Modulating Semantic Integration in the Right Hemisphere:

A Transcranial Direct Current Stimulation Study

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THESIS

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This dissertation is dedicated to my cat, Stinky.

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SUMMARY

Prior research has shown that the right hemisphere is essential for integrating information across a passage to form a coherent thematic meaning. The aim of this dissertation is to evaluate right hemisphere semantic integration processes by directly manipulating the neural excitability of the left or right hemisphere using transcranial direct current stimulation (tDCS) while participants read passages and complete a lexical decision task. For the lexical decision task, participants were presented with either a target word related to the passage's local (word-level) context, a target word related to the passage's global (thematic) context, or a non-word. Because processing global information requires semantic integration processes, right hemisphere anodal (i.e., active) stimulation was predicted to increase the speed and accuracy of lexical decision responses to global targets compared to sham (i.e., inactive) and left hemisphere anodal stimulation. Contrary to predictions, results indicated no effect of tDCS condition, such that participants in each stimulation condition revealed similar patterns of response time and accuracy. However, participants responded faster to local targets compared to global targets, regardless of stimulation condition. This finding provides additional evidence for fast activation of local contextual information and relatively slower activation of global contextual information during discourse comprehension. Future directions are discussed regarding the absence of a tDCS effect on lexical decision response time and accuracy.

I. INTRODUCTION

During text comprehension, readers must process the meanings of individual words and sentences and then integrate those meanings to form a coherent mental representation of the global theme of the text. Research has consistently shown that the right hemisphere of the brain specializes in the integration of semantic information (e.g., Jung-Beeman, 2005). The right hemisphere's ability to integrate semantic information is especially important when comprehending inferences (e.g., Silagi et al., 2018) and non-literal language (e.g., Diaz, & Hogstrom, 2011; Tang, et al., 2017), processing distantly-related concepts and inconsistent information (e.g., Virtue & Joss, 2012), and understanding the theme or gist of stories (e.g., See Johns et al., 2008 for a review). The aim of the present study is to provide causal evidence of the right hemisphere's role in semantic integration processes during reading. This was done by directly modulating neural activity in the left and right hemispheres using transcranial direct current stimulation (tDCS) while participants read passages and respond to targets in a lexical decision task.

A. Semantic Processing in the Left and Right Hemispheres

Studies from the field of visual perception suggest that the left hemisphere specializes in seeing the smaller details in a scene, whereas the right hemisphere specializes in seeing the larger pieces of visual information (Aiello et al., 2018; Bedson & Turnbull, 2002; Deruelle & Fagot, 1997; Flevaris et al., 2010; Martin, 1979). Researchers often use a divided visual-field paradigm to present stimuli initially to one hemisphere. Due to the contralateral nature of the visual system, when a person fixates a central position on a display, information presented to the left visual-field is initially projected to the visual cortex in the right hemisphere, and information presented to the right visual-field is initially projected to the visual cortex of the left hemisphere

(See Bourne, 2006 for review; Beeman et al., 1993). Researchers often have participants complete a behavioral task within this paradigm, such as a simple identification task, lexical decision task, semantic relatedness task, or naming time task, so that response times and accuracy may be recorded. Differences in response times and accuracy between the left- and right-visual-field conditions are assumed to reflect differences in processing ability of the hemispheres. To examine visual processing in the left and right hemispheres, Martin (1979) presented participants with single, large letters that were made from smaller letters. For example, a large H (global shape) could be made by arranging small T's (local shape) to form the lines that make up the H. The letter shapes were presented using a divided visual-field paradigm, and participants were asked to identify either the large or small letters. Identification of the global shape requires the integration of local shapes, and identification of the local shapes requires the selection from the global shape. Participants identified the local shapes faster when they were presented to the left hemisphere compared to the right hemisphere. Additionally, participants identified the global shapes faster when they were presented to the right hemisphere compared to the left hemisphere, although this difference did not reach statistical significance. A similar divided visual-field study was later conducted by Bedson and Turnbull (2002). They showed that local aspects of shapes and letters were most accurately detected by the left hemisphere, and global aspects of shapes and letters were most accurately detected by the right hemisphere, which replicates the pattern of results found by Martin (1979). These studies provide evidence that the left hemisphere specializes in processing local visual information, whereas the right hemisphere specializes in processing global visual information. These hemispheric mechanisms for processing simple visual shapes are also shown to be largely consistent with the mechanisms used to comprehend more complex linguistic information, such as individual words and sentences.

Beeman and colleagues (1994) used the divided visual-field paradigm to examine how the left and right hemispheres process semantic information in two experiments. Participants in the first experiment read three weakly-related words called summation primes (e.g., *foot-cry-glass*) or three unrelated word primes (e.g., *dog-church-phone*) that were presented centrally, followed by a target word (e.g., *cut*) that was laterally presented to the left visual-field (right hemisphere) or right visual-field (left hemisphere). Each word within a summation prime trio does not prime the corresponding target on its own but does so when presented together and summated (i.e., integrated). For example, the word, *foot*, on its own should not prime the target *cut*, but the three words *foot-cry-glass* should prime *cut*. As expected, participants in the experiment named target words preceded by summation primes more accurately compared to target words preceded by unrelated primes, regardless of hemisphere presentation. Summation priming (i.e., facilitation) was calculated by subtracting the proportion correct for target words followed by summation primes from the proportion correct for target words followed by unrelated primes. Summation priming was greater when targets were presented to the right hemisphere compared to the left hemisphere. Beeman and colleagues concluded that this right hemisphere advantage in summation priming provides evidence for a right hemisphere role in integrating distantly-related word meanings (e.g., *foot-cry-glass*), also referred to as coarse-semantic coding. The second experiment implemented the same procedures with the addition of direct primes, which include one word that is strongly related to the target surrounded by two neutral words that are unrelated to the target (e.g., *none-scissors-whether*). Participants named target words more accurately when they followed either summation or direct primes compared to unrelated primes. When targets were presented to the left hemisphere, direct priming was greater than summation priming. Authors interpreted these results to indicate that the left hemisphere activates closely-related meanings more than distantly-related meanings. In contrast, when targets were presented to the right hemisphere, there was no difference in direct priming and summation priming. This means that the right hemisphere activated both closely-related and distantly-related meanings to the same extent. These results support the conclusion that the left hemisphere engages in relatively fine-semantic coding, which is characterized by selecting closely-related word meanings (i.e., direct priming). In contrast, the right hemisphere engages in relatively coarse-semantic coding, which is characterized by selecting both closely-related meanings (i.e., direct priming) and distantly-related meanings (i.e., summation priming).

The results from Beeman and colleagues (1994) are consistent with the Fine-Coarse Semantic Coding Theory (Beeman, 1998; Beeman & Chiarello, 1998; Chiarello et al., 1990), which proposed that the left and right hemispheres of the brain engage in different semantic activation mechanisms during language processing. This theory proposes that the left hemisphere engages in fast and strong activation of closely-related meanings (fine-semantic coding), whereas the right hemisphere engages in slow and broad activation of distantly-related meanings (coarse-semantic coding). For example, when reading the lexically ambiguous word, *foot*, the left hemisphere strongly activates a small semantic field of closely-related word meanings, such as *socks* and *toes*. In contrast, the right hemisphere activates a larger semantic field that includes the closely-related word meanings as well as distantly-related meanings, such as *pay* (as in the figurative phrase “to *foot* the bill”) and *12-inches* (meaning “one *foot* in length”). The large semantic fields for each of the prime words (*foot*, *cry*, and *glass*) in the right hemisphere are thought to overlap with each other, resulting in summation priming of the target word *cut*. The small semantic fields in the left hemisphere do not overlap, therefore activation from *foot, cry, and glass* are not summated, resulting in an absence of summation priming for the target word, *cut*. Jung-Beeman (2005) later extended the Fine-Coarse Semantic Coding Theory and proposed the Bilateral Activation Integration and Selection (BAIS) model. This model proposes that natural language comprehension is comprised of three stages of semantic processing. These stages are activation, integration, and selection, and each process is proposed to take place in a distinct area of the brain. Jung-Beeman (2005) proposed that semantic integration occurs when the degree of word-level overlap between semantic fields is evaluated and a message-level interpretation is formed, and this process is proposed to take place in the anterior temporal lobe. The right hemisphere is proposed to be more efficient than the left hemisphere at integrating semantic information due to the right hemisphere's overlapping, diffuse semantic fields. This corroborates the findings of Beeman and colleagues (1994) in which summation priming occurred in the right hemisphere, but not in the left hemisphere.

B. Evidence for Semantic Integration in the Right Hemisphere

Many studies have provided evidence for the right hemisphere's role in semantic integration processes (e.g., Faust & Lavidor, 2003; Gouldthorp, 2015; Gouldthorp & Coney, 2011; St George, et al., 1999). For example, Faust and Lavidor (2003) had participants view convergent and divergent primes and then make a semantic relatedness response to a lateralized target (Experiment 2). Convergent primes were made up of two words related to either the dominant meaning of an ambiguous target word (e.g., *new*, *fresh* - *NOVEL*) or two words related to the subordinate meaning (e.g., *story*, *book* - *NOVEL*). Divergent primes were mixed and included one word related to the dominant meaning and one word related to the subordinate meaning (e.g., *new, story* - *NOVEL*; *fresh, book* - *NOVEL*). When presented to the left hemisphere, the targets following convergent primes were facilitated, however, there was no facilitation for targets following divergent primes. Alternatively, when presented to the right hemisphere, the targets following convergent primes were facilitated, and facilitation was also found for targets following divergent primes. These results are similar to the results from Beeman and colleagues (1994) and provide additional evidence that the right hemisphere has an important role in summating and integrating distantly-related words to access coherent meanings.

In a similar study, Gouldthorp and Coney (2011) examined how the left and right hemispheres integrate contextual information that is presented across multiple sentences. Participants saw centrally-presented primes composed of one sentence (e.g., *I taste sweet*), two sentences (e.g., *I taste sweet*. *I can be put on toast*), or three sentences (e.g., *I taste sweet*. *I can be put on toast*. *I am made by an insect*), and then made lexical decision responses to lateralized targets (e.g., *honey*). Each sentence is weakly associated with a target, but when presented together, they create strong associations with a target. These primes are similar to the summation primes used by Beeman and colleagues (1994). Facilitation effects for each target were calculated by subtracting the response time from a neutral condition (e.g., *This is a neutral sentence. This is a neutral sentence. This is a neutral sentence.*). As expected, the right hemisphere showed significantly increased facilitation of the targets as the number of prime sentences increased, providing evidence that the right hemisphere engages in summation priming. Interestingly, the left hemisphere also showed significantly increased facilitation as the number of sentences increased. One explanation for these results can be derived from Federmeier's (2007) model. This model postulates that the right hemisphere uses integrative processes, whereas the left hemisphere uses predictive processes. In this case, Gouldthorp and Coney (2011) suggested that both hemispheres utilized the sentential contextual information by engaging in different processes. Specifically, the right hemisphere integrated the sentence primes to facilitate the upcoming target using message-level processes, whereas the left hemisphere anticipated or predicted the upcoming targets using word-level processes. Message-level processes require readers to integrate upcoming semantic information with previously encountered information, whereas word-level processes require readers to simply form relations between lexical information (Gouldthorp, 2015). To better examine message-level processes, researchers should present participants with passages containing inferences.

Generating and understanding inferences requires a reader to use message-level process to integrate individual word meanings to establish a global or more complete understanding of the theme of a text (Mason & Just, 2004). One could argue that the summation primes used in the study by Beeman and colleagues (1994) required readers to make an inference about how the words are related. For example, if the summation primes are thought of as mini stories, the summation prime, *foot-cry-glass*, requires the reader to infer that the subject of this mini-scenario <u>*cut*</u> their *foot* while stepping on *glass* and as a result, is now *crying*. Prior research showing a clear right hemisphere advantage in comprehending inferences supports this idea (e.g., Beeman, 1993; Jung-Beeman, 2005; Brownell et al., 1986; Powers et al., 2012; Purdy et al., 1992; Tompkins et al., 2008; Virtue, van den Broek, & Linderholm, 2006). Gouldthorp (2015) examined how the left and right hemispheres engage in word-level and message-level processes in a divided visual-field study. Participants in this study read short passages and then performed a lexical decision task on lateralized targets. The two types of target words in this study were either global targets or local targets. An example passage and corresponding targets are presented below.

Chris had been driving for hours when the light started to flash.

Later he cursed himself when his car slowed to a halt.

He was already tired and wanted to get home to sleep

Local Target: *BED*; Global Target: *FUEL*

Facilitation of the global target requires information from the first two sentences to be integrated, producing message-level coherence. In this example, the reader needs to infer that the flashing light indicated that the car was low in fuel, but Chris ignored the light and, therefore, ran out of gas. This message-level processing leads to facilitation of the global target word, *fuel*. Facilitation of the local target only requires lexical information from the last sentence, producing word-level coherence. In the example, the last sentence includes the words *tired*, *home*, and *sleep*, which are directly related to the local target word *bed*. Gouldthorp (2015) designed local primes such that comprehension of the third sentence does not depend on comprehension of the prior two sentences. This was done so that the local target is only related to the third sentence, whereas the global target is related to the message-level information provided by the first two sentences. Facilitation was calculated by the subtracting response time to a target following the primes from the response time of the same target following a neutral prime (i.e., *This is a neutral sentence. This is a neutral sentence. This is a neutral sentence*). Participants showed greater facilitation for global targets in the right hemisphere compared to the left hemisphere, and they showed equal facilitation of local targets in the left and right hemispheres. These results suggest that the left and right hemispheres both use local contextual information equally during reading, but only the right hemisphere is able to integrate the message-level contextual information to generate an inference. This finding corroborates the finding from Beeman and colleagues (1994) that both hemispheres facilitate direct primes, but only the right hemisphere facilitates summation primes, and further suggests a right hemisphere role in semantic integration processes when reading short passages.

Other studies have also provided evidence that the right hemisphere demonstrates a greater ability to integrate contextual information in a story to form a coherent understanding of the overall theme than the left hemisphere (Branzi et al., 2020; Ferstl et al., 2005; Mason & Just, 2004; St George et al., 1999; Wapner, Hamby, & Gardner, 1981). For example, St George and colleagues (1999) had participants read paragraphs while changes in left and right hemisphere blood flow were measured using functional magnetic resonance imaging (fMRI). Paragraphs were either titled or untitled and presented to readers one word at a time. The presence of a title provided readers with an overall theme, so they could establish a coherent message-level interpretation of the passages. Untitled paragraphs elicited greater activation overall, reflecting greater processing difficulty. However, a larger difference in activation was found in the right hemisphere when reading untitled than titled paragraphs (i.e., untitled activation – titled activation) than in the left hemisphere. These results provide additional evidence that the right hemisphere plays an important role in integrating semantic information to establish a coherent discourse representation during reading.

Studies on participants with brain lesions provide strong corroborating evidence of the right hemisphere's role in message-level processing. Specifically, lesion studies have shown that participants with unilateral damage to the right hemisphere have a reduced ability to integrate discourse context to generate inferences compared to control participants, whereas participants with unilateral damage to the left hemisphere do not experience these deficits (Brownell et al., 1986; Goel et al., 2007; Lomlomdjian, et al., 2017; Purdy et al., 1992; Saldert & Ahlsén, 2007; Silagi et al., 2018). Purdy and colleagues (1992), for example, had participants with right hemisphere lesions and control participants watch a 9-minute film and then answer comprehension questions. Comprehension questions either required inferences based on background knowledge or required inferences based on information explicitly stated in the film. Control participants performed better on both question types compared to participants with right hemisphere lesions. Interestingly, participants with right hemisphere lesions performed better on inference questions requiring background knowledge than inference questions requiring information from the film. Purdy and colleagues (1992) argued that their results provide evidence that the right hemisphere advantage for processing inferences demonstrated in various studies is due to an ability to integrate semantic information derived from a story rather than an inability to access and apply background knowledge. In a similar study, Silagi and colleagues (2018) instructed participants with unilateral right hemisphere lesions, participants with unilateral left hemisphere lesions, and matched control participants to read passages and answer comprehension questions that required the readers to generate inferences. Both groups of participants with hemisphere lesions exhibited inferior performance in answering the inference comprehension questions than the matched control group. However, participants with right hemisphere lesions performed worse on the types of inference questions that require higher cognitive demand. This is consistent the results of Virtue, van den Broek, and Linderholm (2006), who demonstrated that both hemispheres show facilitation when processing inferences with strong relationships, but only the right hemisphere shows facilitation when processing inferences with weak relationships. These findings provide additional evidence that while both hemispheres contribute to text processing, the right hemisphere shows a clear advantage when integrating distantly-related meanings to produce message-level coherence.

The results from the studies described above are consistent with the right hemisphere semantic integration mechanisms described in the Fine-Coarse Semantic Coding Theory, Federmeier's (2007) model, and the BAIS model. For instance, Gouldthorp's (2015) finding of a right hemisphere advantage in message-level processing is consistent with evidence that the right hemisphere is more efficient in integrating information across a discourse passage (e.g., Johns, et al., 2008) and generating inferences even when hearing discourse from multiple speakers (e.g., Powers et al., 2012). The right hemisphere's important role in semantic integration is supported by studies using various methodologies, such as the divided visual-field paradigm and neuroimaging. Lesion studies have also provided evidence that right hemisphere regions directly support semantic integration processes. Although informative, a major criticism of studies based on patients with hemispheric lesions is that the lesions are often unpredictable, such that neural organization can differ dramatically depending on the age that the lesion is acquired (Adolfs, 2016). Therefore, it is important to examine the right hemisphere's role in semantic integration using methodologies that allow researchers make to causal conclusions.

1. Neuromodulation Evidence

Neuromodulation is a powerful technique that can be used to demonstrate causal relationships between brain areas and cognitive processes. Neuromodulation methods allow for a continuous manipulation of neural excitability while participants perform a behavioral task. One way of modulating cortical excitability is transcranial Direct Current Stimulation (tDCS). With tDCS, weak electrical stimulation is applied to the scalp with two electrodes (using saline-soaked sponges to pass current to the scalp). Depending on how the stimulation is applied, neuronal excitability is enhanced or inhibited (Thair, et al., 2017). Anodal (i.e., positive) stimulation causes depolarization of the resting membrane potential in the cortical region directly under and surrounding the electrode, thereby increasing neuronal excitability. Increased neural excitability means that cells are more likely to fire, and therefore an increase in efficiency in the processes associated with the targeted stimulation area. Note that increased efficiency of neural processes does not necessarily mean increased or faster cognitive processing. Given that some cognitive processes result from excitation of neurons and some processes result from inhibition of neurons, neural activation can lead to faster cognitive processes, slower cognitive processes, or a different pattern of cognitive processes. The important point is that stimulation changes neural processes in a controlled manner. Cathodal (i.e., negative) stimulation causes hyperpolarization of the resting membrane potential, thereby decreasing neuronal excitability (Ihara et al., 2015). Cognitive functions are performed by a combination of activating neural process and inhibiting processes, therefore, increased neural excitability in one area is not synonymous with more or better cognitive functions, and decreased neural excitability in another area is not synonymous with less or worse cognitive functions. In summary, tDCS is a non-invasive method of temporarily modulating neural activity in an area of the cortex to demonstrate causal relationships between brain regions and cognition.

Several researchers have used tDCS to investigate the brain regions involved in language processing. Joyal and Fecteau (2016) reviewed 27 articles in which tDCS was used to examine semantic processing in healthy subjects. Joyal and Fecteau concluded that tDCS can effectively modulate semantic processing when stimulation is applied to the frontal, temporal, or parietal cortical regions. Specifically, tDCS modulated semantic processing in 23 out of 32 experimental conditions when the frontal cortex was stimulated, and in 6 out of 9 experimental conditions when the temporal and parietal areas were stimulated. For example, a study included in the review by Thomson and colleagues (2015) found that a single session of tDCS significantly increased reading efficiency in healthy adults, demonstrating the effectiveness of tDCS on neural activity during reading tasks. Importantly, Joyal and Fecteau (2016) found that eight out of the 27 studies reviewed showed a main effect of stimulation, and seventeen other studies found an interaction between stimulation and stimulus type (e.g., congruency, relatedness). For example, Peretz and Lavidor (2013) found that applying anodal tDCS to the right Wernicke's area resulted in faster response times to target words related to the subordinate meaning (e.g., farmer) of ambiguous primes (e.g., pen), but did not result in faster response times to target words related to the dominant meaning (e.g., paper) compared to sham stimulation. The presence of these interactions is important because it shows that tDCS has selective effects on semantic processing rather than a simple arousal effect that results in faster response times. These studies reviewed by Joyal and Fecteau (2016) provide evidence of the effectiveness of tDCS in causing changes in semantic processing by manipulating neural excitability.

Researchers can use tDCS to provide conceptual replications of prior studies that have used the divided visual field technique. For example, Bardi and colleagues (2013) conducted a study similar to the divided visual-field studies by Martin (1979) and Bedson and Turnbull (2002) to examine how the left and right hemispheres contribute to the processing of simple linguistic information using tDCS. Bardi and colleagues (2013) presented participants with single, large letters that were made from smaller letters. Participants were asked to identify either the small letters (local shape) or large letters (global shape). However, instead of using the divided visual-field paradigm, tDCS was applied to the left or right posterior parietal cortex (PPC) to increase or decrease hemispheric excitability. When left hemisphere excitability was increased via anodal stimulation and right hemisphere excitability was decreased via cathodal stimulation, local shapes were identified more quickly than global shapes. Alternatively, when right hemisphere excitability was increased and left hemisphere excitability was decreased, global shapes were identified more quickly than local shapes. These results provide causal evidence using neuromodulation that is consistent with prior divided visual field research (Bedson & Turnbull, 2002; Martin, 1979) supporting the right hemisphere's role in processing global linguistic information.

Neuromodulation is a relatively novel technique, and only a few studies have used tDCS to evaluate the hemispheric mechanisms involved in semantic integration processes (e.g., Salvi et al., 2020; Sela et al., 2012; Weltman & Lavidor, 2013). In one study, Weltman and Lavidor (2013) showed participants direct and mediated Hebrew word-pairs. Direct items consisted of two words that were strongly related (e.g., rain-cloud), whereas mediated items consisted of two words that were indirectly related to each other via a core concept (e.g., barrel-grapes). These items are similar to the direct and summation primes used in the divided visual field study by Beeman and colleagues (1994) and the sentence primes used by Gouldthorp and Coney (2011), such that semantic integration is necessary when reading the mediated items, but semantic integration is not necessary when reading the direct items. Participants performed a lexical decision task in which they indicated whether a second word was a real Hebrew word or a non-word. In a second experiment, participants performed a semantic priming task in which they had to decide whether the second word was related to the first word. Participants completed these tasks while receiving one of three tDCS conditions: right anodal/left cathodal stimulation, left anodal/right cathodal stimulation, or sham stimulation (i.e., stimulation that is of such low voltage that neural activity is not affected). In all three conditions, the electrodes were placed over Wernicke's area or its right hemisphere homologue. For the lexical decision task, right anodal/left cathodal stimulation was shown to impair overall task accuracy compared to sham stimulation. Weltman and Lavidor (2013) suggested that this impairment in lexical decision accuracy was likely due to an interruption of lexical processing resulting from the simultaneous cathodal stimulation applied to the left hemisphere. For the semantic priming task, right anodal/left cathodal stimulation resulted in greater mediated prime accuracy compared to left anodal/right cathodal and sham stimulation. This mediated priming effect under right hemisphere stimulation is consistent with prior research suggesting that the right hemisphere specializes in integrating semantic information. Weltman and Lavidor's tDCS study is important because it provides causal evidence for this conclusion because the researchers were able to directly manipulate participants' semantic processes by stimulating the left and right hemispheres. The right hemisphere has been shown to be more involved in semantic integration processes when semantic concepts are unpredictable or have weak relationships (Virtue et al., 2006). Researchers have provided causal evidence for the right hemisphere's role in integrating weakly-related semantic information using tDCS (Price et al., 2016; Salvi et al., 2020; Sela et al., 2012). In the study by Sela and colleagues (2012), stimulation was applied to the dorsolateral prefrontal cortex (DLPFC) in one of two stimulation conditions. Participants received either right anodal/left cathodal stimulation or left anodal/right cathodal stimulation while completing a semantic relatedness task. During stimulation, participants read predictable and unpredictable idioms (e.g., *kick the bucket, bite the bullet*) and then indicated whether a subsequent target was related or unrelated to each idiom. Idiom predictability in this study was defined as the proportion of responses in which an idioms last word could be completed correctly with the first word that comes to mind (e.g., *kick the _____; bite the _____*). Interestingly, enhancing left hemisphere excitability (left hemisphere anodal and right hemisphere cathodal condition) resulted in higher accuracy in the semantic relatedness task when idioms were predictable. Alternatively, enhancing right hemisphere excitability (right hemisphere anodal and left hemisphere cathodal condition) resulted in higher accuracy when the idioms were unpredictable. Although accuracy was increased with tDCS, response times were slower when idioms were unpredictable, possibly reflecting a speed-accuracy trade-off. In a similar tDCS study by Price and colleagues (2016), high definition tDCS applied to the left angular gyrus resulted in faster response times for meaningful word combinations (e.g., tiny radish) compared to non-meaningful, unpredictable word combinations (e.g., fast blueberry). High definition tDCS applied to the right angular gyrus resulted in faster response times for non-meaningful word combinations. However, Price and colleagues (2016) found no effect of tDCS on accuracy. In a similar study, Salvi and colleagues (2020) found that high definition tDCS applied to the right anterior temporal lobe resulted in better performance on compound remote associate problems (e.g., pine, crab, sauce) compared to pre-stimulation, left frontopolar stimulation, or sham stimulation. Compound remote associate problems require a reader to integrate the semantic information across the three words and to generate a word that forms a compound phrase with each of the three words provided (e.g., apple). The results from these three tDCS studies provide causal evidence for the right hemisphere's vital role in combining weakly-related semantic information to activate a coherent meaning. However, there are some inconsistent effects of stimulation on accuracy and response times across studies, such that some studies only report an effect of tDCS on response times (e.g., Price et al., 2016) and some studies only report an effect of tDCS on accuracy (e.g., Sela et al., 2012). Additionally, it is still unclear from these studies whether right hemisphere neurostimulation facilitates semantic integration across a passage.

The neuromodulation studies reviewed above using tDCS (Bardi etl al., 2013; Price et al., 2016; Salvi et al., 2020; Sela et al., 2012; Weltman & Lavidor, 2013) support previous findings that the right hemisphere is important for semantic integration processes (e.g., Faust & Lavidor, 2003; Gouldthorp, 2015; Gouldthorp & Coney, 2011). However, only one study specifically targeted the right anterior temporal lobe (Salvi et al., 2020), which has been shown in many prior studies to be important for semantic integration during discourse processing (e.g., Branzi et al., 2020; Ferstl et al., 2005; St George et al., 1999). Additionally, the studies that provide causal evidence using tDCS that the right hemisphere is important for semantic integration have all used short stimuli, consisting of a few words or short phrases (e.g., *bite the bullet* from Sela et al., 2012). No study has used tDCS to examine the role of the right anterior temporal lobe in semantic integration using longer passages to make conclusions regarding discourse comprehension. Additionally, in many of the tDCS studies described (e.g., Price et al., 2016 Sela et al., 2012; Weltman & Lavidor, 2013), anodal stimulation applied to the right hemisphere in is confounded with simultaneous cathodal stimulation of the corresponding region in the left hemisphere. Therefore, it is not entirely clear if these results are due to an increase in neuronal excitability in the right hemisphere or due to a decrease in neuronal excitability of the left hemisphere, or other effects of simultaneous tDCS application. Therefore, further research is needed to make conclusions regarding the right hemisphere's role during discourse processing.

C. Present Study

The aim of the present study is to directly manipulate neural excitability of the left and right hemispheres to show a causal link between activation of the right hemisphere and the semantic integration mechanisms proposed in the Fine-Coarse Semantic Coding Theory, the BAIS model, and Federmeier's model. Hemispheric activity was modulated in the present study using tDCS while participants completed a go/no-go lexical decision task. Participants completed the task while they underwent anodal or sham (inactive) tDCS applied to the left or right anterior temporal lobe. The anterior temporal lobe was selected as the stimulation target area because it is proposed to play an important role in semantic integration processes (Branzi et al., 2020; Jung-Beeman, 2005; St George et al., 1999). Participants read three-sentence prime passages that tell short stories that were developed and used by Gouldthorp (2015), and participants provided lexical decision responses to target words related to the local context, target words related to the global context, or non-words. Responses for global targets were expected to be faster and more accurate during right-anodal stimulation compared to both left-anodal and sham stimulation in the present study, providing causal evidence for the right hemisphere's role in integrating semantic information to produce message-level coherence. Additionally, responses for local targets were expected to be faster and more accurate during left-anodal stimulation and right-anodal stimulation compared to sham stimulation, providing evidence that message-level processes are characteristic to the right anterior temporal lobe.

II. METHOD

A. Design

The present study implemented a 3 (Stimulation: left-anodal, right-anodal, sham) by 2 (Target: local, global) design. Stimulation was manipulated between-subjects, such that participants were exposed to one stimulation condition to one hemisphere. This was done to avoid any carryover effects from multiple stimulation sessions that would be conducted in a within-subjects design. Target was manipulated within-subjects, such that all participants were exposed to both types of targets (local and global).

B. Participants

An a priori power analysis was conducted using the software package, GPower 3 (Faul, Erdfelder, Lang, & Buchner, 2007), to determine the appropriate sample size for the present study based on Gouldthorp's divided visual field lexical decision facilitation effects, which had an effect size *f* of .14 for the two-way interaction effect of target type and visual field. This analysis indicated that a total sample size of 66 participants is required to have 80% power in detecting a medium sized effect. Because GPower is not capable of assessing the power for a linear mixed effects model, the "a priori test for ANOVA: Repeated measures, within-between interaction" in GPower was used here (Faul, Erdfelder, Lang, & Buchner, 2007). Additionally, a sample size of 66 participants (22 participants in each stimulation condition) for the present study will reflect the sample sizes in other tDCS studies that used similar designs, which include between 19-26 participants in each stimulation condition (e.g., Cummine et al., 2019; Thompson et al., 2015).

Forty-six University of Illinois at Chicago (UIC) undergraduates participated in the present study for credit in an Introduction to Psychology course. Data collection was stopped prematurely (before collecting data from 66 participants) due to COVID-19 restrictions. Participants were run individually and were randomly assigned to one of the three stimulation conditions, such that 14 participants received anodal stimulation to the left hemisphere (i.e., left-anodal), 18 participants received anodal stimulation to the right hemisphere (i.e., right-anodal), and 14 participants received sham stimulation (8 left-sham, 6 right-sham). This split sham condition follows the sham design implemented by Cohen-Maximov and colleagues (2015). All participants are predominantly right-handed as indicated by a handedness score of at least .7 as assessed by the Edinburg Handedness Inventory (Appendix A). All participants were required to have attended an English-speaking school for at least 10 years to ensure high proficiency with English.

C. Materials

1. Lexical Decision Task Primes and Targets. The three-sentence primes for this experiment consist of 120 primes that were developed, normed, and used by Gouldthorp (2015). Sixty primes were paired with word targets, and 60 primes were paired with non-word targets. For the primes paired with word targets, each prime (e.g., *Mike was embarrassed when he realized that his wallet was empty. Later, after entering his pin, he passed one of the bills to his friend. Noticing the clouds, he thought they'd better hurry to the car as it was about to pour.*) was paired with a global target (e.g., *BANK*), and a local target (e.g., *RAIN*). Priming of the global targets require information from the first two sentences to be integrated, producing message-level coherence, whereas priming of the local targets only require lexical information from the third sentence. Gouldthorp ensured that all target words were of high concreteness and high imageability, and that these ratings did not differ significantly between the local and global targets. However, any difference in word frequency should not influence the relative pattern of predictions between the stimulation conditions. Non-word targets were pronounceable letter strings (e.g., *BAPLE*). See Gouldthorp (2015) for full norming procedures.

Some minor modifications were made to the stimuli for the present study, such that some names were changed to avoid repetition across trials. Additionally, some words were changed to reflect American language norms (e.g., ‘favourite’ was changed to ‘favorite’; ‘gum boots’ was changed to ‘rubber boots’). A complete list of experimental stimuli is shown in Appendix B. For the list of sixty word-items chosen for the present experiment, average global target word length (M = 4.40, SE = .09) did not significantly differ from local target word length (M = 4.35, SE = .10), $t(118) = 0.38$, $p = .70$. Word frequency was also evaluated based on the Corpus of Contemporary American English (COCA). Average global target word frequency (M =27,726, *SE* = 3,781) was significantly lower than local target word frequency (*M* = 56,351, *SE* = 10,284), *t*(118) = -2.61, *p* =.01. Because of this difference in target word frequency, target word frequency was added as a covariate in the response time and accuracy analyses.

Two counterbalanced stimulus sets were used for the present study so that each participant only saw one target for each prime. For example, set 1 included a prime 1 paired with the global target, set 2 included the prime 1 paired with the local target. Each stimulus set consisted of one practice block and six experimental blocks. Each block contained 20 trials. Trials within each block were presented in random order. Additionally, each stimulus set had four versions so that each block occurred first an equal number of times. Because there are two versions of each stimulus set, this results in eight versions of the lexical decision task SuperLab file (i.e., 1A, 1B, 1C, 1D, 2A, 2B, 2C, 2D). Trials were organized as blocks to ensure that each trial is presented in the first, second, third, and fourth quartile of trials an equal number of times.

D. Measures

1. Edinburg Handedness Inventory. The Edinberg Handedness Inventory (Oldfield, 1971) was used to assess the degree of left- or right-hand dominance. Answers to the questions were incorporated into a mathematical formula that generates a laterality score for each participant. All participants included in this study received a handedness score of .7 or higher, indicating right hand dominance. The Edinburg Handedness Inventory questions are presented in Appendix A.

2. Working Memory Span Tasks. Working memory span was assessed because working memory resources are necessary to make inferences to construct a global context (i.e., situation model) of a passage. (Graesser, & Zwaan, 1995; Marmolejo-Ramos & Cevasco, 2014; Zwaan & Radvansky, 1998). Working memory span was measured using a composite (i.e., sum) score of shortened versions of the Operation Span task (Turner & Engle, 1989) and the Symmetry Span task (Kane et al., 2004). Each task required participants to hold items in working memory while completing distractor tasks. Two span tasks were used, rather than one, based on the recommendations by Foster and colleagues (2015). Additionally, two shortened versions were used to decrease administration time and fatigue effects based on the findings of Foster and colleagues (2015) showing that shortened versions of complex span tasks can provide accurate measures of working memory capacity. Both tasks were run using the Psychology Experiment Building Language (PEBL) software (Mueller & Piper, 2014).

The Operation Span task included 17 experimental trials. In each trial, participants were shown a series of letters and simple math problems. Participants were instructed to remember each string of letters in order while judging whether interspersed simple math problems were correct. Participants were instructed to indicate whether each math problem was correct by clicking “True” or “False” buttons presented under each problem. If participants did not respond within their average response time, the trial was recorded as incorrect. To measure recall at the end of each trial, participants were shown a series of letters and were instructed to click on the letters in the order they were presented. If a letter could not be recalled, participants were provided with the option to click a placeholder “Blank” letter. Trial length ranged from two to seven letters. Prior to the experiment trials, participants first practiced the letter recall task, then they practiced the math problem task, and then they practiced doing both tasks together. The instructions stated that they would be shown a math equation and after they make their decision about whether the equation is true or false, a letter will appear on the screen, and they are to try to remember the letter.

The Symmetry Span task included 14 experimental trials. In each trial, participants were shown a series of 4 x 4 grids with a darkened square and an 8 x 8 grid with symmetrical or non-symmetrical darkened shapes. Participants were instructed to remember the location of each darkened square on a grid in the order they were presented while judging whether interspersed shapes were symmetrical. Participants were instructed to indicate whether each shape was symmetrical by clicking "Symmetrical" or "Non-Symmetrical" buttons presented under each shape. If participants did not respond within their average response time, the trial was recorded as incorrect. To measure recall at the end of each trial, participants were shown a blank 4 x 4 grid and were instructed to click on squares with the computer mouse in the order they were presented. If a square location could not be recalled, participants were provided with the option to click a placeholder "Blank" location. Trial length ranged from two to five squares. Prior to the experiment trials, participants first practiced the grid location recall task, then they practiced symmetry judgement task, and then they practiced doing both tasks together. The instructions stated that they would be shown a shape and after they make their decision about whether the shape is symmetrical or not symmetrical, a grid with a darkened square will appear on the screen, and they are to try to remember the location of that square.

3. Language History Questionnaire. The language history questionnaire (Daniel, 2009) was presented on paper, and participants were instructed to answer each question to the best of their knowledge. The purpose of this questionnaire was to collect demographic information and information regarding each participant's language knowledge. The language history questionnaire is shown in Appendix C.

4. Vocabulary Test. The vocabulary test (Daniel, 2009) was presented on paper and included fifteen words. Participants were instructed to definition for each word among five choices. The purpose of this test is to assess whether there are differences between tDCS stimulation conditions in participants' English vocabulary knowledge. The vocabulary test is shown in Appendix D.

E. Procedure

1. Working Memory Span Tasks. Participants completed the Operation Span task and then completed the Symmetry Span task. Participants proceeded through the instructions of the task that were displayed on the computer screen at their own pace. After completing the practice trials, the researcher asked participants if they had any questions before continuing. A trial was recorded as correct if all of the items (letters or boxes) were recalled in the correct order. If participants did not get at least 80% correct on the distractor task (i.e., math problems in the Operation Span task and symmetry judgements in the Symmetry Span task), the task terminated, and the participants were instructed to start the task over.

2. tDCS Screening Questionnaire. A tDCS Screening Questionnaire (Appendix E) developed by Thair and colleagues (2017) to ensure that participants were eligible to participate in the experiment (e.g., Have you ever had a seizure? Have you ever had an adverse reaction to tDCS, or any other brain stimulation technique?). Based on the exclusion criteria established by Thair and colleagues (2017), participants who answer, "yes", to any of the questions completed an alternative study that does not use tDCS for their safety. These participants were not included in the final data set.

3. tDCS. Participants were randomly assigned to a stimulation site, such that each participant either had the anodal electrode attached to the left or right anterior temporal lobe. The international EEG 10/20 system was used to determine the stimulation sites. To stimulate the left anterior temporal lobe, the anodal electrode was placed over T3, and to stimulate the right anterior temporal lobe, the anodal electrode was placed over T4 (Appendix F). The cathodal electrode was placed on the contralateral upper arm (5 cm above the elbow). Before and after stimulation, participants completed a pre- and post-tDCS comfort questionnaire that was developed by Thair and colleagues (2017) in which they provided comfort ratings on a scale of 1 (absent) to 10 (severe) for various sensations and conditions that are commonly experienced with tDCS application (e.g., itching, scalp irritation) and other sensations that are not usually experienced with tDCS application (i.e., pseudo-items). Pseudo-items include back pain, increased heart rate, hot flush, and dizziness. The pre-tDCS comfort ratings were examined prior to stimulation to check whether ratings of 5 or higher were indicated for any of the items to ensure participant comfort and safety. The post-tDCS comfort ratings were examined to assess whether there were any differences in perception of sensations following tDCS between the active and sham stimulation groups. The pre- and post-tDCS comfort questionnaire is shown in Appendix G.

A single-blind, sham-controlled, randomized method was used with respect to stimulation condition, such that each participant was either assigned to receive anodal (i.e., active) or sham stimulation. For the anodal stimulation conditions, a direct current of 2.0 mA intensity was induced using three inch^2 saline-soaked sponge electrodes and delivered by a battery-driven, constant-current stimulator (The Brain Stimulator v3.0). The current was slowly increased to 2.0 mA. Comfort ratings (Appendix H) were collected as the current was increased to monitor participant comfort. The current was held at 2.0 mA for 30 minutes starting immediately prior to the lexical decision task, and then ramped down. For the sham stimulation conditions, the same ramp up procedures took place, but the current was only held at 2.0 mA for 30 seconds and then was ramped down and turned off without the participants' knowledge for the duration of the lexical decision task (replicating the sham procedures used by Price and colleagues, 2016). After the lexical decision task was completed, participants were asked to guess whether they received active or sham stimulation to evaluate whether the sham condition procedures were effective as a blinding tool. An overview of the study procedures is presented in Figure 1.

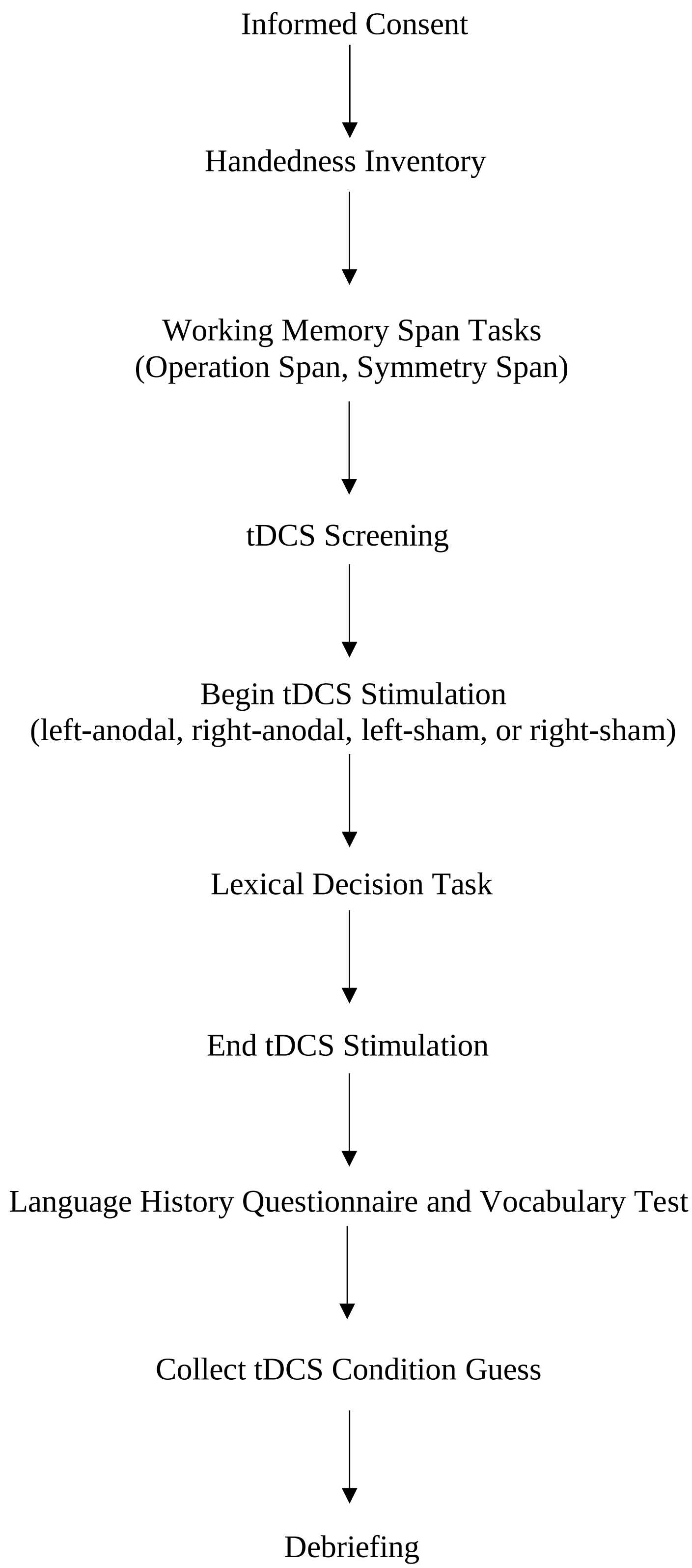

Figure 1. Study procedure overview.

4. Lexical Decision Task. The lexical decision task was programmed and implemented using SuperLab Version 5.0 (Cedrus). Participants were randomly assigned to one of the eight versions of the task. Participants were instructed to indicate via button press with their right hand whether the target was a real English word as quickly and as accurately as they can, and to make no response if the target is a nonword (i.e., a Go/No-Go task). A go/no-go lexical decision task was chosen for the present study because this would replicate the task used by Gouldthorp (2015). An advantage of a go/no-go version of the lexical decision task as opposed to the classic choice lexical decision task (e.g., press the green button when you see a word and press the red button when you see a non-word) is that it has less task demands, which results in faster and more accurate response time data, while maintaining sensitivity to typical effects, such as the word frequency effect (Perea, et al., 2002).

Participants completed a practice block consisting of 20 trials to ensure that they understand the task instructions. During this practice block, the researcher watched participants and provided any feedback that was necessary (e.g., reminders of which buttons to press, reminders to respond quickly). After the practice block, participants completed 120 experimental trials. The prime presentation procedures replicated the lexical decision task procedures reported by Gouldthorp (2015) except that targets were presented centrally instead of laterally. Like in Gouldthorp's study, each passage was presented one sentence at a time (i.e., non-cumulative display) in the center of the screen and each sentence had an exposure duration of 60 ms per letter. For example, a prime sentence with 40 characters were presented for 2400 ms. Then a central fixation cross appeared for 900 ms and participants were instructed to focus their eyes on the fixation. After 900 ms the fixation cross was removed, and a target word or non-word appeared centrally for 150 ms. Participants were instructed to press the green button on the button box in front of them with the index finger of their dominant right hand if the target was a word, and to withhold a response if the target was a non-word (i.e., Go/No-Go response). Similar to Gouldthorp (2015), if a participant provided an inaccurate response (i.e., pressing the green button for a non-word or failing to press the button for a word), an error message (i.e., ERROR) was be presented in red font in the center of the screen for 1500 ms to discourage inaccurate responses. A blank screen was presented for 2000 ms between trials. A schematic of a trial in the lexical decision task is presented in Figure 2.

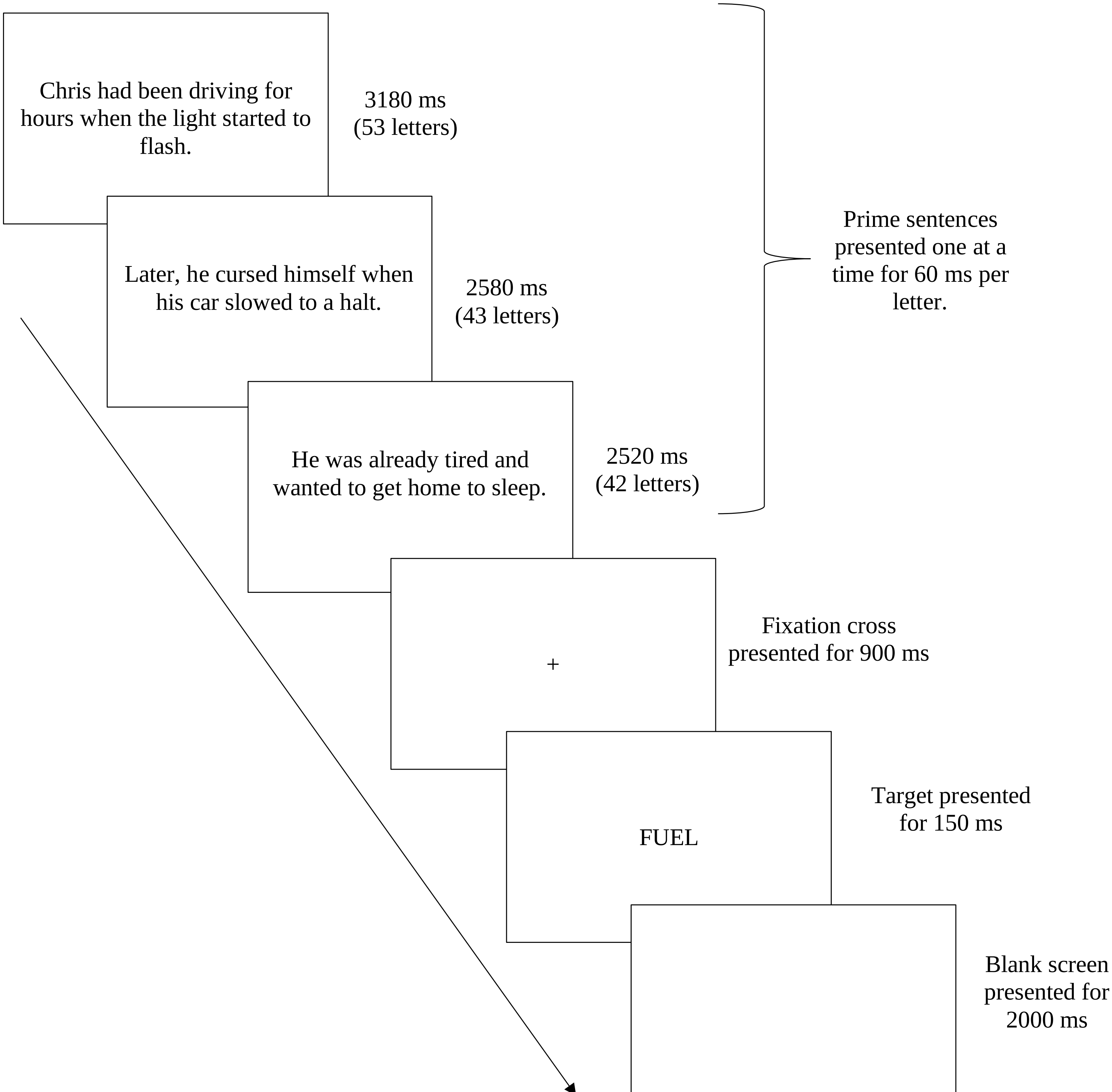

Figure 2. Schematic of a lexical decision task trial.

III. RESULTS

A. Assessment of Sham Blinding

1. Perception of tDCS. Participants' perception of sensations caused by tDCS was assessed because differences in perception may influence condition blinding success (Wallace et al., 2016). Independent samples t-tests were conducted using the jmv package in R (Selker, Love, & Dropmann, 2020) to determine whether participants in the active and sham tDCS conditions differed in their ratings for four sensations following the tDCS portion of the task. These sensations include scalp irritation, tingling, itching, and burning. Participants provided ratings on a scale from 1 (absent) to 10 (severe) for each of these sensations prior to providing a guess of the tDCS condition they were assigned. Participants in the active and sham conditions did not significantly differ in their ratings of scalp irritation or burning sensation, $t(44) = 1.66$, $p = .10$; $t(44) = 1.03$, $p = .31$, respectively. However participants in the active condition reported significantly higher ratings for itching sensation and marginally significantly higher ratings for tingling sensation compared to participants in the sham condition, $t(44) = 2.20$, $p = .03$; $t(44) = 1.88$, $p = .07$, respectively. Mean ratings are shown in Table I.

TABLE I

AVERAGE SENSATION RATINGS ON A SCALE OF 1 (ABSENT) TO 10 (SEVERE) FOR PARTICIPANTS WHO RECEIVED ACTIVE AND SHAM STIMULATION

	Stimulation Condition	
Sensation	Active	Sham
Scalp Irritation	1.66 (0.20)	1.14 (0.10)
Tingling	1.69 (0.15)	1.21 (0.15)
Itching	2.13 (0.23)	1.29 (0.22)
Burning	1.22 (0.14)	1.00 (0.00)

Note: Standard error shown in parentheses.

2. Condition Guess. A binomial proportions test was conducted using the jmv package in R (Selker, Love, & Dropmann, 2020) to determine whether participants were able to accurately guess whether they were in the sham or active tDCS conditions above chance level. After the experiment, participants were asked to guess whether they were in the real (i.e., active) or fake (i.e., sham) stimulation condition. Procedures for assessing tDCS condition blinding were similar to those reported by Wallace and colleagues (2016). All participants were led to believe that they received active stimulation during the experiment, therefore a bias towards guessing that they were in the active stimulation condition was expected. The number of participants in each condition compared to the number of condition guesses is presented in Table II. As shown in Table 2, 28 out of 34 (87.5%) of participants in the active stimulation condition correctly guessed that they were in the active stimulation condition. According to a binomial proportions test, participants in the active stimulation condition correctly guessed their stimulation condition above chance, $p < .001$. This was expected because each participant was told by the researcher that they were receiving stimulation. However, those in the sham condition guessed their correct condition at chance-level, $p = 1.00$, such that 7 out of 14 (50%) of participants in the sham stimulation condition correctly guessed that they were in the sham stimulation condition. This is interesting given that participants in the sham condition were also told that they were in the active condition.

TABLE II

NUMBER OF PARTICIPANTS IN EACH STIMULATION CONDITION AS A FUNCTION OF GUESSED CONDITION

	Condition Guess		
Stimulation Condition	Active	Sham	Total
Active	28	4	32
Sham	7	7	14
Total	35	11	46

TDCS perception ratings tell us that although the tDCS is not painful (i.e., burning), people in the active condition do report feeling more tingling and itching sensations. These differences in sensation ratings and the proportion of people who correctly guessed they were in the sham condition tells us that participants may have been able to detect the condition they were assigned in the present study, suggesting that more rigorous blinding procedures should be conducted in future studies.

B. Assessment of Group Differences

Separate analyses of variance (ANOVA) were conducted using the jmv package in R (Selker, Love, & Dropmann, 2020) to determine whether participants in the three stimulation conditions differed on several individual difference variables that may affect lexical decision task performance. There were no significant differences between the left-anodal, right-anodal, and sham stimulation conditions in working memory capacity composite scores ($F(2, 43) = 0.78$, $p = .46$), vocabulary scores ($F(2, 43) = 0.78$, $p = .46$), handedness scores ($F(2, 43) = 1.64$, $p = .21$), and the ages that participants reported that they began to speak English ($F(2, 43) = 1.94$, $p = .16$), understand English ($F(2, 43) = 1.47$, $p = .24$), and read English ($F(2, 43) = 0.74$, $p = .48$). Means for each of these individual difference variables for each stimulation condition are shown in Table III.

TABLE III

AVERAGE WORKING MEMORY CAPACITY COMPOSITE SCORE, VOCABULARY SCORE, SELF-REPORTED AGE OF ACQUISITION FOR SPEAKING, UNDERSTANDING, AND READING ENGLISH, AND HANDEDNESS SCORE FOR PARTICIPANTS WHO RECEIVED ACTIVE STIMULATION TO THE LEFT HEMISPHERE (LH-ANODAL), ACTIVE STIMULATION TO THE RIGHT HEMISPHERE (RH-ANODAL), AND SHAM STIMULATION.

	Stimulation Condition		
Individual Difference Variable	LH- Anodal	RH-Anodal	Sham
Working Memory Capacity Composite	15.0 (1.5)	14.0 (1.3)	16.3 (1.5)
Vocabulary Test	9.9 (0.7)	10.1 (0.6)	8.9 (0.7)
Age of English Acquisition: Speaking	3.1 (0.5)	2.7 (0.5)	4.1 (0.5)
Age of English Acquisition: Understanding	3.3(0.6)	3.2 (0.6)	4.5 (0.6)
Age of English Acquisition: Reading	5.0 (0.5)	4.4 (0.5)	5.3 (0.5)
Handedness	0.91 (0.03)	0.86 (0.02)	0.91 (0.03)

Note: Standard error shown in parentheses.

C. Lexical Decision Task Analyses

All participants achieved at least 83% accuracy on the lexical decision task. One lexical decision item (local target paired with item number 51 shown in Appendix B) was not included in the analyses because 44% of participants responded incorrectly. All other items included in the analyses showed at least 85% response accuracy. Mixed effects models were conducted using the LME4 package in R (Bates, Mächler et al., 2015) to examine response time and accuracy data. Random effects were selected following the procedures of Bates, Kliegl, and colleagues (2015). First, we started with maximal model (Barr et al., 2013) and found random structure that would converge and yield parsimonious random structure (Matuschek et al., 2017). The best fitting random structure was random intercepts of participants and items, which were allowed to vary as a function of target type. Accuracy data were fit using a binomial logistic mixed-effect model with the optimx package (Nash, 2014) using the nlminb optimizer. The emmeans package (Lenth, 2018) was used for follow-up contrasts using corrected degrees of freedom (Kenward–Rogers method). Logistic mixed models and linear mixed models are reported in analysis of variance (ANOVA) format such that we have main effects and interactions. Conversion from mixed model to ANOVA was made with the CAR package (Fox & Weisberg, 2011) and lmertest package (Kuznetsova, Brockhoff, & Christensen, 2017), and degrees of freedom were estimated using the Satterthwaite's method. No effect sizes are reported as there is no standard approach yet developed for mixed models.

1. Response Time, A linear mixed effects model analysis was conducted on target response time with target type (local, global), stimulation condition (left-anodal, right-anodal, sham), and the interaction between target type and stimulation condition included in the model as fixed factors. Mean response times are shown in Figure 3. Response time was skewed, so a log transformation of response time was implemented for the model. Subject and item were included as random intercepts, and composite working memory score and target word frequency were included as covariates. Both covariates were scaled, and a log transformation of target word frequency was implemented. Analyses are reported in analysis of variance (ANOVA) format such that we have main effects and interactions. Only correct responses were included in the analysis, and response times that were under 100 ms were removed, as stimulus perception and motor responses require at least 100 ms (Luce, 1986). Following the outlier trimming process (Winsorization process) implemented by Gouldthorp (2015), response times above 2.5 standard deviations from each participant's mean for each condition were replaced with 2.5 standard deviation value. This resulted in the replacement of 2.7% of data points.

This analysis revealed a significant main effect of target type on response time, such that response times for local targets (*M* = 349, *SE* = 11.8) were significantly faster than response times for global targets (*M* = 370, *SE* = 11.8), $F(1,56.61) = 6.72$, $p = .012$. However, there was no significant main effect of stimulation condition, such that response times did not differ between participants in the left-anodal (*M* = 358, *SE* = 20.5), right-anodal (*M* = 362, *SE* = 19.2), or sham (*M* = 359, *SE* = 19.1) conditions, $F(2, 48.91) = 0.11$, $p = .89$. Additionally, there was no significant target type by stimulation condition interaction, $F(2, 48.42) = 0.41$, $p = .67$. There was also no significant effect of composite working memory score on target response time, $F(1, 48.90) = 0.25$, $p = .62$. There was a significant effect of target word frequency on target response time, such that response times were faster as target word frequency increased $F(1, 94.49) = 28.84$, $p < .001$.

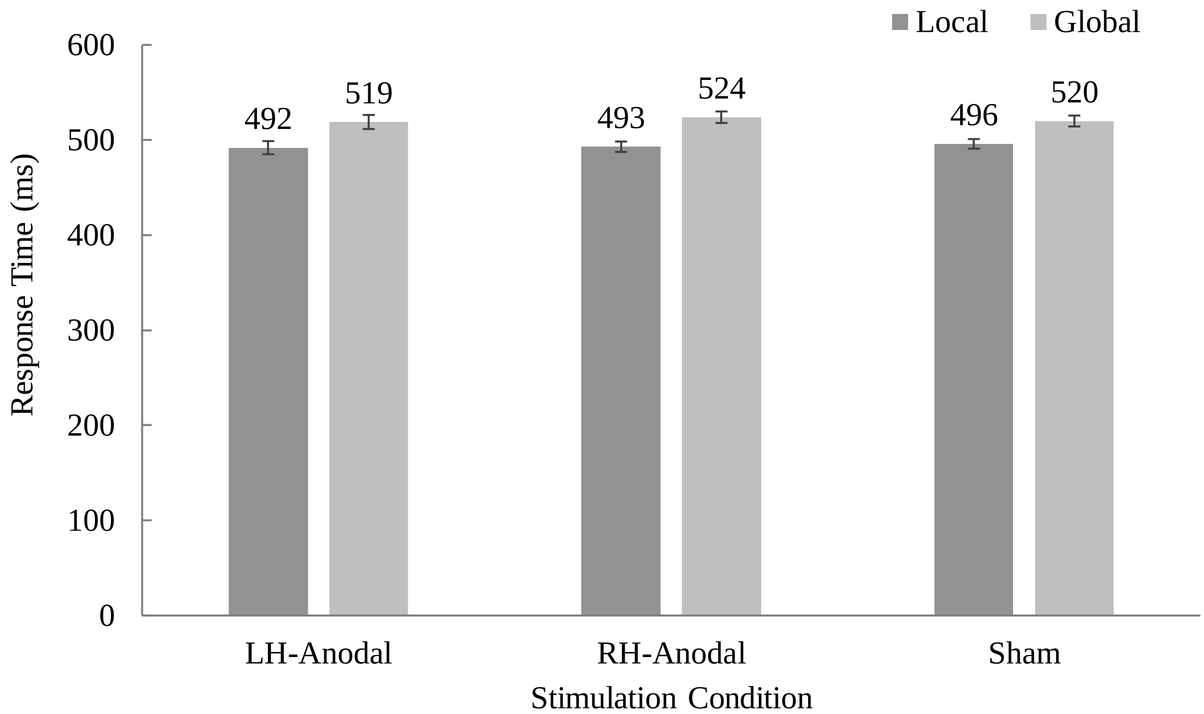

Figure 3. Average lexical decision response time in milliseconds for local and global targets for participants who receive active stimulation left hemisphere (LH-anodal), active stimulation in the right hemisphere (RH-anodal), and sham stimulation. Error bars represent standard error.

2. Accuracy. A binomial logistic mixed effects model analysis was conducted on target accuracy (correct, incorrect) with target type (local, global), stimulation condition (left-anodal, right-anodal, sham), and the interaction between target type and stimulation condition included in the model as fixed factors. Mean proportion correct are shown in Figure 4. Subject and item were included as random intercepts, and composite working memory score and target word frequency were included as covariates. Both covariates were scaled, and a log transformation of target word frequency was implemented. Analyses are reported in analysis of variance (ANOVA) format such that we have main effects and interactions. This analysis revealed no significant main effect of target type, such that accuracy for global targets (*M* = 98.8, *SE* = .004) was similar for local targets (M = 98.6, SE = .01), $\chi 2(1) = 0.05$, p = .82. There was no significant main effect of stimulation condition, $\chi 2(2) = 1.40$, p = .50. Additionally, there was no significant target type by stimulation condition interaction, $\chi 2(2) = 1.16$, p = .56. There was no significant effect of composite working memory score, $\chi 2(1) = 0.77$, p = .38. However, there was a significant effect of target word frequency, such that accuracy was higher as target word frequency increased, $\chi 2(1) = 4.75$, p = .03.

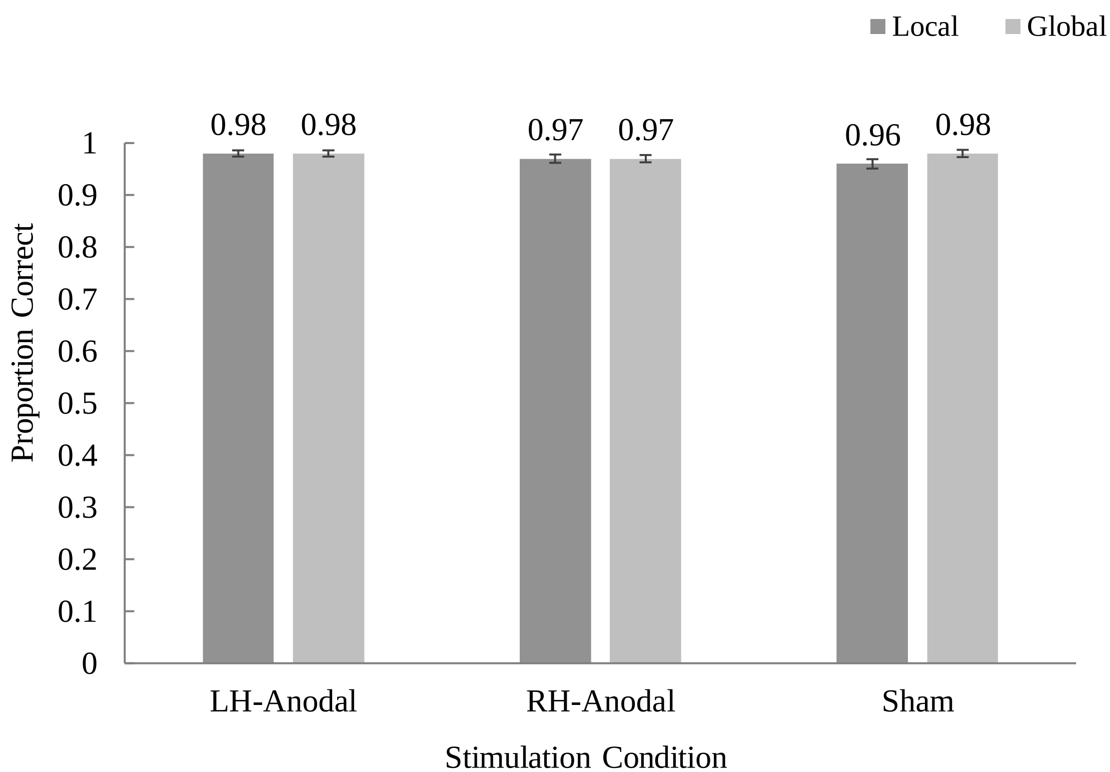

Figure 4. Average lexical decision accuracy depicted as proportion of items correct for local and global targets for participants who receive active stimulation left hemisphere (LH-anodal), active stimulation in the right hemisphere (RH-anodal), and sham stimulation. Error bars represent standard error.

IV. DISCUSSION

The aim of the present study was to evaluate right hemisphere semantic integration processes by directly manipulating the neural excitability of the left and right hemispheres using transcranial direct current stimulation (tDCS). Participants in this study completed a lexical decision task with response times and accuracy recorded. I predicted that stimulation to the right anterior temporal lobe would result in faster response times and higher accuracy to global targets compared to stimulation to the left anterior temporal lobe and sham stimulation, providing evidence supporting previous findings that the right hemisphere is important for semantic integration processes (e.g., Branzi et al., 2020; Faust & Lavidor, 2003; Ferstl et al., 2005; Gouldthorp, 2015; Gouldthorp & Coney, 2011; Jung-Beeman, 2005; Salvi et al., 2020; Sela et al., 2012; St George et al., 1999; Weltman & Lavidor, 2013). I also predicted that a different pattern would emerge for participants who received stimulation to the left anterior temporal lobe. Specifically, I expected faster response times and higher accuracy to local targets compared to those in the sham and right stimulation conditions. Contrary to the predictions, stimulation condition had no effect on response time or accuracy--the pattern of response times and proportion correct was similar across the three stimulation conditions. Additionally, there was no stimulation condition by target type interaction. However, there was a significant effect of target type on response time, such that response times were faster for local targets compared to global targets for the two stimulation conditions and the sham condition. This finding indicates there was greater activation of local than global information prior to responding to the lexical decision targets.

The mixed effects models for response time and for accuracy included target word frequency and composite working memory span as covariates. Adding the composite working memory span covariate resulted in no changes to either model. Adding target word frequency as a covariate to the accuracy model made the main effect of target type non-significant. However, adding the target word frequency covariate to the response time model did not statistically remove the effect of target type. This shows that even after accounting for target word frequency effects and individual composite working memory span scores, local target response times were faster than global target response times. This finding is consistent with research using eye-tracking methods that found that the local context is processed at initial stages of discourse processing, whereas global context is processed at later stages (e.g., Albrecht & O'Brien, 1993; Binder & Morris, 1995). For example, Binder and Morris (1995) demonstrated that both local and global contextual information influence semantic access during lexical ambiguity resolution, such that changes in local context influenced early word-level, lexical access processes and changes in global context influenced later message-level, integrative processes. The present study's finding is also consistent with prior research showing that simple lexical activation requires substantially less time than inference generation (Till et al., 1988). Conclusions regarding the availability of global contextual information in memory cannot be made because the present study did not include any unrelated targets. Future studies should include an unrelated target type to allow researchers to make conclusions regarding the facilitation of semantic information related to the global context of passages relative to information that is unrelated to the passage (i.e., a baseline). For example, if participant response times to global targets are faster than response times to unrelated targets, it could be concluded that information related to the global context is facilitated. If global targets are facilitated relative to unrelated targets, researchers could conclude that participants were able to form a coherent global representation of the passages. As is, the only conclusion that can be made is that targets related to the local context were facilitated relative to the global targets.

One goal of the present study was to use tDCS to create a conceptual replication of the pattern of facilitation presented in Gouldthorp's (2015) divided visual field study. There were three key methodological differences between the present study and Gouldthorp's (2015) study that might help explain why tDCS did not influence response times or accuracy. One key difference involves how the targets were presented. The central presentation of targets used in the present study allowed both hemispheres to process the information simultaneously from the onset of the stimulus, which may have masked any effects produced by tDCS. It is possible that the effect found by Gouldthorp is only detectable in a divided visual field paradigm, in which the targets are presented very briefly to only one hemisphere. A second key difference is that Gouldthorp (2015) used a within-subjects manipulation of hemisphere (i.e., visual field presentation), such that all participants were presented targets in both left visual field (i.e., right hemisphere) and the right visual field (i.e., left hemisphere). The present study used a between-subject manipulation of hemisphere (i.e., stimulation condition), such that participants either received stimulation to the left hemisphere, right hemisphere, or sham stimulation. Stimulation condition was manipulated as a between-subjects variable to control for possible carry-over effects from one stimulation session to another. However, the adaptation of Gouldthorp's within-subjects variable to a between-subjects variable in the present study may have made it more difficult to find any differences between stimulation conditions. Future studies should separate each experiment session with a one-week interval as other authors have done to implement a within-subjects manipulation of stimulation condition (e.g., Sela et al., 2012). This would account for any variation in response times between participants across conditions, thereby increasing the statistical power of the design. A third key difference involves how hemisphere facilitation was examined. Hemispheric facilitation effects were calculated in Gouldthorp's (2015) study by subtracting the response times for targets presented to the left or right visual field following the three-sentence passages by response times to the same targets following neutral passages (i.e., This is a neutral sentence. This is a neutral sentence. This is a neutral sentence). In the present study, hemispheric facilitation effects were examined by comparing response times for targets presented centrally for participants in the left-anodal and right-anodal stimulation conditions to participants in the sham condition. It is possible that the stimuli and procedures from Gouldthorp's (2015) study cannot be adapted to a tDCS paradigm, or that the tDCS procedures need to be modified to detect the effect of interest. These three differences might explain why the present study did not find evidence for right hemisphere facilitation. I will not interpret how the null stimulation condition results relate to previous research and theories because I do not believe these results are meaningful given potential design and methodology issues (reviewed in the next section). Additionally, data collection was suspended early due to the COVID-19 pandemic, so the number of participants needed to achieve appropriate statistical power was not achieved.

A. Limitations and Future Directions

There are several possible explanations for the lack of an effect of stimulation condition in the present study that involve the tDCS procedures. Researchers who have used tDCS to examine right hemisphere integration mechanisms have implemented both anodal and cathodal stimulation while participants completed the study tasks (e.g., Bardi et al., 2013; Sela et al., 2012; Weltman & Lavidor, 2013). Anodal stimulation increases the likelihood that neurons in the targeted area will fire, whereas cathodal stimulation decreases the likelihood that they will fire. Only anodal stimulation was applied to either the left or right hemisphere in the present study, while the cathodal electrode was placed on a neutral area (i.e., the contralateral upper arm). Simultaneous cathodal stimulation was not applied to the contralateral hemisphere in the present study in an attempt to make more accurate conclusions regarding the impact of increasing neural excitability in one hemisphere, while eliminating the confounding simultaneous decrease in excitability to the other hemisphere. Although researchers have successfully modulated semantic processing using only anodal stimulation (e.g., Brückner & Kammer, 2016) with simultaneous cathodal stimulation applied a neutral area (e.g., the contralateral arm), applying simultaneous cathodal stimulation to the contralateral hemisphere may be necessary to detect hemispheric differences in local and global processing. To test this possibility, a second study is needed that replicates the present study's procedures using anodal stimulation of the right anterior temporal lobe with simultaneous cathodal stimulation of the left anterior temporal lobe. Future research would also benefit from including an active stimulation control group, such that active stimulation is applied to another area of the cortex that is not known to be involved in semantic integration during reading. The addition of an active control condition would provide evidence that any tDCS effects found in future studies are directly attributed to an increase in neural excitability to area of interest (i.e., the anterior temporal lobe).

Another possible reason for the lack of an effect of stimulation condition in the present study is due to the tDCS device itself (i.e., The Brain Stimulator v3.0). It is possible that the device used in this study was not sufficient to generate the effect of interest. Conventional tDCS, as used in the present study, consists of one electrode applied to each area of interest. Alternatively, high definition tDCS involves one electrode on the area of interest surrounded by return electrodes that constrain the electric flow to provide focal stimulation the target area. Kuo and colleagues (2013) compared the physiological effects of conventional tDCS and high definition tDCS applied to the primary motor cortex and found that both tDCS procedures were effective at inducing excitability with anodal stimulation and inducing a reduction in excitability following cathodal stimulation. However, high definition tDCS produced significantly more excitability and longer-lasting effects compared to conventional tDCS. Additionally, Datta and colleagues (2009) compared the cortical electric fields that were produced by conventional tDCS with high definition tDCS and found that the conventional tDCS showed diffuse electrical activity with peak activity found around the electrode, whereas the high definition tDCS showed focal electrical activity with peak activity found directly under the electrode. The study by Datta and colleagues (2009) suggests that high definition tDCS may be ideal to provide evidence that a particular area of the cortex causes a specific pattern of performance. Given the findings of Kuo and colleagues (2013) and Datta and colleagues (2009), future studies investigating the role of the anterior temporal lobe in semantic integration processes should compare standard tDCS with high definition tDCS. However, this might be difficult given that high definition tDCS devices are much more costly. Higher tDCS focality has also been shown by simply using smaller electrodes (Nitsche et al., 2007), so future studies should also use smaller electrodes to restrict the tDCS effects to one location. The modifications to the tDCS procedures described above might increase the likelihood of finding an effect of stimulation condition.

There are several other procedural modifications that might increase the likelihood of finding differences in semantic integration processes across the hemispheres. For example, the present study's instructions could be modified to direct readers to integrate the global context of each passage into their mental representations. Previous research has shown that reading outcomes can be greatly influenced by small changes in the instructions or task goals (Brothers et al., 2017; Calvo et al., 2006; Helder et al., 2019; Virtue & Joss, 2017). Participants in the present study were simply told to read the passages for comprehension and press the button on the button box as quickly and as accurately as they can when they see a word as opposed to a non-word. Participants were not told how to process the passages or that some of the target words would be related to the passages. Helder and colleagues (2019) examined the influence of a global theme on text processing in an ERP study and found that a simple modification in the task instructions greatly influenced processing of global context. In their first experiment, participants were instructed to read short passages and then make a true/false judgement about the passages. The passages all had a title presented at the beginning and a global theme that was established in the first few sentences. ERPs were examined on the final sentence nouns that were related to the global context and local context of the passage. The authors did not find the expected N400 reduction for global targets compared to local targets, so they conducted a second experiment with modified task instructions. Participants in their second experiment were not shown passage titles prior to reading the passage and instead they were instructed to read each passage for comprehension and then choose an appropriate title for the passage they just read among two options (e.g., Vivian the Photographer; Vivian the Food Critic). After modifying the instructions, Helder and colleagues found the predicted N400 reduction for global targets compared to local targets. They concluded that the revised task and instructions encouraged participants to pay attention to the global theme of each passage. The task and instructions used in the present study seem similar to Helder and colleagues' first experiment. Thus, the simple instructions to read for comprehension and then determine whether a target was a word or non-word might have resulted in incomplete processing of the global information presented in the passages. This conclusion could be tested in a simple follow-up study without tDCS.

Specifically, participants could be given instructions to think of a title for each passage and then, after a portion of the lexical decision responses, to choose a title for the previously read passage among a set of competing alternatives (i.e., multiple choice). Potential titles could be related to the global meaning, the local meaning, or an unrelated meaning. If integrative processes were enhanced, as reflected by a smaller difference in responses to global targets relative local targets, then a tDCS study could be implemented using the presents study's procedures with the addition of the title probes to promote better global processing.

The ability to integrate passage information and make inferences is essential to forming a coherent global representation of a passage. Calvo (2001) demonstrated that readers with high working memory capacity are more efficient at text integration and inference generation than readers with low working memory capacity. The present study did not find any significant effects of individual working memory span; however, previous fMRI studies have shown that the right anterior temporal lobe is more engaged than the left anterior temporal lobe when an increase in working memory resources is necessary, that is, when readers' need to update the global representation of a text as new, contradicting information is encountered (e.g., Branzi et al., 2020; Ferstl et al., 2005). Branzi and colleagues (2020) found fMRI evidence of bilateral contribution of the anterior temporal lobe during semantic processing. Interestingly, the right anterior temporal lobe was more engaged than the left anterior temporal lobe when updates to the reader's initial text representation were needed. This is consistent with the findings of Ferstl and colleagues' (2005) that the right anterior temporal lobe involvement increased when participants encountered inconsistencies in passages, which requires readers to rely on working memory resources to resolve. Additionally, Yang and colleagues (2020) found that ERP effects differed between individuals with high and low working memory spans during semantic integration processes. Participants in their study read passages that included a target word in final sentence of each that was either congruent or incongruent with the first sentence or the passage. Yang and colleagues found that high-working memory span readers showed an N400 and P600 effect in response to incongruent targets, whereas low-working memory span readers only showed the P600 effect. These findings suggest that low-working memory span readers may integrate semantic information at a delay compared to high-working memory span readers. These results imply that response times to local and global targets in the present study could be influenced by working memory capacity. However, the present study found no effect of working memory capacity, based on composite scores from the Operation Span (Turner & Engle, 1989) and Symmetry span (Kane et al., 2004) tasks.

Future studies could more thoroughly evaluate the impact of working memory by manipulating the availability of working memory resources using a resource depletion paradigm. Researchers have shown that that if participants first complete a cognitively demanding task that requires controlled processing, this temporarily depletes working memory resources, which in turn reduces performance on a second task that requires controlled processing (e.g., Leahy & Sweller, 2019). Christofalos and colleagues (in preparation) demonstrated that cognitive resource depletion significantly impacts situation model comprehension. They had participants perform a resource depleting typing task (i.e., retype two passages as quickly and as accurately as possible while skipping the letter ‘e’) or a non-resource depleting (control) typing task (i.e., retype two passages normally as quickly and as accurately as possible) prior to reading a set of passages and answering questions about the passages. Participants who performed the depletion task performed worse on questions targeting situation model (i.e., thematic) comprehension following difficult passages than participants who first performed the control typing task. Interestingly, there was no effect of resource depletion on surface form and textbase comprehension. This finding provides additional evidence that working memory resources are particularly important when integration processes are necessary, such as when comprehending the overall theme (i.e., global context) of a passage. A similar resource depletion manipulation could be added to the present study to evaluate the influence of working memory capacity on right hemisphere semantic integration processes.

B. Conclusion

The findings of the present study suggest that information related to the local context is processed significantly faster than information related to the global context. This finding is consistent with eye-tracking research illustrating the stages of word and discourse processing (e.g., Albrecht & O'Brien, 1993; Binder & Morris, 1995). Although the tDCS manipulation did not impact lexical decision response time or accuracy, there are many directions for future research that might increase the likelihood of finding an effect of tDCS on semantic integration processes (if such an effect exists).

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VI. APPENDICES

A. Appendix A

Edinburg Handedness Inventory
(Developed by Oldfield, 1971)

Instructions: Please indicate your preference in the use of hands in the following activities by putting a number in the appropriate column. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, put a ‘2’. If you use both hands equally, put a ‘1’ in both columns. Please try to answer all the questions and only leave a blank if you have had no experience at all with the object or task.

	Left Hand	Right Hand
Writing		
Drawing		
Throwing		
Scissors		
Toothbrush		
Knife (when chopping vegetables)		
Spoon		
Broom (upper hand)		
Striking a match (holding the match)		
Opening a Box (grabbing the lid)		

Handedness Score Formula = (Right Hand Sum-Left Hand Sum)/(Right Hand Sum+Left Hand Sum)

B. Appendix B

Lexical Decision Task Stimuli

List of experimental stimuli to be used in the lexical decision task (originally developed by Gouldthorp, 2015). Some names were changed to avoid repetition. Other minor modifications were made to reflect American spelling and word choice norms (e.g., 'favourite' was changed to 'favorite'; 'gum boots' was changed to 'rubber boots'). Item numbers correspond to item numbers stated in data files.

Item Number	Prime	Local Target	Global Target	Target Type
3	Bobby brought home his new pet to put in the tank. Later, as he went to feed it, he realized he didn't have any mice. He grabbed his keys and wallet and drove to the pet shop.	SNAKE	CAR	word
4	Anna noticed that the floor was filthy and filled the bucket with hot soapy water. Later, she let the floors dry as she emptied the dirty water into the garden. She went to the bathroom to scrub the mold from the shiny white floor.	MOP	TILES	word
5	Arthur got scared when all of the lights suddenly went out. Later he shone a torch onto the meter box. He realized that was the problem so he reset the switch.	WEBOT	TRENF	non-word
6	Brittany decided that she ought to increase her assets. Later, she looked up the phone book to find a number for a surgeon. She was looking forward to wearing revealing new clothing.	PLONS	LOURT	non-word
7	John had been held up at work and got home quite late. Later, he forced himself to eat the whole plate of food as his wife had gone to a lot of trouble. He didn't tell her that on the way home he had gone past the pub.	POLTE	MOISH	non-word
8	Joey was thrilled to be the secretive leader and had agreed to take part. Later, his editor told him that this was a really big scoop. He took out his pen and paper to write down the story.	WOURP	TROTH	non-word
9	Kaitlyn was not feeling well and went to bed with a bucket. Later, after cleaning up the mess, she went to brush her teeth. She ran a small plastic comb through her tangles.	VOMIT	HAIR	word
10	Tim got out of his car and ran to the nearby building. Later, after returning home, he put his shirt in the dryer. He turned on the television and sat down.	RAIN	COUCH	word
12	Sarah was pleased when her visitors arrived with pink balloons. Later, as she lay on her hospital bed, she tried to think of a name. The nurse came in mid-morning and asked what she would like to eat.	BABY	LUNCH	word
13	Marcus the hermit came slowly hobbling out of the cave. Later, he was horrified to discover someone else's footprints along the beach. He went back to his home to see if he could find something to make a fence.	ERONG	ROGET	non-word
14	Fred has been on the boat for months and each day he looked hopefully out to sea. Later, he finally saw something on the horizon. He ran into the cabin to check the map.	PIATO	MILTA	non-word
15	Ken was getting older and knew he was too fat. Later, the doctor warned him to drink less. He decided he had better start doing weights.	BIRLP	GOLTE	non-word
16	Jolene softly strummed the chords of the song. Later, after pulling the strap over her head, she placed it in its hard case. She reached down to collect the tips.	WIRNT	PILPO	non-word

17	Gary was feeling very hungry when he inspected the cupboard. Later, as he wiped the crumbs from his mouth, he felt regret for breaking his diet. He decided that tomorrow he would start working out.	CAKE	GYM	word
20	Malcolm had great difficulty walking as the wind howled around him. Later, as an emergency warning was issued for his area, he grew concerned. He taped the windows and carefully slid all the bolts across.	STORM	DOORS	word
21	Madison was cleaning the house when she noticed the carpets were filthy. Later, she realized she must have accidentally sucked up the small metal screws. She thought she had better buy some new ones but wasn't sure whether she would have time to get to the store.	HUIDE	TURY	non-word
22	Ron admired his flexed muscles in the mirror at the gym. Later, one of the regulars asked him how much he could lift. He took a long gulp from his bottle.	BRULF	SARIT	non-word
23	David got home from work and decided to take his dog for a walk. Later, he filled up the bowl in the sink. He was sweaty and needed to take a shower.	PLOTE	BIDY	non-word
24	Mario strutted out onto the catwalk and posed at the end. Later, everyone congratulated him on a great show. He was thrilled that he was allowed to keep the designer clothing.	WERNE	FRAM	non-word
25	Kelly spent most of the warm summer afternoon reading magazines in a salon chair. Later, she was pleased when her friend noticed that she was no longer a blonde. Feeling hot and needing some cool air, she reached for the control and changed the setting to 'high'.	DYE	FAN	word
26	Bianca examined her hands and decided her nails were too long. Later, she was happy with the shorter, rounded shape. Wanting to catch up on her reading, she opened her book.	FILE	PAGE	word
27	Jeff wanted to celebrate his big win in style and called all of his friends. Later, as the bellhop carried his bags up to the room, he looked at the view. Pouring himself a drink, he looked around for the bucket.	HOTEL	ICE	word
29	Eloise flipped through the magazine and cut out pictures that she liked. Later, she used them to explain the sort of style and cut she was after. The stylists sat her in front of the basin to wash her hair.	STRAK	WUNT	non-word
30	Samantha was ecstatic when she had won the race final. Later, as she stood on the podium she heard the music play. She was overcome with emotion when they raised her country's flag.	SROUP	STUIT	non-word
31	Tom threw on his uniform when he realized he had slept through his alarm. Later, he was required to stay after the bell to make up for being late. To fill in the time, he wrote graffiti on the wall.	RARSE	SRUNK	non-word
32	Carrie and her best friend were having a huge fight. Later, as they cleaned up the feathers, they couldn't stop giggling. They decided to make a nice mug of hot chocolate.	KICHT	LORK	non-word
34	Katie was driving her car when she heard her favorite song come on. Later, she got sick of the constant ads and switched stations. She angrily signaled to the driver of the car that just cut in front of her.	RADIO	HORN	word
35	Travis sat expectantly on his surfboard, waiting for the next wave. Later, he became afraid when he saw something moving under the water. He hurried up to the flags to tell the authorities.	SHARK	GUARD	word
36	Karen was at work when she remembered it was her mother's birthday. Later, as she hurried around the shop, she had trouble making a decision. She was looking forward to putting her feet up with a soothing warm beverage.	GIFT	TEA	word

37	Brianna thought carefully about what she wanted to write. Later, as she folded up the pages and tucked them into the envelope, she hoped she had done the right thing. She went downstairs to try to find a stamp.	ARD	LARP	non-word
38	Joyce balanced on her tiptoes as she twirled gracefully with one leg outstretched. Later, her feet ached as she carefully removed her pink satin shoes. She thought it was all worth it to hear the applause from the crowd.	LECK	LUG	non-word
39	Henry sat bravely on his horse as he carefully grasped his lance. Later, as he removed the armor, the Princess came to congratulate him. He became nervous and felt color spread over his cheeks.	MOINT	HONGE	non-word
40	Lucy was nervous the night before her exam and wanted to stay up all night studying. Later, after her fifth cup, she suspected that she had enough. She continued to make notes as she read the thick textbook.	BROIN	METCH	non-word
42	Sally was sweltering from the heat of the day as she walked around without any cover. Later, she was thankful when she was able to sit down under a large leafy tree to eat her lunch. She thirstily sipped from her juice box.	SHADE	STRAW	word
43	Leon was suspended from competing in the international athletics for four years. Later, he put in an official appeal against the decision. He was worried that he would be stripped of all his winnings.	DRUGS	MEDAL	word
44	Michelle was very slim and beautiful and loved being the center of attention. Later, he friends encouraged her to sign up with an agency. She started to daydream as she stroked her silky locks.	MODEL	HAIR	word
45	Alice carefully sketched the outline of the fruit bowl. Later, she brushed away the sharpenings from her desk and admired her artwork. She saw that it was getting dark so she turned on the small lamp.	BINE	BOID	non-word
46	Sam heard the thunder crash as the storm grew stronger. Later, he grew worried about the tall metal pole in his backyard He decided it was also not the best day for him to fly his kite.	DOIR	BAPLE	non-word
47	Marc turned the television on and sat on the couch. Later, he double checked the numbers on the screen with the winning ticket in his hand. Realizing that he was a millionaire, he decided that he would resign from his job.	DRUSS	DRIM	non-word
48	Lenny moved the glazed pot so that it was next to the window. Later, he poured a cup full of water into it. All of the leaves had withered and turned a dull brown.	NIRET	CLECK	non-word
49	Moose the bulldog did not look very well cared for and was forever scratching himself. Later, the vet realized he was infested. Moose looked much cleaner once they washed him thoroughly.	FLEAS	BATH	word
51	Sophie spent the afternoon happily playing with her favorite toy. Later, her mischievous brother cut off all its hair. She started to cry and cry until her mother gave her something sweet and red.	DOLL	LOLLY	word
53	Ellie lay contentedly on the sun lounge in her bikini. Later, she took a shower to wash the chlorine out of her hair. She exfoliated her skin using a loofah.	CRIWN	GLISS	non-word
54	Brad was a famous actor who starred on the big screen. Later, at his most recent premiere, he was asked about the storyline. The interview would be published in all of the gossip magazines.	AWL	IWL	non-word
55	Mia purred contently after drinking the milk. Later, she sharpened her claws by scratching the rough post. She sat under a tree watching the chirping birds.	BEP	GROST	non-word
56	Colin took the old bedding off and carefully remade the bed. Later, just before dozing off, he pulled the crisp cotton over himself. The weather was far too hot to also have a blanket.	SNER	BORP	non-word

57	Lara lit some candles and put on some soft background music. Later, her muscles were soothed as she relaxed in the warm water. She thought about what color polish she would use later.	BATH	NAILS	word
58	Simon felt nervous as he looked over the rocky edge. Later, he recalled the excitement of climbing down. Feeling thirsty, he went to get a drink from his bottle.	CLIFF	WATER	word
59	Emma was tired and cold by the time they finally arrived at their camping spot. Later, she ventured into the bush to find some dry twigs. She stumbled on a rock and fell over in pain.	ANKLE	FIRE	word
60	Chris had been driving for hours when the light started to flash. Later, he cursed himself when his car slowed to a halt. He was already tired and wanted to get home to sleep.	FUEL	BED	word
61	Monique sat outside a café smoking a cigarette. Later, she spread jam onto the light pastry. She felt very French wearing a beret.	NIRL	GUP	non-word
62	Roland pulled on his wetsuit and grabbed his board. Later, he was dumped by an enormous wave as he headed into the shore. He felt a bump on his head and knew he'd get a headache.	PLONT	SCRAF	non-word
63	George was cleaning his car in his front yard. Later, he turned on the tap so he could wash off the soapy residue. He then dried it off with a microfiber cloth.	FROBE	PILSE	non-word
64	Joy rolled the pastry out and cut it into circles. Later, she spooned in the frosting mixture. She hoped she had made enough to give it to all her friends.	KUY	EDEK	non-word
66	Kevin waited impatiently in line outside of the airport as he was keen to get home. Later, as he arrived outside his house, he took out his wallet to pay the driver. He went to the back of the car to get his luggage out.	TAXI	BOOT	word
67	Matt listened carefully at the protest against hunting endangered animals. Later, he was outraged to see a wealthy woman wearing a brand new coat. Wanting to hide his identity, he put dark sunglasses on and pulled his hat down low.	FUR	FACE	word
68	Jack pounded the sticks in a frenzy while the rest of the band thrashed their guitars. Later, after they finished their last song, he threw his sticks into the crowd. He was sweating from the bright lights directed at him.	DRUMS	STAGE	word
69	Ryan went to check on his baby daughter when he smelled something unpleasant. Later, as he washed the soiled fabric, he considered changing to disposables. The baby cried because she wanted to be fed.	BUHP	CIW	non-word
70	Sue was madly in love with her boyfriend. Later, she regretted having his name permanently on her arm. She covered it up by wearing a long-sleeved shirt.	LOIP	KNOF	non-word
71	Amy was feeling full but ordered dessert anyway. Later, she wished she ordered it without the nuts and cherry. She delicately wiped her mouth with the napkin.	HEARF	BOSK	non-word
72	Will pulled on his rubber boots and went outside in the rain. Later, his mother scolded him for jumping in the puddles. She took him inside to dry in front of the heater.	THEV	CIMB	non-word
73	Derek became frightened when out of the corner of his eye he saw a green little man. Later, he was convinced that he had also seen a spaceship. His friend suggested he was overdosing on illicit substances.	ALIEN	DRUGS	word

74	Barry loaded up all the boxes and carefully secured the double back doors. Later, as he was driving along the long, dusty highway, he stopped at a service station for a rest. He saw another driver eating a fruity pastry.	TRUCK	PIE	word
75	Peter the prince was horrified to have been captured by the evil witch. Later, as he made a home in the swamp, he hoped a maiden would give him a kiss. Feeling hungry, he decided to see if he could find something to eat.	FROG	FOOD	word
77	Gavin read the 'for sale' adverts in the paper with great interest. Later, he called one of the numbers to ask how many miles it had. He was sick of always having to take the bus to work.	BREAT	WINT	non-word
78	Jeanette couldn't find a matching pair as she sorted through the washing. Later, she put a blue one on her left foot and a red one on her right foot. She then did her laces up in a double bow.	MULK	TREP	non-word
79	Molly cut all of the fruit up into small pieces and mixed it around. Later, she served the fruit for dessert. She asked if anyone would also like a cup of coffee.	SEILT	YUVEN	non-word
80	Rita wanted breakfast so she put two slices in the toaster. Later, she looked at the loaf and saw that it was moldy. She decided that instead of toast, she would just have cereal.	SNOR	RIRF	non-word
81	Brian cursed when he realized his only good shirt was wrinkled. Later, as he arrived for his date, he was glad that he had taken the time to fix it. Nervously, he checked his mouth in the mirror for anything that was stuck.	IRON	TEETH	word
82	James looked at his wrist and decided he had plenty of time to stop. Later, when he was the last to arrive, he realized the battery must have stopped. Quietly entering the room, he moved forward to find somewhere to sit	WATCH	SEAT	word
83	Jim realized he had made a critical error by not wearing gloves. Later, the police arrested him after finding evidence that he had touched the lock. He asked his lawyer to represent him when he went before the judge.	PRINT	COURT	word
84	Susan got into the shower and turned the hot tap up high. Later, her husband walked into the bathroom and exclaimed that he couldn’t see. She reluctantly turned off the water and dried herself.	STEAM	TOWEL	word
85	Simone prepared the cake and got the lighter ready. Later, as she cut the slices, she realized some wax had dripped on the icing. Instead of using plates, she handed the pieces out on paper plates.	MADOL	VARE	non-word
86	Cameron was worried about his sore teeth and made an appointment. Later, as he sat in the chair, he hoped he wouldn’t need a filling. He realized he had better start to eat less sugar.	JARIL	SNOIL	non-word
87	Richard sat in the dark room and lit some candles. Later, one of the curtains was up in flames. He coughed and sputtered from breathing in the smoke.	SORAP	COATH	non-word
88	Holly poured herself a strong drink with a little bit of ice. Later, as she lay asleep on the couch, her friend asked how much she had drunk. Her friend decided to give her a strong cup of coffee.	BOINS	BEASH	non-word
89	Tommy rode his bike to the deli and left it outside. Later, when he saw that it was gone, he realized he’d forgotten to secure it. He went back inside and asked the shopkeeper to make a call to report it.	LOCK	COPS	word
90	Kelly spent most of the warm summer afternoon magazines in the salon chair. Later, she was pleased when her friend noticed that she was no longer a blonde. Feeling hot and needing some cool air, she reached for the control and changed the setting to high.	DYE	FAN	word
91	Mike was embarrassed when he realized that his wallet was empty. Later, after entering his pin, he passed one of the bills to his friend. Noticing the clouds, he thought they’d better hurry to the car as it was about to pour.	BANK	RAIN	word

93	Marissa was unimpressed when her house wasn't completed in time. Later, the company blamed it on the contractors. She decided that she would switch to a different builder.	BIPLE	POIG	non-word
94	Janine was thrilled when her husband took her on a surprise trip. Later, as she lay sunning herself on the deck, she wondered how long it took to sail between the islands. She shielded her eyes from the glare of the sun.	MAWT	LARN	non-word
95	Dylan cried out as he was digging through the well-known mining site. Later, he knew he was going to be rich from his find. He thought of how he would spend his new-found wealth.	LOAC	HESRE	non-word
96	Matthew picked the tomatoes from the garden just before he started cooking. Later, everyone commented on the delicious pasta. There was plenty left over, which he put into the dish.	KNOGE	BIAR	non-word
97	Tammy was halfway through her piece when she ran out of blue. Later, she returned from the art store and got back to work. She hoped it would look nice hanging above her lounge.	PAINT	WALL	word
98	Kate spread the paste all over the base and then piled on the toppings. Later, she bit into a slice and realized she hated olives. She picked them off and threw them away.	PIZZA	BIN	word
99	Chloe gazed around the jewelry store and excitedly tried several pieces on. Later, as she tried to take the last one off, she realized her finger had swollen. She wondered if she could walk out without setting off the security measures.	RING	ALARM	word
100	Brandon inspected the list and made his choice. Later, the waiter informed him that they had run out of that vintage. He felt like having some red meat, so he ordered the ribeye.	WINE	STEAK	word
101	Carly got her baby dress and got ready to go out. Later, as she pushed her along, one of the wheels stopped working. She picked her baby up and held her in her arm.	VONE	RITOL	non-word
102	Seth was excited about going up to the mountains. Later, he was disappointed when he heard the snow wasn't heavy enough yet to go skiing. His head was feeling cold and so he put on a beanie.	TOORT	HINOY	non-word
103	Greg was worried about his first shift at the hospital. Later, the nurse asked for his opinion and he couldn't answer. He decided to take a break so he could get over his anxiety.	BOLL	WIRM	non-word
104	Kim looked inside her lunchbox and pulled out some fruit. Later, her mom was disgusted to find she'd left a peel in the bottom of her bag. She was grounded for a week and wasn't allowed to watch television.	EIR	AVPOL	non-word
105	Emily was feeling nervous in her expensive dress. Later, after the ceremony, she started to relax and have a good time. After the speech, the guests raised their glasses.	BRIDE	TOAST	word
106	Thomas climbed aboard and smiled nervously at his fellow passengers. Later, when he saw the clouds below him, he wished he had taken the bus. He kept himself busy by watching the romantic comedy.	PLANE	MOVIE	word
107	Eduardo kicked the ball expertly around the defenders and prepared to take the shot. Later, his teammates congratulated him for winning them the game. Sitting in the locker room, he bent down to untie his shoes.	GOAL	LACES	word
108	Jon assured his parents that he would look after the house while they were away. Later, all of his friends drank and danced until the early morning. The next day, he went around picking up the empty cans.	PARTY	BEER	word
109	Darren didn't have enough cash, so he wrote the amount on the slip before signing it. Later, he found out it had bounced as he didn't have sufficient funds in that account. He called the store to pay the bill using his credit card.	CIR	OTEAN	non-word
110	Bethany was excited that it was Valentine's Day when she heard the doorbell. Later, she was pleased by the beautiful scent as she picked up the vase. She was annoyed when she pricked her finger with a thorn.	SNOITE	WASE	non-word

111	Claire hated running outside but wanted to get fit. Later, she got a membership down the road so that she could use their indoor equipment. She also wanted to lift weights in order to build up some muscle.	CUIGE	BOIRD	non-word
112	Lilly tripped over the branch and cut open her leg. Later, she showed the children the white skin that the cut had left. She was glad that she hadn't needed stitches.	LAVER	CRAWN	non-word
113	Trey was playing in the field when he made a great hit. Later, when the owner of the car asked about the cracked windshield, he denied any knowledge of it. He knew he'd be in trouble as he was not meant to have stopped anywhere when walking back from school.	BALL	HOME	word
114	Jessica went into the change room with a tight-fitting dress. Later, she asked the sales assistant if she could help her do it up. She was delighted to find that there were some matching shoes that made her very tall.	ZIP	HEELS	word
116	Patricia sat in the chair as the sales assistant added the finishing touches to her cheeks. Later, when she saw herself in natural light, she was horrified to see two red circles on her face. She quickly went to the bathroom to wash it off.	BLUSH	SOAP	word
117	Michael chewed constantly and enjoyed the fruity flavor. Later, he made a game of trying to blow the biggest bubble. His mother warned him that it might get stuck in his hair.	SNIW	PLOTE	non-word
118	Chelsea scrubbed the pots and pans until they were spotless. Later, she wiped them dry until the fabric was soaked. She put the plates away in the cupboard.	MIRCH	FEX	non-word
119	Kelsey set the table for a formal banquet. Later, she was annoyed to see how filthy the white linen had become after the meal. She filled the basin up to soak it in bleach.	TROCK	BRITH	non-word
120	Jason was chased by the paparazzi into the waiting vehicle. Later, they didn't know which of the identical long black cars he was in. While on the red carpet, he signed autographs for his fans.	FEP	TRET	non-word
121	Jeremy preferred his coffee to be very white and very sweet. Later, his dentist told him he needed fillings in his teeth. He realized that he would need to take the day off work, so he asked if he could get it in writing.	SUGAR	NOTE	word
122	Ed stroked his long white beard as he puffed away in thoughtful silence. Later, as he re-packed the tobacco, he decided that he was too old to give it up now. Sitting in his dark office, he tried to tidy up the papers that were spread out.	PIPE	DESK	word
123	Kerry was bending over in her tight pants. Later, she found a needle and thread to repair the seam. Since her hands were feeling dry, she looked around for the tube.	TEAR	LOTION	word
124	Jennifer brought her puppy home and then checked where the nearest engraver was. Later, she attached the small metal disc to the puppy's collar. When she got home, she put out some water and some biscuits.	TAGS	BOWL	word
129	Alan picked out the matching jacket to wear to the wedding. Later, he felt uncomfortable being so dressed up. He tried to catch the eye of the waiter so he could order another round.	SUIT	DRINK	word
130	Boris hesitated as he looked out the window and noticed the white layer forming. Later, he zipped up his thick jacket and put on his gloves. He went outside and went to check the mailbox.	SNOW	MAIL	word
131	Julia carefully arranged the freshly cut flowers and placed them on the counter. Later, as she was tidying up, and accidental knock sent the glass shattering across the floor. Feeling frustrated, she started to sweep it into the dustpan.	VASE	BROOM	word
137	Andrea woke up early and whipped up a batch of pancakes. Later, just as she finished cooking and was ready to top them, she noticed the bottle was just about empty. She carried the plate across to where everyone was sitting.	SYRUP	TABLE	word

139	Murray drew a diagram to try to explain to his class what the theory meant. Later, he realized that he had chalk all over his hands. Feeling frustrated, he wiped his hands clean on his thighs.	BOARD	PANTS	word
140	Marta really enjoyed riding and was looking forward to going that afternoon. Later, she checked her pockets to see whether she had any sugar cubes left to give as a special treat. She was feeling a little cold, so she buttoned herself up.	HORSE	COAT	word
146	Barbara was spending the afternoon baking and was making quite a mess. Later, as she untied the strings behind her back, she was thankful that her favorite skirt was clean. After baking the break, the counter was covered in white.	APRON	FLOUR	word
147	Daniel heard a bang and saw everyone running in all directions. Later, he heard on the news that someone had been killed. He recalled seeing the tall and heavily built assailant.	GUN	MAN	word
153	Jordan enjoyed a lazy morning sipping a cup of tea and eating eggs on toast. Later, he briefly skim-read over the main headlines to see if anything interested him. He spent the rest of the day planting new seedlings in his veggie garden.	PAPER	PATCH	word
155	Alana was just about to get married and was feeling very nervous. Later, as she walked down, she could barely see due to all the tulle in front of her eyes. She was glad that she made it to the end without tripping over the hem of her gown.	VEIL	DRESS	word

C. Appendix C

Language History Questionnaire
(Daniel, 2009)

Subject # ________

Sex _________ Age _________ Years in English-Speaking Schools _________

(1) What is the FIRST language spoken to you at home by your parents or guardian when you were less than five years old? If your parents/guardian spoke two languages to you, list BOTH languages in the order your learned them (or which language you used most if you learned both at the same time).

(2) List from MOST fluent to LEAST fluent all of the languages that you know or have tried to learn (write on the back of this page if you need more space). Note that the language you learned first is not necessarily the language you now know best. Specify the age at which you began to learn the language (if it is your native language you should specify age as "birth") and where you learned it (e.g., school, home, church).

	Language	Age learned	Location learned (home, school, etc.)
Most fluent	____________________	__________	_________________________
	____________________	__________	_________________________
	____________________	__________	_________________________
Least fluent	____________________	__________	_________________________

(3) Answer the following questions. Complete only those questions that apply to you.
At what age did you begin <u>speaking</u> **English**? __________
At what age did you begin <u>reading</u> **English**? __________
At what age did you begin <u>speaking</u> your most fluent language **OTHER THAN** English? __________
At what age did you begin <u>reading</u> your most fluent language **OTHER THAN** English? __________

(4) Complete the following ratings. If you think you are more proficient in either English or your OTHER language, your ratings should reflect this difference. Answer only those questions that apply to you.

	NOT fluent									VERY fluent
For ENGLISH:										
How fluent are you in <u>speaking</u>?	1	2	3	4	5	6	7	8	9	10
How fluent are you in <u>understanding</u>?	1	2	3	4	5	6	7	8	9	10
How fluent are you in <u>reading</u>?	1	2	3	4	5	6	7	8	9	10
For your most fluent language OTHER THAN English:										
How fluent are you in <u>speaking</u>?	1	2	3	4	5	6	7	8	9	10
How fluent are you in <u>understanding</u>?	1	2	3	4	5	6	7	8	9	10
How fluent are you in <u>reading</u>?	1	2	3	4	5	6	7	8	9	10

D. Appendix D

Vocabulary Test
(Daniel, 2009)

Directions: Choose the BEST definition for each word.

1. ASCEND
A. to go up or mount
B. consent
C. improve with time
D. to leave behind
E. to replace a leader

2. WARY
A. tired out
B. rude; uncouth
C. perturbed
D. brand-new
E. cautious; careful

3. INFINITESIMAL
A. very long
B. very slow
C. well defined
D. uncompromising
E. very small

4. INDIFFERENT
A. similar
B. unconcerned
C. diffident
D. solicitous
E. opposite

5. VERBOSE
A. slow
B. impressive
C. complicated
D. wordy
E. meaningless

6. OPAQUE
A. transparent
B. slippery
C. impenetrable by light
D. gem-like
E. financially well-off

7. SYNTHESIS
A. musical rendition of a written work
B. a theory of immoral behavior
C. the combination of parts to form a whole
D. watching or guarding
E. properties of artificial chemicals

8. SPONTANEITY
A. unwanted laughter
B. uncontrollable danger
C. unplanned action
D. unneeded socialism
E. stand-up attitude

9. VALIDATE
A. to prove
B. to get paid back
C. to expire
D. to run away
E. to complete successfully

10. MEAGER
A. not full, inadequate
B. to beg
C. without self-respect
D. in good shape, healthy
E. wise, full of advice

11. ECLECTIC
A. providential
B. of religious origins
C. purified
D. out of fashion
E. from various sources

12. IMPLAUSIBLE
A. could happen at any moment
B. not believable
C. unyielding
D. considered tactless
E. to serve or worship

13. INCONTROVERTIBLE
A. useless
B. prone to trouble making
C. indisputable
D. successful
E. unprotected

14. DISPERSE
A. to seize one's assets
B. to live in exile
C. to break up and scatter
D. to weaken connections
E. to make vacant

15. AUTONOMOUS
A. unknown identity
B. having many names
C. uncontrollable
D. independent existence
E. self-confidence

E. Appendix E

TCDS Screening Questionnaire
(Thair, et al., 2017)

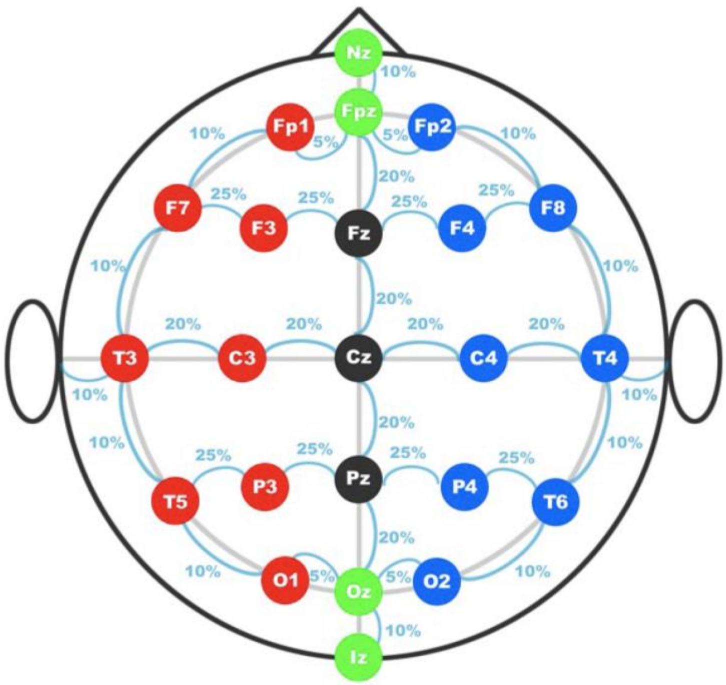
It is important that you answer all of the following questions truthfully. If any of the questions/terms on this form are unclear, or if you are unsure how to answer them, please do not hesitate to ask the researcher of the study.

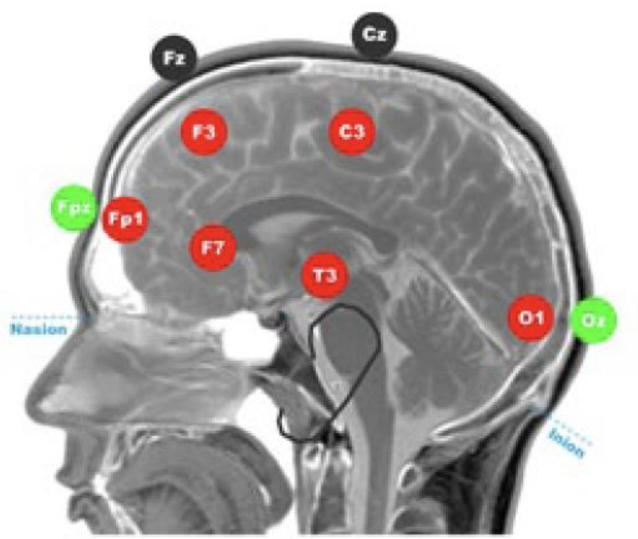
	Yes	**No**
Have you ever had a seizure?		
Have you ever had a head injury resulting in a loss of consciousness that has required further investigation (including neurosurgery)?		
Do you suffer from migraines?		
Do you currently have a medical diagnosis of a psychological or neurological condition?		
Do you have any metal in your head (outside of the mouth) such as shrapnel or surgical clips?		
Do you have any implanted devices (e.g., cardiac pacemaker, brain stimulator)?		
Do you have a skin condition on your scalp that may have resulted in cuts or abrasions? (e.g., psoriasis)		
Do you have a head wound that has not completely healed?		
Have you ever had an adverse reaction to tDCS, or any other brain stimulation technique (e.g., TMS, tRNS)?		
For female participants: Is there the possibility that you might be pregnant?		

F. Appendix F

10/20 System Positioning Diagrams

Electrodes were applied to the T3 (left hemisphere) and T4 (right hemisphere) areas in the present study. Diagrams are from Trans Cranial Technologies





G. Appendix G

Pre- and Post-tDCS Questionnaire

This questionnaire will be filled in before and after receiving tDCS. Please enter a value from 1-10, ranging from absent to severe, in the ‘Rating’ space below in response to the question: “Do any of these statements currently apply to you?” It is important that you answer all questions truthfully.

Absent									**Severe**
1	2	3	4	5	6	7	8	9	10

Do any of these statements currently apply to you?	Rating		Notes
	Before tDCS	**After** tDCS	
1. Headache			
2. Neck pain			
3. Back pain			
4. Blurred vision			
5. Scalp irritation			
6. Tingling			
7. Itching			
8. Increased heart rate			
9. Burning sensation			
10. Hot flush			
11. Dizziness			
12. Acute mood change			
13. Fatigue			
14. Anxiety			

H. Appendix H

Comfort Scales

1. *<u>Please rate your discomfort on the scale:</u>*

1 2 3 4 5 6 7

Comfortable Uncomfortable

2. *<u>Please rate your discomfort on the scale:</u>*

1 2 3 4 5 6 7

Comfortable Uncomfortable

3. *<u>Please rate your discomfort on the scale:</u>*

1 2 3 4 5 6 7

Comfortable Uncomfortable

4. *<u>Please rate your discomfort on the scale:</u>*

1 2 3 4 5 6 7

Comfortable Uncomfortable

5. *<u>Please rate your discomfort on the scale:</u>*

1 2 3 4 5 6 7

Comfortable Uncomfortable

6. *<u>Please rate your discomfort on the scale:</u>*

1 2 3 4 5 6 7

Comfortable Uncomfortable

<u>Condition Guess</u>

<u>Can you guess whether you were in the active (real) or sham (fake) stimulation condition?</u>

Active Sham

VII. HUMAN SUBJECTS COMMITTEE PROTOCOL APPROVAL

This research was approved by the University of Illinois Human Subjects Institutional Review Board under protocol 2019-0770.

VIII. VITA

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EDUCATION:	Ph.D., Cognitive Psychology, University of Illinois at Chicago, Chicago, Illinois, 2021	
	M.A., Cognitive Psychology, University of Illinois at Chicago, Chicago, Illinois 2017	
	B.S., Psychology, DePaul University, Chicago, Illinois, 2013	
AWARDS:	2020	Psychonomic Society Graduate Conference Award
	2019	UIC Dean's Scholar Fellowship ($25,000 to Support Dissertation Research)
	2019	UIC Jamie Carter Award
	2017	Society for Computers in Psychology (SCiP) Birnbaum Scholarship
	2017	Michael J. Piorkowski Award for Excellence in Cognitive/Biopsychology
	2016	UIC Provost Award for Graduate Research ($1,799 to Support Thesis Research)
	2016	APA Anne Anastasi General Psychology Graduate Student Award
	2016	American Psychology Foundation (APF) and the Council of Graduate Departments of Psychology (COGDOP) Fellowship Nominee
	2012	DePaul University Undergraduate Research Assistantship Program Award
EXPERIENCE:	2014 - 2021	Graduate Research Assistant UIC Language Research Laboratory Principle Investigator: Gary E. Raney, Ph.D.
	Summer 2019	Temporary Data Coordinator MAPSCorps
	2014	Research Project Coordinator Northwestern Clinical and Translational Sciences Institute
	2013 – 2014	Research Assistant, Research Coordinator DePaul University Better Outcomes for Neurodevelopment Laboratory Principle Investigator: Cecilia Martinez-Torteya, Ph.D.

2012 – 2014	Research Assistant, Lab Manager DePaul University Brain and Language Laboratory Principle Investigator: Sandra Virtue, Ph.D.
2012	Research Support DePaul University Cities Project Principle Investigator: Kathryn Grant, Ph.D.
2012	Research Assistant DePaul University Chronic Fatigue Syndrome Laboratory Principle Investigator: Leonard Jason, Ph.D.

PUBLICATIONS:

Christofalos, A. L., Raney, G. E., Daniel, F., and Demos, A. P. (2020) Titles support the development of coherent situation models. *Journal of Research in Reading,* 43: 417– 433. https://doi.org/10.1111/1467-9817.12315.

Christofalos, A.L., Pambuccian, F. S., & Raney, G.E. (Under Review, Journal of Cognitive Psychology). Too depleted to comprehend: resource depletion impairs situation model comprehension.

Christofalos, A.L., & Raney, G.E. (In Preparation). Comparing paper-based and computerized letter-detection tasks.

Miller, K.A., Christofalos, A.L., Pambuccian, F. S., & Raney, G.E. (In Preparation). The effect of word frequency on idiom comprehension changes as a function of idiom familiarity.

E-BOOK CHAPTERS:

Christofalos, A.L. (2017). Between-Subjects ANOVAs in R. In Demos, A. & Salas, C. (Eds.), *A Language, not a Letter: Learning Statistics in R (Chapter 15).* Available at: https://ademos.people.uic.edu/Chapter20.html

CONFERENCE PRESENTATIONS:

Christofalos, A.L., Pambuccian, F. S., & Raney, G.E. (April 2021). *Resource Depletion Impairs Situation Model Comprehension.* Poster Presented at the Virtual Midwestern Psychological Association Conference.

Li, A., Christofalos, A.L., & Raney, G.E. (April 2021). *The Effects of Emotional Priming on Reading Comprehension.* Poster Presented at the Virtual Midwestern Psychological Association Conference.

Christofalos, A.L., & Raney, G.E. (November 2020). *Facilitating Right Hemisphere Integration Processes: A tDCS Study.* Poster presented at the Virtual Psychonomic Society Conference.

Christofalos, A.L., & Raney, G.E. (November 2019). *My Title is Up Here: The Effect of Title Position on Situation Model Comprehension.* Poster presented at Psychonomic Society Conference, Montreal, Quebec, Canada.

Christofalos, A.L. (March 2019). *It's All Right: The Right Hemisphere's Role in Language Comprehension*. Talk given at Wonder & Skepticism, Chicago, Illinois.

Raney, G.E., Campbell, S.J., Riaño Rincon, C., Miller, K., Christofalos, A.L. *Spanish-English Bilinguals Perceive Less-Familiar English Metaphors as Being More Familiar Than Do English-Spanish Bilinguals and English-Speaking Non-Bilinguals*. (November 2018). Talk given at Psychonomic Society Conference, New Orleans, Louisiana.

Christofalos, A.L., & Raney, G.E. (November 2018). *This Presentation is Not a Sedative! The Right Hemisphere Activates Salient and Non-salient Meanings of Low Familiarity Metaphors*. Poster presented at Psychonomic Society Conference, New Orleans, Louisiana.

Savchuk, S., Christofalos, A.L., Raney, G.E. (October 2018). *The Bilingual Advantage: Does it Exist?* Poster presented at the University of Illinois at Chicago Bilingualism Forum.

Christofalos, A.L., Raney, G.E. (November 2017). *Computerized Letter Detection Tasks Are Not Worth the Effort.* Talk given at the Meeting of the Society for Computers in Psychology Conference, Vancouver, British Columbia, Canada.

Christofalos, A.L., & Raney, G.E. (November 2017). *Hemispheric Processing of High and Low Familiarity Metaphors*. Poster presented at Psychonomic Society Conference, Vancouver, British Columbia, Canada.

Christofalos, A.L., & Raney, G.E. (August 2017). *Normed Metaphors with Figurative and Literal Targets.* Poster presented at Society for Text and Discourse Conference, Philadelphia, Pennsylvania.

Christofalos, A.L., & Raney, G.E. (November 2016). *Evaluating Text Difficulty using a Computerized Letter Detection Task*. Poster presented at Psychonomic Society Conference, Boston, Massachusetts.

Raney, G. E., Christofalos, A.L., Pambuccian, F.S., & Bovee, J. C. (July 2016). *Using Letter Detection to Explore High-Level Text Processing.* In Roy-Charland, Annie (Chair). The Missing Letter Effect: History, Models and Current Avenues.

Symposium presentation at the meeting of the Canadian Society for Brain, Behavioral, and Cognitive Sciences, Ottawa, CA.

Christofalos, A.L., & Raney, G.E. (August 2016). *Evaluating the Influence of Text Difficulty on Word Processing.* Poster presented at Society for Text and Discourse Conference, Kassel, Germany.

Christofalos, A.L., & Raney, G.E. (May 2016). *Evaluating the Influence of Text Difficulty on Word Processing*. Poster presented at Midwestern Psychological Association Conference, Chicago, Illinois.

Christofalos, A.L., & Virtue, S. (May 2013). *Hemispheric Processing of Puns*. Poster presented at DePaul University's 18th Annual Psychology Night, Chicago, Illinois.

Christofalos, A.L., Figge, C., Martinez-Torteya, C. (November 2013). *An Examination of Intimate Partner Violence during Pregnancy and Perinatal Health Outcomes*. Poster presented at DePaul University's 11th Annual Science, Mathematics, and Technology Showcase, Chicago, Illinois.

Christofalos, A.L., Cordell, S., Virtue, S. (May 2012). *The Effects of Nicotine on Hemispheric Lateralization of Language*. Poster presented at DePaul University's 17th Annual Psychology Night, Chicago, Illinois.

DEPARTMENTAL TALKS:

Christofalos, A.L. *Semantic Integration in the Right Hemisphere* (March 2021). To be presented at the Department of Psychology Current Topics in Cognitive Psychology Seminar.

Christofalos, A.L. *Hemispheric Sensitivity to Context During Lexical Ambiguity Resolution*. (March 2019). Presented at the Department of Psychology Current Topics in Cognitive Psychology Seminar.

Christofalos, A. L. *The Role of the Right Hemisphere in Language Processing.* (November 2017). Presented at the Department of Psychology Current Topics in Behavioral Neuroscience Seminar.

Raney, G. E., Christofalos, A, L., Miller, K. A., Pambuccian, F. S., & Riaño, C. E. *Figurative Language Research at UIC*. (October, 2017). Colloquium given at the DePaul University Psychology Department.

Christofalos, A.L. *Hemispheric Processing of High and Low Familiarity Metaphors.* (May 2017). Presented at the Department of Psychology Current Topics in Cognitive Psychology Seminar.

Christofalos, A.L. *Letter Detection Beyond the Word Level: Evaluating Text Difficulty.* (May 2014). Presented at the Department of Psychology Current Topics in Cognitive Psychology Seminar.

TEACHING:

University of Illinois at Chicago, Department of Psychology

Instructor

Cognition and Memory (PSCH 352), Summer 2020

Introduction to Research Methods in Psychology (PSCH 242), Spring 2019

Teaching Assistant

Behavioral Neuroscience (PSCH 262), Summer 2018, Spring 2020

Introduction to Research Methods in Psychology (PSCH 242), Fall 2014, Spring 2015, Summer 2015, Summer 2016, Fall 2016, Summer 2017, Fall 2018, Fall 2020, Spring 2021

Cognition and Memory (PSCH 352), Fall 2020, Spring 2021, Summer 2021

Laboratory in Cognition and Memory (PSCH 353), Fall 2015, Spring 2016, Fall 2017

Laboratory in Cognitive Neuroscience, (PSCH 367), Spring 2018

Social Psychology, (PSCH 312), Spring 2015

Guest Lecturer

Behavioral Neuroscience (PSCH 262), Summer 2018, Topic: Brain Asymmetry, Spatial Cognition, and Language

UNDERGRADUATE MENTORSHIP:

Anna Li, Spring 2019 – Spring 2021, Honor's Capstone: *The Effects of Emotional Priming on Reading Comprehension*

Sol Savchuk, Fall 2016 – Spring 2018, Honor's Capstone: *Effects of Bilingualism and Musicianship on Lateralization and Executive Control*

Magdalena Krolak, Fall 2016 – Spring 2017, Nancy Herschberg Memorial Grant for Undergraduate Research, Project Title: *Implicit Processing of Gender Stereotypes*

SERVICE:

Ad-Hoc Reviewer, *Journal of Cognitive Psychology*, 2020
Psi Chi Conference Submission Reviewer, *Midwestern Psychological Association*, 2017 – Present
Book Buddy Volunteer, *SitStayRead Literacy Nonprofit Inc*., 2017 – 2018
Graduate Student Program Assistant, *UIC Psychology Cognitive Program*, 2016 – 2017
Alumni Speaker, *DePaul University College of Science and Health Honors Banquet*, 2015
Founder and President, *DePaul University Psychology Peer Mentor Organization*, 2013
Pre-Health Volunteer, *Advocate Illinois Masonic Medical Center*, 2012