The Executive-Attention view of WMC also posits that the act of paying attention during reading is governed by

the same attentional control mechanisms as those used in previous, non-lexically-based studies of attention and WMC. Thus, measuring an individual's capacity to sustain their attention on simple stimuli (e.g., a number or a word) can provide valuable insight into their ability to pay attention during reading.

The Executive-Attention view holds that there are two primary components that comprise WMC: goal maintenance and competition resolution (Engle & Kane, 2004; McVay & Kane, 2012). Goal maintenance guides attention toward task-relevant information and provides a mechanism for sustaining attention in the face of distractions (e.g., environmental interference, irrelevant thoughts, or mind wandering) (McVay & Kane, 2012). By contrast, competition resolution provides a mechanism for overcoming moment-by-moment interference from goal irrelevant stimuli (McVay & Kane, 2012). Researchers have contrasted these dual components of attention as being “proactive” versus “reactive” processes, respectively (Braver, Gray, & Burgess, 2007). That is, the proactive process of goal maintenance is initiated prior to task performance in order to maintain attention on a desired stimulus or action and minimize experiences of conflict from outside distractions (Braver et al., 2007). By contrast, the reactive process of competition resolution is initiated in the moment as a response to an attentional conflict (i.e., interference from habit, environmental distractors, or irrelevant thoughts) (Braver et al., 2007). Engle and Kane (2004) explained these two factors of executive control using results from an antisaccade task, a task in which participants are instructed to make a controlled eye movement in the opposite direction of a presented stimulus. Goal maintenance facilitates a participants' ability to keep the task goal (i.e., to look away from the presented stimulus) in active memory whereas competition resolution resolves

the conflict between the current task goal and prepotent or habitual behaviors (i.e., the reflex to look at the presented stimulus) (Engle & Kane, 2004). While reading a text, goal maintenance is the process that allows a reader to maintain their focus on comprehending the content they are reading whereas competition resolution allows a reader resolve attentional conflicts and prevent activation of irrelevant information. In this way, goal maintenance is the mechanism for directing and sustaining attention on a task. Competition resolution, on the other hand, is the mechanism by which distractions and irrelevant information is inhibited.

Research on attentional control during text comprehension has suggested that attentional control primarily contributes to the goal maintenance component of WMC as it allows readers to sustain attention during text comprehension (McVay & Kane, 2012). Using the antisaccade task, research by Engle & Kane (2004) showed that participants with high WMC were better able to direct their attention away from a presented stimulus than participants with low WMC. Further research by Molenberghs, Gillebert, Schoofs, Dupont, Peeters, and Vandenberghe (2009) found that commission errors (i.e., errors in a go/no-go paradigm associated with incorrectly responding to a no-go trial) were associated with fluctuations in sustained attention. Research has postulated that commission errors may arise from a switch to automatic processing, which affects goal maintenance in such a way that subjects are not able to inhibit a pre-potent go response in a no-go trial. In this way, goal maintenance is the primary component associated with attentional control (McVay & Kane, 2012). Thus, while competition resolution (e.g., suppressing inappropriate word meanings) may play a role in the relation between WMC and reading comprehension, research suggests that attentional control is more heavily

reliant on goal maintenance processes (Gernsbacher, 1993; Gernsbacher & Robertson, 1995; McVay & Kane, 2012). For example, research shows that readers who are lower in attentional control are more prone to activating task-irrelevant representations in LTM and mind wandering during reading than readers who with higher attentional control, which negatively affects comprehension by drawing attention away from the goal of understanding a text (Unworth et al., 2009; McVay & Kane, 2012). Further, inefficient goal maintenance processes can affect situation model construction and inference generation by initiating less-constrained searches of LTM during reading which, in turn, can create interference with task-relevant thoughts (McVay & Kane, 2012). Thus, attentional control could play a crucial role in facilitating readers' ability to activate predictive inferences during reading by promoting the goal maintenance processes that allow readers to activate inference-related concepts in LTM while filtering out task-irrelevant thoughts.

To summarize, research has indicated that despite being helpful for comprehension, predictive inferences are cognitively demanding and are not routinely generated by all readers during text comprehension. Research has also suggested that the right hemisphere is involved in facilitating predictive inferences and that hemispheric activation of predictive inferences during reading varies as a function of textual constraint. Further research has indicated that readers with high versus low WMC are better able to activate predictive inferences during reading and that these differences are reflected in differing patterns of hemispheric activation during predictive inference generation. Research has also shown that levels of textual constraint can influence patterns of inference generation in readers with high versus low WMC. Finally,

attentional control has been identified as a crucial component of WMC that facilitates goal maintenance processes during reading. Taken as a whole, these research findings suggest that attentional control could play an important role in predictive inference generation and that this role could provide a clearer picture of the processes that underlie WMC-related variation in predictive inference generation in the hemispheres as a function of textual constraint.

Rationale

Previous research has established that individual differences in WMC can successfully predict variance in predictive inference generation during reading. Research has also indicated that variance in the ability to generate predictive inferences is manifested in the hemispheres and can be measured by varying the degree of textual constraint in inference-related texts. Research supports the view that attentional control is a crucial component of WMC that facilitates goal maintenance processes during reading. However, the specific contribution of attentional control to predictive inference generation in the hemispheres as a function of textual constraint has not been investigated. Investigating this potential link could provide valuable information about how an individual's ability to sustain their attention during reading can affect their ability to successfully predict what will happen next in a text. Thus, the present study investigates the extent to which attentional control affects the speed and accuracy of predictive inference generation in the hemispheres during reading and how this effect varies as a function of textual constraint.

Statement of Hypotheses

It is hypothesized that strongly constrained predictive inferences will be processed faster than weakly constrained inferences in both hemispheres. With regard to attentional control, it is predicted that a three-way interaction will occur; with higher levels of right hemisphere facilitation occurring for weakly constrained predictive inferences in the low attentional control condition than in the high attentional control condition.

METHOD

Research Participants

78 undergraduate students (59 female, 19 male) at DePaul University participated in the experiment in exchange for course credit. All participants were native speakers of American English with normal or corrected-to-normal vision. All participants were right-handed, as indicated by a score of 0.30 or greater on the Edinburgh Handedness Inventory (mean laterality quotient = .84) (Oldfield, 1971).

Materials

Semantic Sustained Attention to Response Task (SART)

Before the inference task, participants were asked to complete the Semantic Sustained Attention to Response Task (SART), taken directly from McVay and Kane (2009). The Semantic SART is a go/no-go task in which subjects respond quickly with a key press to all presented stimuli except infrequent (11%) targets. This version presents words—other versions of the SART have used digits—for 300 ms followed by a 900 ms mask. Most of the stimuli (non-target go trials) belonged to one category (e.g., animals) while infrequent no-go targets belonged to another category (e.g., foods). Participants were instructed to indicate, as quickly and accurately as possible (via a button press), each time they saw a word that fit into the category of “animal” (e.g., *giraffe*) appear on the screen but NOT when they saw a word that fit into the category of “food” (e.g., *apple*). After some of the target trials, participants had to complete a thought probe. This short questionnaire asked them to indicate which item from a list of options best described what they were just thinking about (e.g., “daydreaming”). The present study

utilized a 20-minute version of the Semantic SART containing 540 trials, 60 targets, and 36 thought probes, which occurred after 60% of targets.

Semantic SART performance was measured based on response time variability. Response time variability (RT variability) was calculated by taking the standard deviation of a participant's non-target, "go" trials (Jensen, 1992; McVay & Kane 2009, 2012). RT variability has been shown to reflect attentional fluctuations over the course of the Semantic SART task and has been correlated with WMC variation, frontal cortex function, deficits in sustained attention, and rates of mind wandering (Bellgrove, Hester, & Garavan, 2004; Johnson, Kelly, Bellgrove, Barry, Cox, Gill, & Robertson, 2007; McVay & Kane, 2009). Unlike go/no-go accuracy scores, which can be subject to floor and ceiling effects (e.g., near-ceiling accuracy on non-target "go" trials and/or less than chance accuracy on "no-go" target trials), RT variability provides a simple and reliable measure of a participant's ability to sustain their attention on a task over time (McVay & Kane, 2012). As it relates to goal maintenance—which research suggests is the primary process by which attentional control contributes to WMC—RT variability provides a measure of a reader's ability to continually maintain the goal of the task (i.e., pressing the space bar for non-target stimuli but not for target stimuli) while resisting interference from task unrelated thoughts and environmental distractions. To distinguish low and high attentional control readers, a median split was performed. After performing a median split on participants' Semantic SART RT variability scores, 39 participants were identified as low attentional control readers ($M = 155.54$, $SD = 42.15$) and 39 participants were identified as high attentional control readers ($M = 91.48$, $SD = 17.32$).

Texts

The materials for the inference task consisted of three sets of 48 texts (inference, neutral, and filler), taken from texts used in Virtue, van den Broek, and Linderholm (2006). Texts consisted of four sentences, the last of which promoted a predictive inference. For each constraint condition, the final sentence of the text was designed to promote either a strongly or weakly constrained a predictive inference regarding the scenario described in the previous three sentences. In the neutral and filler conditions, the final sentence contained information that was designed not to promote a predictive inference about the preceding sentences. Examples of predictive inference texts are featured in Table 1.

Table 1. Example Predictive Inference Text (Taken from Virtue, van den Broek, and Linderholm, 2006)

Inference Text

Tom and Krista were standing together holding hands.

Both of them were a little nervous, but mostly excited about today.

Tom imagined the future as he looked at Krista.

Strong textual constraint: They were just pronounced as man and wife.

Weak textual constraint: They were just announced as college graduates.

Target word: kiss

Neutral Text

The three women had been friends since childhood.

No matter where they were, they stayed in touch.

Currently, they were together to celebrate New Year's Eve.

They spent the evening discussing old memories and talking about the future

Target word: kiss

Target Words

Each of the inference and neutral texts were followed by a target word that corresponded with the inference invoked by the sentence. For example, in the text in Table 1, the first three sentences of the passage provide the context for the reader to infer that Tom and Krista will kiss. The fourth sentence in the passage was either strongly or weakly related to target word (i.e., *kiss*). Neutral texts were paired with target words, but the neutral texts did not promote the targeted inference. For example, the neutral text in Table 1 should not cause a reader to activate the target word (i.e., *kiss*), as it does not fit the context of the preceding sentences. Therefore, the neutral texts provided a baseline for reaction times in each hemisphere. Target words in the present study were one or two syllable action verbs and were similar in number of letters and frequency across conditions. The filler texts did not promote these intended inferences and were paired with non-word targets to keep participants from developing a positive response bias (Neely, Keefe, & Ross, 1989). Data from the filler texts were excluded from the analyses because it is extremely unlikely that a reader would activate a non-word in response to a text.

Procedure

For the inference task, participants were asked to place their head in a chin rest positioned 50 cm from a computer screen. This was done to ensure that each participant

maintained a consistent distance and visual angle from the central fixation point for the entirety of the experiment.

Participants were presented with an equal number of texts from the inference (weakly and strongly constrained), neutral, and filler conditions on a PC using E-Prime software (Schneider, Eschman, & Zuccolotto, 2002). The order and type of inference texts were randomized using six between-subject counterbalancing conditions.

Participants only saw each text once in each version of the experiment. Participants read each sentence at their own pace, one sentence at a time, as they appear on the computer screen. Participants proceeded from one sentence to another using via a button press.

After reading the fourth and final sentence of each text, participants were instructed to fixate on the center of a fixation plus (+) for the entire time (750 ms) that it appeared on the computer screen.

Participants were then asked to perform a lexical decision task, during which they had to decide (via button press), as quickly and as accurately as possible, whether a string of letters (e.g., *kiss*) presented to either their right or left visual field for 176ms was a word or a non-word. Targets words were presented approximately 3.5° to the left or right of the fixation point at the center of the computer screen. Each participant was presented with 144 texts (48 inference texts, 48 neutral texts, and 48 filler texts).

RESULTS

Response time latencies and accuracy for the target words were analyzed. Only correct responses were included in the analyses. To control for outlier effects, the top and bottom 1% of response times were not included in the analyses. F_1 refers to by-subject analyses and F_2 refers to by-item analyses.

Inference-Related Response Time Facilitation Effects

To test the first hypothesis that strongly constrained inferences would be processed faster than weakly constrained inferences, a repeated measures ANOVA was conducted on facilitation scores for mean inference response times in the strongly and weakly constrained conditions in each visual field-hemisphere. Facilitation scores were calculated by subtracting the inference condition response times from the neutral condition response times in each visual field—hemisphere. The independent variables were textual constraint (weak or strong) and visual field-hemisphere (right visual field—left hemisphere or right visual field—left hemisphere). By participant analyses showed no significant effect of sex, response hand, and counterbalancing condition, so these are not reported.

Mean inference facilitation by constraint and visual field—hemisphere is presented in Figure 1 (refer to Table 2 for mean response times by condition). There was no main effect of visual field—hemisphere, $F_1(1, 76) = 0.01$, $MS_e = 115.25$, $p = .913$; $F_2(1, 47) = 0.02$, $MS_e = 268.41$, $p = .88$. There was a main effect of textual constraint, $F_1(1, 76) = 26.95$, $MS_e = 71,788.78$, $p < .05$; $F_2(1, 47) = 13.32$, $MS_e = 53136.29$, $p < .05$. Results indicated greater facilitation for strongly constrained texts ($M = 37.88$, $SE = 10.19$) than for weakly constrained texts ($M = 7.544$, $SE = 10.97$).

Two-tailed paired sample *t*-tests were conducted to test whether or not facilitation scores differed significantly by condition in each visual field—hemisphere. In the rvf-LH, strongly constrained texts showed greater facilitation than weakly constrained texts, $t_1(77) = -3.72, SE = 9.65, p < .05; t_2(47) = -2.77, SE = 14.71, p < .05$. In the lvf-RH, strongly constrained texts also showed greater facilitation than weakly constrained texts, $t_1(77) = -3.00, SE = 8.31, p < .05; t_2(47) = -2.25, SE = 11.47, p < .05$. There was no significant difference between strongly constrained inferences in the rvf-LH and lvf-RH, $t_1(77) = 0.33, SE = 12.75, p = 0.75; t_2(47) = 0.28, SE = 18.12, p = 0.78$ and there was no significant difference between weakly constrained inferences in the rvf-LH and lvf-RH, $t_1(77) = -0.49, SE = 13.38, p = 0.62; t_2(47) = -0.52, SE = 19.06, p = 0.61$. Thus, greater facilitation was evident for strongly constrained than for weakly constrained inferences in both hemispheres.

One sample *t*-tests were conducted to test whether or not facilitation differed significantly from zero by condition in each visual field—hemisphere. Facilitation was significantly greater than zero for strongly constrained inferences in the rvf-LH, $t_1(77) = 3.99, SE = 10.01, p < .05; t_2(47) = 2.35, SE = 16.54, p < .05$ as well as in the lvf-RH, $t_1(77) = 3.45, SE = 10.37, p < .05; t_2(47) = 2.48, SE = 13.66, p < .05$. Facilitation was not significantly greater than zero for weakly constrained inferences in the rvf-LH, $t_1(77) = 0.33, SE = 12.82, p = 0.74; t_2(47) = -0.13, SE = 14.43, p = 0.90$ nor in the lvf-RH, $t_1(77) = 1.19, SE = 9.11, p = 0.24; t_2(47) = 0.55, SE = 14.53, p = 0.58$. Thus, only responses in the strongly constrained inference condition showed facilitation that differed significantly from zero.

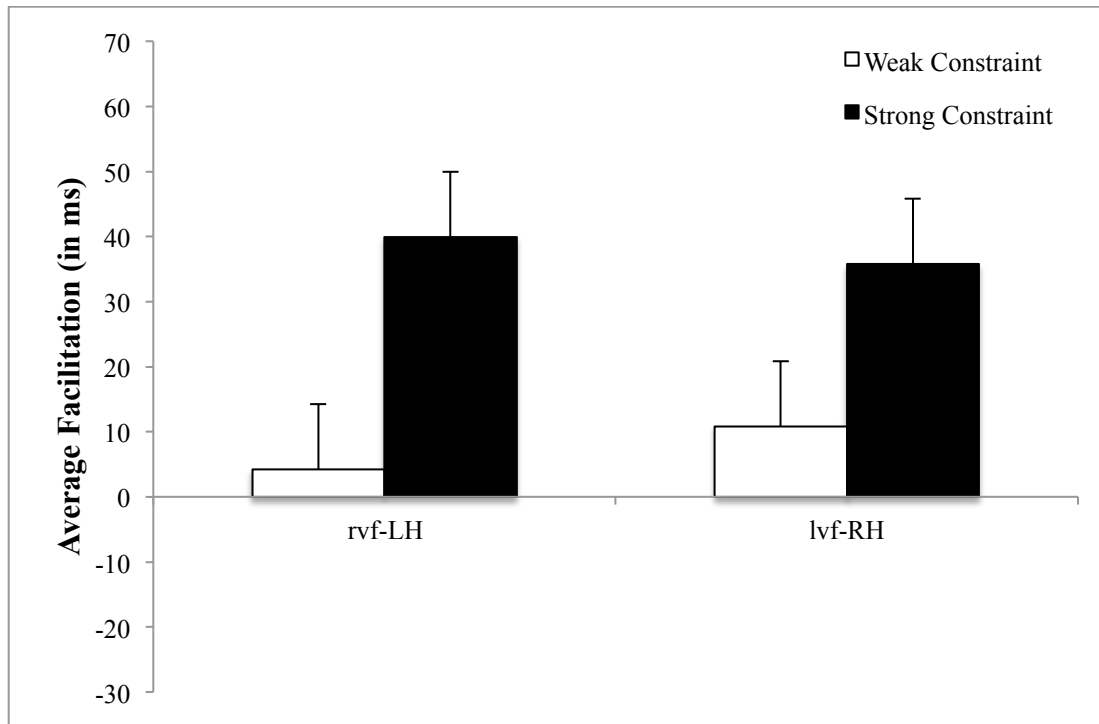


Figure 1. Average facilitation for strongly and weakly constrained predictive inference by visual field—hemisphere. *rvf-LH* = right visual field—left hemisphere, *lvf-RH* = left visual field—right hemisphere.

Table 2. Mean Response Times (in ms) and Standard Errors for Strong, Weak, and Neutral Textual Constraint Predictive Inference Texts by Visual Field—Hemisphere.

Condition	rvf-LH		lvf-RH	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Strong Textual Constraint	397	14.87	412	15.10
Weak Textual Constraint	432	18.09	437	15.10
Neutral Textual Constraint	437	14.12	448	14.16

Note: *rvf-LH* = right visual field—left hemisphere, *lvf-RH* = left visual field—right hemisphere.

Accuracy

To test for accuracy effects by condition (see Table 3 for mean accuracy percentages by condition), a 3 (Textual Constraint: Strong, Weak, or Neutral) \times 2 (Visual Field—Hemisphere: rvf—LH or lvf—RH) repeated measures ANOVA was conducted. There was no main effect of visual field—hemisphere, $F_1(1, 77) = 0.01$, $MS_e = .01$, $p = .50$; $F_2(1, 47) = 0.31$, $MS_e = .01$, $p = 0.58$. There was a main effect of textual constraint, $F_1(1, 76) = 12.77$, $MS_e = 0.16$, $p < .05$; $F_2(1, 47) = 5.88$, $MS_e = 0.09$, $p < .05$. There was not a significant interaction between visual field—hemisphere and textual constraint $F_1(1, 76) = 1.70$, $MS_e = 0.01$, $p = 0.19$; $F_2(1, 47) = 0.63$, $MS_e = 0.01$, $p = 0.54$. Results indicated higher accuracy for both strongly constrained texts and weakly constrained texts than for neutral texts.

Table 3. Mean Accuracy Percentages and Standard Errors for Strong, Weak, and Neutral Textual Constraint Predictive Inference Texts by Visual Field—Hemisphere.

	rvf-LH		lvf-RH	
Condition	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Strong Textual Constraint	94	0.01	96	0.01
Weak Textual Constraint	93	0.01	94	0.01
Neutral Textual Constraint	90	0.02	88	0.02
Note: rvf—LH = right visual field—left hemisphere, lvf—RH = left visual field—right hemisphere.				

Attentional Control Effects on Inference-Related Response Time Facilitation

To test the second hypothesis that attentional control would display a three-way interaction along with textual constraint and visual field—hemisphere, a 2 (Attentional

Control: High or Low) \times 2 (Textual Constraint: Strong or Weak) \times 2 (Visual Field—Hemisphere: rvf—LH or lvf—RH) mixed factors ANOVA was conducted (see Table 2 for mean response times by inference condition). Results indicated no significant three way interaction between attentional control, textual constraint, and visual field—hemisphere, $F(1, 76) = 1.23$, $MS_e = 4542.19$, $p = 0.27$. However, follow-up contrasts revealed that while the same pattern of significantly greater facilitation for strongly constrained inferences than weakly constrained inferences in both visual field—hemispheres was evident in the high attentional control group (see Figure 3, right panel) for both the rvf-LH, $t(38) = -2.34$, $SE = 11.22$, $p < .05$ and the lvf-RH, $t(38) = -3.36$, $SE = 9.17$, $p < .05$, in the low attentional control group (see Figure 3, left panel), facilitation was only significantly greater for strongly constrained inferences than weakly constrained inferences in the rvf-LH, $t(38) = -2.87$, $SE = 15.71$, $p < .05$ and not in the lvf-RH, $t(38) = -1.37$, $SE = 13.93$, $p = .18$. Thus, facilitation for strongly constrained inferences was greater than facilitation for weakly constrained inferences in both visual field—hemispheres in the high attentional control group but this pattern was only evident in the rvf-LH in the low attentional control group. One sample t -tests indicated that facilitation for strongly constrained inferences in the high attentional control group (see Figure 3, right panel) was significantly greater than zero in the rvf-LH, $t(38) = 4.79$, $SE = 11.51$, $p < .05$ and in the lvf-RH, $t(38) = 4.44$, $SE = 10.82$, $p < .05$. Facilitation for weakly constrained inferences in the high attentional control group was significantly greater than zero for in the rvf-LH, $t(38) = 2.30$, $SE = 12.55$, $p < .05$ but not in the lvf-RH, $t(38) = 1.44$, $SE = 11.92$, $p = 0.16$. In the low attentional control group, facilitation for strongly constrained inferences was not significantly greater than zero in the rvf-LH, $t(38) = 1.53$,

$SE = 16.17$, $p = 0.13$ or in the lvf-RH, $t(38) = 1.34$, $SE = 17.64$, $p = 0.19$. Facilitation for weakly constrained inferences in the low attentional control group was also not significantly greater than zero in the rvf-LH, $t(38) = -0.93$, $SE = 21.84$, $p = 0.36$ or in the lvf-RH, $t(38) = 0.324$, $SE = 13.87$, $p = 0.75$. Thus, the high attentional control group showed significant facilitation for inferences in all conditions except for weakly constrained inferences in the lvf-RH whereas the low attentional group did not show significant facilitation for any of the conditions.

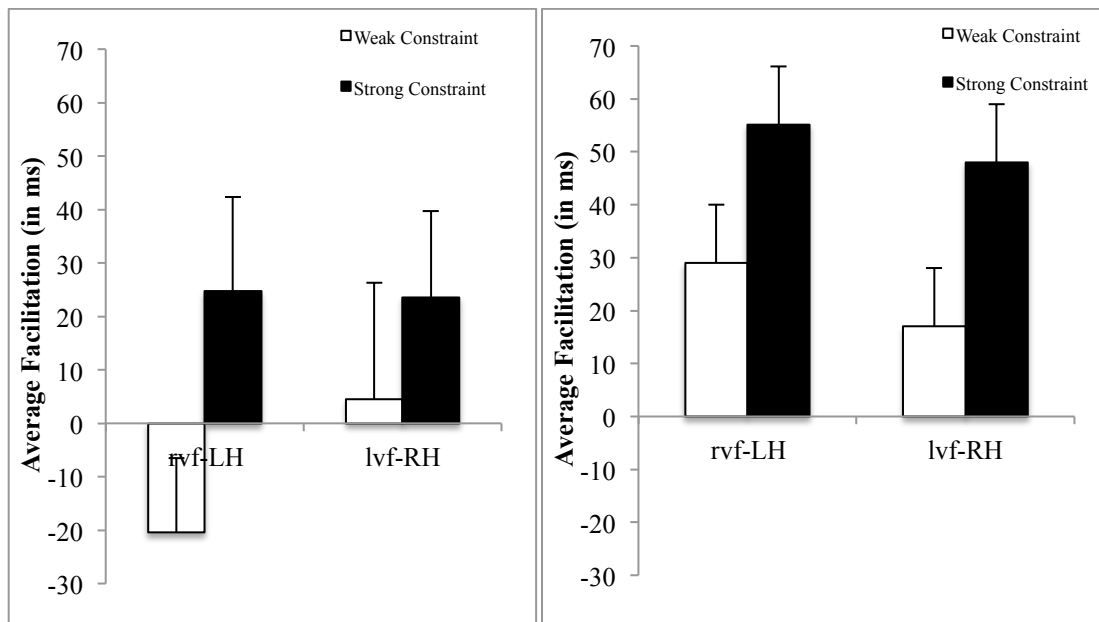


Figure 2. Average facilitation for strongly and weakly constrained predictive inferences by visual field—hemisphere and attentional control. Facilitation for low attentional control readers is shown on the left and facilitation for high attentional control readers is shown on the right. rvf-LH = right visual field—left hemisphere, lvf-RH = left visual field—right hemisphere.

Table 4. Mean Response Times (in ms) and Standard Errors for Strong, Weak, and Neutral Textual Constraint Predictive Inference Texts by Visual Field—Hemisphere for Low and High Attentional Control Groups.

Condition	Attentional Control			
	Low		High	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Strong Textual Constraint				
rvf-LH	413.33	24.59	380.85	16.67
lvf-RH	429.51	24.92	395.42	18.99
Weak Textual Constraint				
rvf-LH	458.47	29.90	407.15	19.93
lvf-RH	448.62	23.10	426.22	19.58
Neutral Textual Constraint				
rvf-LH	438.08	20.13	436.03	20.08
lvf-RH	453.12	22.82	443.41	17.05
Note: rvf—LH = right visual field—left hemisphere, lvf—RH = left visual field—right hemisphere.				

Table 5. Mean Accuracy Percentages and Standard Errors for Strong, Weak, and Neutral Textual Constraint Predictive Inference Texts by Visual Field—Hemisphere for Low and High Attentional Control Groups.

	Attentional Control			
	Low		High	
Condition	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Strong Textual Constraint				
rvf-LH	94	0.01	93	0.01
lvf-RH	96	0.01	95	0.02
Weak Textual Constraint				
rvf-LH	95	0.02	91	0.02
lvf-RH	94	0.02	95	0.02
Neutral Textual Constraint				
rvf-LH	90	0.03	91	0.02
lvf-RH	88	0.03	87	0.02
Note: rvf—LH = right visual field—left hemisphere, lvf—RH = left visual field—right hemisphere.				

DISCUSSION

The results from this study show the effects of attentional control on predictive inference generation in the hemispheres as a function of textual constraint. These findings support the hypothesis that facilitation for strongly constrained inferences was greater than for weakly constrained inferences in both hemispheres. This demonstrates the effect of textual constraint on predictive inference generation in the hemispheres and is consistent with findings from previous studies (Linderholm, 2002; Virtue et al., 2006). Specifically, this pattern of results suggests that both cerebral hemispheres respond faster to inference-related target words when they are preceded by passages that are strongly related to the target word than passages that are weakly related to the target word.

The finding that, overall, only strongly constrained inferences showed significant facilitation for inference-related targets in both hemispheres further supports the initial hypothesis that strongly constrained inferences would show greater facilitation than weakly constrained inferences in both hemispheres. However, these findings do not replicate the results of Virtue et al. (2006) with regard to weakly constrained inferences. Virtue and colleagues (2006) found significantly greater facilitation for weakly constrained predictive inferences in the right hemisphere than in the left hemisphere. These results did not indicate a significant processing advantage for predictive inferences in the right hemisphere compared to the left hemisphere, nor did they show significant facilitation for weakly constrained predictive inferences in either hemisphere. Further, the observation of this pattern in both hemispheres does not support predictions based on the Fine-Coarse Semantic Coding Theory that weakly constrained predictive inferences—

which contained target words that were distantly related to the preceding passages—would show greater activation in the right hemisphere than in the left hemisphere.

One potential explanation for this pattern of results is that the Semantic SART task was administered before the inference task rather than afterward. By contrast, Virtue et al. (2006) administered the R-Span working memory task after the inference task. This may have had an effect on the patterns of hemispheric activation observed during the inference task in this study. Previous studies have shown that the right-lateralized fronto-parietal attentional network is less active after performing a psychomotor vigilance task (PVT) than before the task (Lim, Wu, Wang, Detre, Dinges, & Rao, 2010). Further, research has also suggested that the cerebral blood flow velocity (CBFV) in both the right and left hemispheres can decline over time as participants perform a sustained attention task (Shaw, Finomore, Warm, & Matthews, 2012). In this way, it is possible that participants' activation patterns were affected by fatigue due to sustained attention in the Semantic SART task. Specifically with regard to low attentional control readers, it is possible that attentional fatigue after performing the Semantic SART task could have led to difficulties in performing the cognitively demanding task of predictive inference generation and, consequently, less facilitation than might have been observed if the inference task had been performed before the Semantic SART task. By contrast, the high attentional control readers may have been more resistant to the effects of attentional fatigue and, thus, may have had less difficulty in generating predictive inferences after performing the Semantic SART task than low attentional control readers. This would explain why, despite showing several similarities to the pattern of results observed in Virtue et al. (2006) (i.e., greater facilitation for strongly than weakly constrained

inferences, similar facilitation for strongly constrained inferences in the LH and RH, and greater—albeit non-significant—facilitation for weakly constrained inferences in the RH than in the LH) the results of this study were not more closely aligned with the results from Virtue et al. (2006) and predictions made based on the Fine-Coarse Semantic Coding Theory.

Another potential explanation for this difference can be found in the contrast between the facilitation results for the high attentional control group versus the low attentional control group. The high attentional control group showed significantly greater facilitation for strongly constrained inferences than for weakly constrained inferences in both hemispheres. Further, the high attentional control group showed significant facilitation for all conditions except for weakly constrained inferences in the right hemisphere. This suggests that readers with high attentional control activate word meanings related to strongly constrained predictive inferences in both hemispheres, but that they only activate meanings related to weakly constrained inferences in the left hemisphere.

By contrast, readers with low attentional control only showed significantly greater facilitation for strongly constrained inferences than for weakly constrained inferences in the left hemisphere. Further, low attentional control readers did not show significant facilitation for strongly or weakly constrained inferences in either hemisphere. These results did not confirm the hypothesis that low attentional control readers would display higher facilitation for weakly constrained inferences than high attentional control readers. However, consistent with the Capacity Constrained Comprehension (CCC) theory, these results suggest that readers with low attentional control do not possess enough available

cognitive resources to facilitate either strongly or weakly constrained predictive inferences (Just & Carpenter, 1992). These results also support the Minimalist Hypothesis in that not all readers in this study appeared to routinely generate predictive inferences during reading (McKoon & Ratcliff, 1992). However, the specific distinction between attentional control and WMC as evidenced by the differences between the results of this study and the results of Virtue et al. (2006) and other theories of hemispheric inference processing (e.g., the Fine-Coarse Coding theory) is difficult to determine solely based on these results. However, the Executive Attention view of WMC does offer a potential explanation.

The Executive Attention view states that working memory capacity is comprised of two primary mechanisms: goal maintenance (i.e., the ability to sustain attention on a specific task or stimulus) and competition resolution (i.e., the ability to overcome moment-by-moment interference from goal-irrelevant stimuli). Previous research has suggested that attentional control is primarily associated with the goal maintenance component of working memory (McVay & Kane, 2012). This is consistent with the finding that high attentional control readers show greater facilitation for strongly constrained (i.e., more likely) predictive inferences than for weakly constrained (i.e., less likely) predictive inferences because strongly constrained inferences are more closely related to the goal of comprehending a text (i.e., they are more immediately relevant to the context of the sentence) than weakly constrained inferences. Further, the finding that only high attentional control readers showed significant facilitation for weakly constrained inferences suggests that, consistent with the Executive Attention view and CCC theory, only readers with high attentional control had enough cognitive resources

available to generate weakly constrained predictive inferences. By contrast, the readers with low attentional control may not have had enough available resources to maintain the goal of comprehension while reading the texts to generate strongly or weakly constrained inferences about information in the texts. Thus, the difference between these findings and the findings of Virtue et al. (2006) could be that while the low WMC readers from their study were more likely to activate less likely (i.e., weakly constrained) inferences in the right hemispheres, low attentional control readers did not possess enough available resources generate any predictive inferences.

These findings suggest that readers with high attentional control are more likely to generate predictive inferences during text comprehension than readers with low attentional control. These results also highlight a distinction between predictive inference generation in low working memory capacity readers versus low attentional control readers in that low working memory capacity readers show right hemisphere facilitation for weakly constrained inferences whereas low attention control readers do not (Virtue et al., 2006). Predictive inference generation is a cognitively demanding task that requires available working memory resources to generate predictions about what will happen next in a text (Linderholm, 2002). Since predictive inferences contribute to reading comprehension by promoting anticipation of future text events, causal connections between text events, and improved situation model construction, these findings suggest that readers with high attentional control may be better comprehenders than readers with low attentional control (van den Broek, 1990; Fincher-Kiefer, 1993). These findings differ from those of previous studies in that low attentional control readers appear to have difficulty generating predictive inferences regardless of the level of constraint whereas

previous studies have suggested that low WMC readers activate strongly constrained inferences in both hemispheres and activate weakly constrained predictive inferences in the right hemisphere (Virtue et al., 2006). This finding may suggest that attentional control is an essential factor in the process of predictive inference generation. Future studies should further examine the specific mechanisms that contribute to the differences between low attentional control and low WMC readers. In sum, this study improves our understanding of text comprehension by showing how attentional control contributes to predictive inference generation during reading, how textual constraint can influence predictive inference generation in readers with high versus low attentional control, how attentional control contributes to working memory processes during predictive inference generation, and how these processes are activated in the cerebral hemispheres during text comprehension.

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