The Impact of Audiovisual Speech on Working Memory During Semantic Processing

Max Hebert

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By: Max Hebert

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Signed by the final Examining Committee:

______________________________ Chair: Dr. Wayne Brake

______________________________ Examiner: Dr. Krista Byers-Heinlein

______________________________ Examiner: Dr. Roberto de Almeida

______________________________ Supervisor: Dr. Natalie Phillips

Approved by ____

Dr.Jean-Roch Laurence, Chair of Department or Dr. Wayne Brake, Graduate Program Director

___________ 2013 ______________________________________

Dean of Faculty of Arts and Science: Dr. Joanne Locke

Abstract

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The current study investigated the relation between the bottom-up mechanism of audiovisual speech perception and top-down mechanism of semantic integration, with specific attention paid to working memory (WM). Event-related potentials (ERPs) were recorded from 28 younger adult participants to determine if the neurophysiological reaction to semantic language information (or the absence of it) could be modified by presenting speech in an audiovisual modality or in the auditory modality alone, with the prediction being that audiovisual speech would provide a benefit to processing sentences with an absence of semantic information. The N400 ERP component, a neural indicator of the effortful processing of semantic content, was observed to determine this reaction. Initial analyses did not reveal an interaction between speech modality and degree of semantic content, but a subsequent grouping of participants based upon individual WM capacity yielded significant results. In the auditory modality it was found that while participants with a high WM capacity were able to utilize semantic content to reduce the N400 amplitude, low WM participants had a higher amplitude N400 for both low-constraint for acceptance (LC) and high constraint for acceptance (HC) sentences, indicating significant processing demands. Conversely in the audiovisual modality, low WM participants displayed a reduction in N400 amplitude similar to high WM participants for HC sentences, indicating that the addition of visual speech cues assisted in maintaining the semantic content. The results are discussed with regards to implications for maintaining face-to-face communication, particularly for those individuals with lower WM capacities.

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The Impact of Audiovisual Speech on Working Memory During Semantic Processing

The typical presentation of speech (i.e. face-to-face conversation) provides listeners with the benefit of auditory and visual speech cues. Presenting these speech cues provides a benefit to speech perception and comprehension, known as the audiovisual enhancement (AV) effect, but the exact nature of this benefit has not been fully explored. While there are demonstrated benefits for the AV enhancement effect in challenging communication environments such as situations with significant background noise, various other forms of language communication pose unique challenges that may be alleviated by AV speech. One form of potentially challenging communication involves semantic content analysis and integration, the concept of anticipating (or being unable to anticipate) the content of a sentence or story based on earlier contextual information. Generally speaking, sentences that provide context and allow prediction as to how a sentence will conclude are easier to process, requiring fewer cognitive resources then sentences where certain words or concepts may be entirely unanticipated given the preceding information (D'Arcy, Service, Connolly & Hawco, 2005; Salisbury, 2004). The potential for a relationship between these harder to process low context sentences and the benefits to comprehension afforded by AV speech was explored in this thesis to determine the extent of the AV enhancement effect in semantic processing.

The challenges posed by unpredictable semantic content have often been investigated through neuroimaging techniques such as event-related potential (ERP) analysis. The benefit of this technique is that it allows a temporally precise observation of electrical activity directly following the presentation of targeted language stimuli. The ability to observe electrophysiological changes in the brain in the milliseconds (ms) following stimulus onset allows an effective comparison of speech modalities and has been used readily to investigate various ERP components (consistently evoked negative or positive electrical shifts at specific time periods following stimulus presentation) reflective of speech processing. Specifically in regards to speech, ERP analysis allows the direct observation of how responses to a given stimulus change over very small periods of time. After perceiving a specific stimulus many ERP components of interest occur in less than one second, requiring such a specific neuroimaging technique. Furthermore the high temporal resolution allows comparison of minute variations in latency, the time post-stimulus that a given event occurs. Comparing latency between stimuli types can provide valuable data on processing speed.

Before delving into ERP research as it specifically relates to speech and language, a general review is required. ERP analysis is derived from electroencephalogram (EEG) analysis whereby electrodes attached to the scalp can measure voltage variations in the +/- 100 microvolt (μV) range (Rugg & Coles, 1995). EEG measurement is continuous but specifically defining a time window to observe the EEG results following a specific stimulus presentation yields what is known as an ERP. Through the repeated observation of ERPs in response to specific stimuli (e.g., audiovisual speech) ERP components can be identified, patterns of activation that are uniquely elicited with certain stimuli. For example, the N1 ERP component involves a negative shift voltage typically at the 100ms post-stimulus and is concerned with the processing of auditory information. The P300 on the other hand is a positive voltage shift at the 300ms range typically elicited in circumstances requiring a participant to categorize a presented stimulus into one of two classes. These and other ERP components present three unique dependent variables:

amplitude, latency and topography. Amplitude concerns the specific voltage of the ERP component, latency concerns the onset of the component as compared to the onset of the eliciting stimuli, and topography concerns the distribution of electrical activity across the scalp. Together these variables allow a comparison of stimuli responses at the neural level with implications for cognitive variables such as working memory.

Among the many ERP components is the N400 (a broad negativity shift occurring around 400ms following stimulus onset), which has been consistently linked with the processing of semantic content (Kutas & Hillyard, 1980). The current study utilized ERPs to specifically examine the N400 effect in regards to the AV speech processing of semantic content. One of the seminal research papers to establish the role of the N400 in semantic processing was published by Kutas and Hillyard in 1980. Their initial research involved presenting participants stimuli consisting of sentences that were manipulated either for unanticipated physical characteristics (increased letter size of the terminal word) or unanticipated semantic incongruity (modifying the terminal word to be unusual or anomalous given the preceding context). In the congruity example the sentence “he took a sip from the cup” could be manipulated to a moderate level of incongruity with “he took a sip from the waterfall” or a strong level of incongruity with “he took a sip from the transmitter.” When participants were presented with these semantically incongruent stimuli in an ERP study a late negative wave of electrical activity occurring around the 400ms time frame was determined. They theorized that this negative wave might be a reflection of participants’ processing this unanticipated terminal word given the preceding context. As a result the N400 was proposed as an electrophysiological indictor of semantic processing, an early theory that has persisted into current research.

Previous studies have reliably demonstrated the N400 in a variety of language stimuli manipulating semantic content. A review paper from Lau, Phillips and Poeppel (2008) outlined two paradigms that have been found to modulate the size of the N400 response: the semantic-priming and semantic-anomaly paradigms. The semantic-priming paradigm involves the presentation of either a related or unrelated word before a target word (e.g.,“coffee-tea” or “chair-tea”). The semantic-anomaly paradigm involves presenting a terminal word that is congruous or incongruous with the preceding language information (e.g., “I like my coffee with cream and sugar/socks”). While both manipulations elicit N400 components with similar latencies and scalp distributions, the magnitude of the effect has been found to be larger in sentence-based stimuli (Kutas, 1993). Despite these magnitude differences both paradigms have ultimately been determined to reflect the same component of semantic processing, simply varying in the degree of resources required (Lau et al., 2008).

Early research on the semantic-anomaly paradigm subject sought to determine the precise nature of the stimuli that commonly elicited the N400 (Kutas & Hillyard, 1983). As it was indicated that the previous study demonstrated the presence of the N400 component during word-by-word reading but it has also been proposed as a speech processing ERP component, clarification is required. In this regard, Kutas, Neville and Holcomb (1987) conducted further research on the N400 response across reading, listening and signing communication mediums. Through the presentation of typical semantic anomalous content to either normal hearing range or deaf participants in the case of signing, it was found that the N400 effect consistently presented as a centropaterietal negative activity in the 350 to 500ms range across communication mediums. It was interestingly found that the N400 has a consistently earlier presentation in the auditory modality as compared to reading and signing. It was proposed that the auditory modality allows some capacity to predict the semantically anomalous word briefly based upon the pronunciation of the word directly preceding it (i.e., coarticulation), a small but noticeable benefit that reading and signing do not provide. Despite this small variation, these findings further cement the N400 as a reliable indicator of semantic speech processing rather than restricted only to reading-based communication mediums.

Willems, Ozyürek and Hagoort (2008) sought to determine differences in the N400 elicited from the integration of linguistic stimuli (specifically speech-based auditory stimuli) and non-linguistic stimuli (specifically pictures of objects). To accomplish this they constructed sentences that either contained a predictable noun (e.g., The man give his wife a nice *flower* that evening) or a less predictable noun (e.g., The man gave his wife a nice cherry that evening). These sentences were presented alongside a particular picture, with the picture providing contextual anticipation. For example, a participant could be presented the sentence “The man gave his wife a nice *flower* that evening” while also being shown a picture of a flower or a cherry. The results of their manipulation were four sentence types, correct sentences, sentences with a language mismatch, sentences with a picture mismatch, or sentences with a double mismatch. Willems et al. (2008) determined highly consistent N400 effects for all of the conditions as compared to the correct sentence condition, also noting that in the double mismatch condition N400 effects had not interacted to yield a higher N400 effect compared to the isolated language or picture mismatch conditions. This study ultimately argues that N400 effects elicited from either speech or picture-based stimuli present similarly and are therefore comparable in terms of their reaction to semantic language information.

Recent research has sought to determine if the N400 could be demonstrated as a reaction to not only semantic manipulations in auditory speech but also phonological manipulations. Perrin and Garcia-Larrea (2003) conducted a study to compare the N400 effects elicited from typical semantically congruent/incongruent priming stimuli to the effects of phonologically related (rhyming) on unrelated (non-rhyming) auditory stimuli. In their experiment participants were presented with a priming task that contained a word pairing that was either semantically and phonologically related (e.g., *animal-cheval (French for horse)),* semantically unrelated but phonologically related *(e.g., animal-fiscal),* semantically related but phonologically unrelated *(e.g., animal-brebis*) or semantically and phonologically unrelated *(e.g., animal-judge).* It was interestingly found that while a reliable N400 effect was found when the pairing presented a semantically unrelated (and therefore unanticipated) word, an N400 reaction for phonological unrelated stimuli could only be elicited when participants were specifically instructed to monitor for them (N400 effects for semantic language stimuli occurred even without prompting). This research demonstrates the robust N400 effect that can be elicited by auditory stimuli manipulated for degree of semantic context.

Van Berkum, Hagoort and Brown (1999) conducted a study examining the variations in magnitude of the N400 that could be elicited depending on the degree of contextual information provided. In this regard they conducted an ERP experiment that presented participants either sentences or entire stories (discourses) that reinforced certain contextual expectations. These sentences were presented as a combination of auditory stimuli for the initial sentences that provided context and visual text-based stimuli for the final sentence being tested. At the end of either the discourse or individual sentence a congruous or incongruous sentence was presented. For example, in a story that described the brother of Jane as very quick, the final sentence would indicate "Jane told the brother that he was exceptionally *slow*." They determined that in the discourse stimuli N400 effects were greater in magnitude and earlier in latency while maintaining the same basic morphology and scalp distribution of the typical N400 effect. The researchers therefore argued that the integration of new information with overall semantic context is not limited to the sentence-only level but generally a reflection of overall contextual evidence.

In a review paper from Kutas & Federmeier (2011) published thirty years after the initial research of the N400, the authors highlight the role of auditory linguistic stimuli in N400 research. They highlight how N400 effects elicited by auditory stimuli tend to begin earlier, last longer and have a generally more frontal distribution compared to the N400 effects elicited from visual-based stimuli. Despite these variations they affirm that the N400 elicited form auditory language is representative of the general N400 component, affirming its use in the current study as a reliable indicator of semantically manipulated speech-based stimuli.

Importantly the N400 has not only reliably been found within the context of outright semantic-anomalies but also in sentences that provide limited contextual information to allow anticipation of the terminal word. Research has previously demonstrate that when participants are presented sentences with neutral contextual information that does not allow effective anticipation (known as "low constraint for acceptance" sentences, i.e. "He wants to talk about the risk") as compared to sentences with relevant contextual information (known as "high constraint for acceptance" sentences, i.e. "His plan meant taking a big risk") that N400 differences are elicited despite the absence of an outright semantic incongruity (Connolly, Phillips, Stewart & Brake, 1992). Specifically, low constraint sentences, based on stimuli from the Speech Perception in Noise test (Kalikow, Stevens & Elliott, 1977), elicited a greater N400 component compared to high constraint sentences (Connolly et al., 1992). This N400 therefore reflects how the absence of available contextual information resulted in the inability to anticipate the terminal word of the low constraint sentences. Without this contextual information there is no ability to filter out the array of possibilities any given sentence can terminate with, resulting in a significant difficulty in ultimately integrating the final word with the preceding sentence information.

With the N400 established as a reliable electrophysiological indicator of the processing of both incongruous and unanticipated semantic content, it is necessary to review the role of the N400 in the overall process of semantic integration. This relationship involves the understanding that the N400 does not merely reflect the identification of unusual or challenging sentence content, but rather it is an indicator of the cognitive resources utilized to integrate new information with the existing contextual information already accumulated (Lau et al., 2008). This view is in contrast to the lexical-level view of the N400 which argues that the negative activity is not due to integration but rather due to the fact that predictable words are easier to recall from memory than non-predictable words and so the context provided simply regulates this level of predictability. The integration view of the N400 also affirms that N400 eliciting words need not be necessarily anomalous, simply unanticipated given the preceding context of the information presented.

Semantic integration draws upon cognitive resources in order to allow the resolution of unanticipated language information with preceding sentence context (D'Arcy et al., 2005; Salisbury, 2004). These cognitive resources are more commonly understood as working memory (WM) resources, without which the process of semantic integration would be unachievable. These WM resources are required to activate existing networks of information based upon incoming semantic content, allowing anticipation of upcoming information and ultimately the integration of these predictions with what is actually presented. Without WM an individual cannot hold their preexisting semantic knowledge in memory and recognize the patterns inherent to language content. Further understanding is therefore necessary on the role of WM within speech perception and recognition and semantic integration. WM resources are required for a number of language tasks including semantic content analysis and integration (Just & Carpenter, 1992). In environments where comprehending speech is challenging (e.g. large social gatherings with loud music) those resources can become strained in an attempt to properly integrate and comprehend the available information. In situations involving more challenging speech WM resources are utilized to maintain the semantic information presented and the relevant anticipations associated with this information over longer periods of time until it can be resolved. Significant discussion has therefore centered on the precise relationship between language mechanisms such as semantic processing and the degree of WM involvement in terms of maintaining attention and extending the minimum processing time.

Salisbury (2004) attempted to explore the relationship between semantic integration and verbal working memory through utilizing neuropsychological tests indicative of WM capacity and determining differences in N400 amplitudes to homographs vs. unambiguous congruent words. Thirty English-speaking subjects were presented with sentences visually that utilized four specific nouns manipulating them for semantic interpretation. These were either unambiguous (e.g., “the door was shut”), containing a dominant homograph (e.g., “the panel was oak”), a subordinate homograph (e.g., “the panel was voting”) or completely nonsensical (e.g., “the radio was fluffy”). The subordinate homograph and nonsensical sentences were both expected to elicit an N400 effect, with the former doing so due to the activation of the more anticipated (i.e., the dominant homograph) interpretation of “panel,” requiring the WM resources to go back and revise the original semantic activation. To assess WM resources WAIS-III symbol-digit coding and Trails B tests were administered (Wechsler, 1997). This represents a significant limitation as both of these measures are not utilized as measures of WM but rather reflect processing speed. In light of this the implications for any findings relating WM capacity to N400 activity must be understood as not accurately reflecting WM but instead an unrelated cognitive process. The current study will utilize more established measures of WM activity in order to accurately determine the implications for varying WM performance on N400 activity.

ERP analysis in this study revealed characteristic N400 effects for the subordinate homograph endings and the incongruous sentences. The interesting finding, however, involved the relationship between these N400 findings and the WM capacity of participants. Salisbury (2004) determined a significant association in which the N400 effect elicited from the subordinate homographs were greatest in participants who demonstrated a greater working memory capacity and by extension a greater degree of resources to integrate the unanticipated semantic meaning of the target noun with the context of the sentence. These findings are proposed to support the role of the N400 as a reflection of a top-down verbal working memory mechanism. Interestingly Salisbury (2004) comments that the increased N400 amplitudes are unanticipated as it would be expected that individuals with a greater WM capacity would be more efficient in the semantic integration of the subordinate homograph sentences, requiring fewer cognitive resources and by extension a reduced N400 amplitude. The current project instead utilized this finding as encouraging, a reflection that when WM resources are available they will be distributed as needed to semantic integration, resulting in higher N400 amplitudes.

D'Arcy et al. (2005) similarly investigated the effect of increased working memory load on elicitations of the N400. In their study 16 university students were presented text-based sentence pairs wherein the terminal word either was congruent or incongruent with the preceding word. The word pairs were presented in a novel way in order to additionally tax WM resources. Two levels of WM load were tested based around manipulations in priming. In the first WM load, participants were presented with a priming sentence that would provide context for the terminal word in a subsequent sentence (e.g. first sentence: "The woman is riding on the underground train," second sentence: "The woman is in the subway (congruous)/church (incongruous)"). In the second WM load, participants were presented two priming sentences that contained conflicting information before being provided the terminal word sentence that could provide a terminal word congruous with either of the two priming sentences or an entirely unanticipated third word (e.g. first sentence: “the boy is sitting on the witness stand,” second sentence: “the boy is standing at the grave,” third sentence: “the boy is in the courtroom (congruous) / laboratory (incongruous) / cemetery (congruous)”). The second WM load task was specifically designed to create a greater demand on WM resources by requiring the maintenance of two different sets of contextual information allowing for two different semantic activation networks to be online simultaneously.

D’Arcy et al. (2005) collected behavioral data on reaction times (RTs) to the presented stimulus in addition to ERP data of N400 effects. The reaction times were specifically measured on participants’ ability to identify the terminal word of the last sentence as congruous or incongruous with the preceding sentences. Participants also had their WM capacity measured through the Digit Span (Forward and Backward) test of the Wechsler Memory Scale-Revised (WMS-R; Wechsler, 1987). Regarding the RT data, the anticipated effect was observed wherein the second working memory load manipulation yielded slower reaction times than the first working memory load. RT was also slower for incongruous language content. It was further found that participants with identified lower WM capacities experienced a much higher increase in RT from the first to the second working memory load as compared to participants with a high working memory capacity. Regarding the N400 findings it was found that the second working memory load task reduced the congruency effect of the stimulus, resulting in a decrease in amplitude of the N400 component. A 50ms delay in the onset of the N400 was also determined. It was proposed that the increased WM load introduced an overload in semantic activation and by extension delayed the process of semantic integration. It was interestingly noted that variations in the amplitude of the N400 were only specifically observed in the congruent condition, which is unanticipated as the processing of semantic incongruency should tax WM resources and result in a higher amplitude ERP component. This finding significantly opposes the traditional view that incongruent semantic content demands additional cognitive resources and instead indicates that anticipated semantic content may have been the more challenging to process. One explanation of this finding is that the task required participants to maintain two semantically appropriate activations simultaneously; producing a reduced N400 component as compared to studies only presenting one anticipated semantic language stimuli. Aside from this unexpected result, these findings corroborate other studies, which have demonstrated the link between semantic processing and WM resources. Specifically, in instances where attention was diverted to unrelated tasks or where the semantic processing task was specifically manipulated to be more challenging, semantic integration was delayed or suppressed in some capacity. This conclusion allows for the possibility of investigating if other cognitive mechanisms known to free up WM resources might therefore be able to yield a performance boost in the semantic integration process.

Research findings on the link between semantic processing and WM has ultimately suggested a two-stage model that accounts for the integration of semantic activation and the maintenance provided by WM, also referred to more specifically as verbal working memory. Verbal working memory governs the ability to process large amount of verbal information concurrently, as opposed to other components such as visuospatial working memory which concerns the processing of visual and spatial stimuli (Firtel, 2011; King & Just, 1991). In this two-stage model it is indicated that when language information is presented that provides contextual information (be it a single word or a short sentence) an automatic spread of activation occurs (Collins and Loftus, 1974). For example, when the word “red” is processed associations such as “fire” and “orange” are activated. These activations together form a rapidly activated network of anticipations that are required for the semantic integration paradigms of semantic-priming and semantic-anomalous language communication mentioned earlier. It is important to note that this model of semantic activation is not itself verbal WM, rather verbal WM comes into play maintaining the initial semantic activation, providing the necessary mental resources to maintain activation over time.

Verbal working memory plays an important role due to the relatively short duration of this initial spread-of-activation without effortful maintenance. Hagoort (1993) conducted a study involving aphasic patients with specific deficits in verbal working memory. In a semantic priming manipulation he presented participants with three words as auditory stimuli that were either ambiguous or semantically congruous, varying the interval between the words to be either 100, 500 or 1250ms. This interval manipulation was selected as 500ms has been proposed as the window for automatic priming activation. After this time period any priming activation must be maintained with effort and WM involvement. Hagoort (1993) determined that in the 1250ms interval condition aphasic participants who previously had shown expected semantic-priming reactions suddenly failed to show the anticipated semantic associations (Hagoort, 1993). The proposed mechanism that allows the average individual to maintain semantic associations past 500ms semantic priming activation window is verbal working memory. This transition from the bottom-up process of automatic priming activation to the top-down processes of controlled semantic priming activation via verbal WM involvement is essential, as initially all available associations to a target word are activated. It is only when the top-down verbal WM is activated that inhibitory mechanisms are activated, narrowing down the focus based on additional contextual information provided. The end of this process allows an individual to take in a sentence or entire discourse worth of contextual information, beginning with thousands of anticipated associations and filtering these associations down to the most probable (Salisbury, 2010).

This two-stage model of semantic activation and verbal working memory further indicates how the process can be modified when limited contextual information is provided. In language information where there is adequate contextual information this spread of activation occurs rapidly, but when little to no contextual information is provided semantic activation cannot be utilized to filter out the wide array of possibilities for how a given sentence could end. What results is a significant tax on verbal WM resources as the brain attempts to maintain the vast unfiltered expectancies for how the semantic information could continue. This process is differentiated from the findings of Salisbury (2010) where instead of unfiltered semantic activation occurring due to the lack of contextual information, incorrect contextual information results in verbal WM being required to suppress this activation and integrate a secondary one. Both processes ultimately tax WM but utilizing different methods. Generally it can be understood that in sentences where limited contextual information is provided semantic integration becomes more difficult as working memory resources are depleted in an effort to filter out the much wider array of possible activations. Sentences with a high degree of contextual information make this process more efficient but it must ultimately be of note that in each instance verbal working memory is required to maintain the semantic associations derived from the initial burst of activity. Semantic activation and subsequent semantic integration all are contingent upon effortful working memory activation, allowing for the implication that any process that can alleviate the demand for working memory processes to provide a performance boost to these stages of semantic processing.

With the role between WM resources and semantic processing established, this paper can turn to reviewing the mechanisms of speech perception itself and specifically in regards to AV speech. It is crucial to have a clear understanding of the factors involved in speech perception and recognition. It has been previously identified that there is a unique framework of factors (both beneficial and challenging) implicated in speech perception and recognition, factors such as the ability to extract auditory and visual information and the utilization of semantic or syntactic content (Grant, Walden & Seitz, 1998). This framework highlights the need for an effective understanding of how speech processing occurs. AV Speech processing can be considered as a system that takes in sensory information from both auditory speech cues and visual speech cues (lip movements), combining them together in what is referred to as multisensory integration. This integrated perception is then used by the listener in a combination with top-down factors such as linguistic competence, individual knowledge and verbal working memory.

Multisensory integration is the essential mechanism through which isolated sensory inputs can be effectively combined in order to enhance a particular perception (Meredith & Stein, 1986). Through this mechanism, impaired or sensory inputs (i.e. listening to a person speaking in a loud concert) can be supplemented with other sensory inputs (i.e. lip reading) to enhance overall activation and improve the efficiency of processing. Research has demonstrated that when multiple sources of sensory information are available multisensory integration occurs throughout the brain. One instance of this integration was conducted on single neurons in the superior colliculus of adult cats to determine the extent of the neural activity. Meredith and Stein (1986) concluded that, as compared to unimodal sensory input, multisensory stimulation had a multiplicative (rather than summative) enhancement effect for the number of neuronal discharges. This indicates that when presented with multiple sensory inputs, rather than the inputs operating independently, integration did occur whereby neuronal activity was made more efficient through an overall significant increase in the number of discharges elicited by the stimulus. This understanding is critical as it reflects the underlying process that allows such information sources as auditory communication and lip-reading to work in tandem rather independently.

It has already been established that semantic activation, an early bottom-up language process, requires WM resources in order to be maintained, but other speech and language systems obviously also draw on WM. Specifically the established mechanisms of speech perception and recognition also draw on WM resources to effectively integrate available sensory inputs. With this in mind any observation of how higher-order processes are implicated in WM utilization must also take into account any variations in WM resources caused by the earlier processing of speech. One phenomenon that has been utilized repeatedly to investigate the relationship between speech perception and recognition and working memory resources is the audiovisual enhancement (AV) effect (Erber, 1969; Walden, Prosek & Worthington, 1975). As previously indicated, speech information typically comes from two sensory inputs, auditory information and visual information. Speech perception and recognition is achieved primarily through audio, the dominant modality, but can be significantly augmented with the presence of visual speech information. AV enhancement refers to the benefits to speech perception and recognition afforded by the presence of visual speech cues (e.g., from the lips) to accompany auditory speech cues and augment speech perception (Erber, 1969). AV enhancement has been suggested to occur via the use of visual information as a form of complementary evidence when audio information is presented (i.e., in a noisy room, lip movements confirm what is otherwise distorted speech information; Summerfield, 1987). Other explanations have suggested that the faster transmission of visual information vs. audio information (visual speech information tends to precede audio information in the ten to hundred milliseconds range) allows effective prediction of the audio information (van Wassenhove, Grant & Poeppel, 2005). Through either mechanism AV speech perception affords a significant benefit to comprehension over audio speech information alone. AV enhancement is significantly advantageous due to the often challenging circumstances where audio information is presented, such as in scenarios involving multiple speakers or significant background noise. The integration of visual cues allows for more effective speech recognition during these challenging scenarios.

A variety of studies (Garstecki, 1983; Walden, Busacco & Montgomery, 1993; Grant & Seitz, 1998) have utilized AV speech to quantify the benefit afforded by providing visual speech cues in addition to auditory speech. Older adults have reliably demonstrated a strong benefit to comprehension derived from AV speech, even when taking into account the decreased visual speech comprehension of older adults. The latter interestingly reveals that even though older adults are less effective than younger adults at comprehending speech from visual speech cues alone, they are actually more effective at utilizing this information to augment auditory speech processing. Due to the common presentation of hearing decline in older adults, this benefit is interpreted as an adaptation whereby older adults become more efficient in utilizing visual speech cues due to a greater need to rely on available speech comprehension aids (Winneke & Phillips, 2011).

It is important to note that other studies have similarly investigated AV enhancement in older and younger adults and found that the AV enhancement does not differ between age groups (Gordon & Allen, 2009). Instead it was found that while younger adults had a better overall performance in identifying the final word of a sentence when presented with background noise, both groups showed the same degree of AV enhancement relative to their auditory only condition. Interestingly when the AV condition was manipulated to be blurry, this quality loss removed the AV enhancement effect for older adults but not for younger adults, implying that younger adults were able to utilize their higher visual acuity to preserve the benefit.

Various studies have sought to utilize AV speech stimuli to determine the neural processing changes it elicits as compared to auditory only speech. The seminal article by van Wassenhove, Grant and Poeppel (2005) presented 26 English-speaking participants with either audio or audiovisual recordings of brief syllables. Among other results they successfully determined the N1 ERP component, an electrophysiological reflection of early bottom-up auditory processing, occurred earlier and had a reduced amplitude when elicited from audiovisual stimuli vs. audio stimuli. Pilling (2009) conducted a replication of van Wassenhove et al.'s research, further confirming the reduction in the N1 elicited by the AV stimuli. Both studies also determined that the AV enhancement effect was contingent upon AV synchrony (having the visual speech information synchronized with the audio information presented), confirming that the benefit in cognitive processing is specific to the visual speech information and not simply the presence of any given visual stimulus. In other words it was determined that visual stimuli were not simply acting as a priming trigger to facilitate attention, rather the relevant visual speech content was necessary for the AV enhancement effect to occur. These findings together are evidence of how audiovisual speech, through providing greater speech cues, increases the efficiency of speech processing. The benefit manifests both as an earlier processing time and a decrease in the need of cognitive resources necessary to identify and process the speech information. The latter effect was crucial to the current study, as the benefit AV speech affords to early speech processing may allow these resources to be redistributed to later top-down speech processes that are demanding to an even greater degree on WM resources.

While the AV enhancement effect can specifically be utilized to improve performance on WM-specific tasks, it also can provide a general benefit to speech by reducing the degree of WM resources required for speech processing, freeing these resources up for later top-down processes. A series of studies by Phillips and colleagues have directly investigated this concept through utilizing AV speech enhancement research designs in experiments focusing on WM performance. One of these studies investigated the n-back task, where participants were presented a series of sequential unmasked spoken digits and asked to determine if a number currently being shown was presented immediately prior or several numbers prior (Frtusova, Winneke & Phillips, 2013). The n-back task becomes more difficult as the lag increases between the currently presented stimulus and the one being recognized, making this task a sensitive test of WM capacity. Twenty-three younger adults and 20 older adults were tested using ERP analysis. The study demonstrated that when both younger and older adults were asked to complete the n-back task, they were faster and more accurate when the information was presented in an AV context compared to auditory alone (Frtusova et al., 2013). This suggests that the AV speech mode frees processing resources that can be used downstream for higher-order processing. Further evidence was found in the ERP data which demonstrated that the N1, a component related to the detection and encoding of auditory stimuli, showed a decrease in amplitude and an earlier latency in the AV condition. This N1 facilitation demonstrates at the neural level how AV speech can free processing resources for later use.

Further confirming the relationship between audiovisual integration of speech and working memory resources, Alsius, Navarra, Campbell & Soto-Faraco (2005) investigated changes in the typical AV enhancement when participants were tasked with a separate unrelated pattern change detection task (described below) requiring significant attention resources. Unlike the previously indicated studies that utilized designs wherein the AV information could enhance the WM-dependent task itself, in this experiment the task was unconnected to the AV information. Instead Alsius et al. (2005) sought to determine if the enhancement might be reduced or cancelled out if significant attention could not be paid to speech processing. The researchers presented participants with a McGurk effect illusion, an audiovisual presentation where the audio and visual stimulus are incongruous to the extent that multisensory integration often results in a “fused” response (i.e. hearing the word “bait” while seeing the lip utterance for “gate” results in the fused perception of the word “date”; McGurk & MacDonald, 1976). Concurrent to presentations of either an AV McGurk effect or the isolated audio/visual streams were two different detection tasks. The first involved participants simultaneously observing an outline image superimposed on the visual speech information and providing a response when the image changed to a different image. The audio detection task worked similarly but had participants provide a response when a sound that was being played simultaneously to the audio track randomly changed from a specific recognizable sound to a different one.

Results from Alsius et al. (2005) demonstrate that the McGurk effect audiovisual fused response, a typically reliable indication of multisensory integration, significantly decreased in frequency when participants were presented with an unrelated attention-demanding task. These results are critical as they demonstrate that multisensory integration is not merely an automatic process but one that does utilize attentional resources. The ability to maintain focus or attention on a given task draws on WM resources similar to how WM is used to maintain recalled information beyond initial activation. As a result, this finding for the utilization of attentional resources holds implications for subsequent research on WM. These findings lend further credence to the current study’s expectation that a relationship can be determined between the AV enhancement effect on WM resources and the top-down processes of semantic processing that have significant WM demands.

Winneke and Phillips (2011) conducted a study investigating AV speech within the context of speech perception in challenging circumstances (i.e., significantly noisy environments. Both younger and older adults were presented words from either a list of natural (e.g., tree, pear, etc.) or artificial (e.g., bike, clock, etc.) objects with a persistent babble noise (individually adjusted per participant) in the background. Participants were tasked with listening to each word and categorizing them into the appropriate respective category list. During stimulus presentation a persistent babble noise was played. Words were presented in auditory, visual or audiovisual conditions and ERP analysis was conducted to observe the electrophysiological differences elicited. Analysis revealed that the N1 had a lower amplitude overall and an earlier latency in the audiovisual condition as compared to audio or visual alone. Through changes in presentation of the N1 it can be safely concluded that AV speech has a reliable effect in reducing the degree of resources allocated to bottom-up auditory processing.

In a natural progression of utilizing AV speech to benefit early auditory processing of speech and free up resources for later top-down processes, the current project investigated the relation between AV speech and semantic content, with specific attention paid to WM implications. It has been demonstrated that the processing and integration of semantic content, depending on the level of context provided by the sentence, can significantly tax WM resources (D'Arcy et al., 2005; Salisbury, 2004. Given the established AV enhancement effect and the anticipated benefit to WM resource availability, it is a reasonable hypothesis that sentences presented in an audiovisual modality will allow access to greater WM resources to facilitate semantic language integration. The current study will therefore aim to discern this relationship and determine the precise benefit to semantic integration afforded by the AV enhancement effect.

The current study tested 25 younger adults via ERPs while presenting them with a variety of stimuli known to elicit the N400 component, a neural indication of semantic processing. (Connolly & Phillips, 1992). The latency of the N400 component relative to terminal word onset allows comparisons of how quickly the semantic content is being processed and integrated with the preceding contextual information. The N400 amplitude will indicate any relative facilitation of neural activity, indicative of WM involvement. The sentences presented were derived from the Speech Perception in Noise test (Kalikow, Stevens & Elliott, 1977), where sentences are presented that either have a high constraint (e.g, “We saw a flock of wild geese”) or low constraint (e.g., “You’d been considering the geese”) for acceptance. The high constraint sentences served as a control sentence by providing participants with adequate semantic context in order to anticipate the type of final word presented, a form intended to yield little to no evidence of an N400. Conversely the low constraint sentences, due to their unpredictability caused by the lack of context information, were used to elicit high N400 components as the participant must engage WM resources to process and integrate the unanticipated terminal word with the low-context sentence. Eighty high constraint sentences and 80 low constraint sentences were presented and randomly assigned to either A or AV conditions to examine the interaction of AV enhancement and semantic context on the amplitude and latency of the N400 component.

This study sought to demonstrate that when younger adults are presented with stimuli known to significantly tax WM (sentences requiring semantic integration with ambiguous contextual information provided), this process can be alleviated by utilizing earlier bottom-up processes to enhance speech perception and recognition. In this way the AV enhancement effect is predicted to compensate by yielding a faster auditory processing that takes up less cognitive resources. These available resources can then be reallocated to later semantic integration processes, which are predicted to manifest in lower N400 components (as a result of better integration) across sentence types relative to auditory only presentations. It is further predicted that sentences with ambiguous contextual information (low constraint for acceptance sentences) will yield a significantly higher N400 amplitude as compared to sentences with sufficient contextual information (high constraint for acceptance sentences). The observable effect will be an increase of the N400 effect in AV conditions for participants when presented sentences with low contextual information, sentences previously established to elicit an N400 component. The predicted amplitude increase in the N400 will ideally demonstrate that AV "enhancement" is not strictly an enhancement of auditory processing but a facilitation of cognitive resources that can be generalized to enhance other challenging aspects of language communication.

Methods

Participants

All participants were required to be right-handed, between the ages of 18 and 35, speak English as a first language or fluently by the age of 10 and have no pre-existing health issues implicated in impaired neurological functioning. To assess these initial criteria a confidential history questionnaire (see Appendix A) was administered over the phone for each participant prior to the testing date. This questionnaire was designed to collect relevant demographics information in addition to ruling out the aforementioned health issues. Other variables such as ongoing medical treatments and recreational drug use were questioned for similar purposes of ensuring minimal interference to the data being collected.

From this initial screening process 28 younger adults (seven males, 21 females) were ultimately recruited and tested. Their ages ranged from 18 to 35 and all were residents of the Montreal area. Prior to collecting ERP data all participants were screened for intact sensory and cognitive abilities. To assess vision, participants completed the MARS Letter Contrast Sensitivity test (Arditi, 2005) and the MNREAD acuity charts (Mansfield, Ahn, Legge & Leubeker, 1993). To assess hearing participants were measured for pure tone averages (PTA; minimum thresholds for the perception of an auditory signal, measured at the 500, 1000 and 2000 Hz frequencies (based on auditory acuity testing from Frtusova et al., 2013). Finally cognitive functioning was measured through the Montreal Cognitive Assessment (MoCA; (Nasreddine, et al., 2005) and the Letter-Number Sequencing (LNS) task of the WAIS-IV (Wechsler, 2008). Regarding the testing of hearing levels, participants were excluded for any PTA above 20dB and no differences between the left and right ear PTAs of more than 10dB were accepted. All screening test results as well as relevant demographic information is presented in Table 1. The project was approved by the Concordia University ethics research board and all participants provided their informed consent for participating without any complications or difficulties.

Materials

Montreal Cognitive Assessment (MoCA; Nasreddine, Phillips, Bédirian, Charbonneau, Whitehead, Collin, Cummings & Chertkow, 2005). The MoCA is a cognitive assessment tool designed to accurately measure executive functioning deficits indicative of neurological disorders such as mild cognitive impairment (Nasreddine et al., 2005). The MoCA assesses participants on various areas of cognitive functioning such as visuospatial skills, naming, and memory. Each category of functioning involves a related activity or series of questions, with the participant receiving a point for each correct part of the answer. For example, in the visuospatial category the participant is asked to draw a clock with a time of ten past eleven. The maximum score for the scale is 30 and the cut-off for evidence of cognitive impairment is less than 26. For the detection of mild cognitive impairment, the MoCA has 90% sensitivity and 87% specificity. These results indicate that the MoCA is a valid tool for the assessment of cognitive functioning (Nasreddine et al., 2005).

Letter Number Sequencing (LNS; Wechsler, 2008). The Letter Number Sequencing is a subtest of the *Weschler Adult Intelligence Scale –IV* and is specifically used as an optional subtest of the working memory index. The LNS presents participants with a randomized set of numbers and letters increasing in length from an initial two to a potential eight letters and numbers. The set is presented orally to the participant and they are instructed to reorder the set and say it back to the experimenter with the numbers going first in numerical order followed by the letters in alphabetical order. The test increases in difficulty in order to determine the precise span that can no longer be sequenced, therefore the test serves as an excellent supplement to gauge the attention and WM capacity of younger adults. For the current study the LNS was utilized to group participants into either a low or high WM performance group. Participants with a raw score of 10 or lower were grouped as low WM while participants with a score of 13 or higher were grouped as high WM. This grouping was done based off a median split of the LNS data which revealed that two clusters of scores existed which justified grouping participants into either the low scoring cluster (lowWM) or the high scoring cluster (highWM). Scores of 11 and 12 were excluded to avoid inappropriately classifying scores that were so close together as either low or high.

MARS Letter Contrast Sensitivity Test (MARS; Arditi, 2005). The MARS is an effective tool for assessing contrast sensitivity in participants. The test involves presenting three charts (one for either eye and one for both eyes) to a participant at a distance of 50cm. On each sheet are letters designed to gradually decrease in contrast and participants are instructed to read the letters until the contrast becomes too small for their eyes to detect. After two consecutive errors in identifying a letter the last correctly identified contrast sensitivity is recorded, with a subtraction of 0.04 from the contrast sensitivity value for every error made prior to the final correct letter. The average contrast sensitivity score for participants with normal vision between the ages of 22 and 77 was found to be 1.62 (SD=0.06). Evaluation of the MARS have found it to have a test-retest reliability of .95 and a correlation with the Pelli-Robson (a previously well-established contrast sensitivity test) of .83, indicating the MARS is a reliable tool for the assessment of contrast sensitivity (Haymes et al., 2006).

MNREAD Acuity Charts (MNREAD; Mansfield et al., 1993). The MNREAD is a test of reading acuity and speed and served as a second test for normal visual acuity in participants. The MNREAD allows the measurement of overall reading acuity and maximum reading speed. The test contains two sheets each with a number of sentences presented in a decreasing size, starting with a size equivalent to 20/400 vision and going as small as a vision equivalent to 20/6 vision. The two charts are presented so that one measures acuity and the other speed (odd numbered participants received chart 1 for acuity and chart 2 for speed and vice versa for even numbered). For the acuity test participants are asked to read each sentence slowly and accurately until they can no longer make out a single word in a sentence. For reading speed participants are timed while they read each sentence as quickly as possible, noting when the print size begins to slow their reading speed below their usual average. The MNREAD was demonstrated to be a reliable assessment tool with mean difference in reading acuity between test and retest phases to be 0.01 (LogMAR units; Subramanian & Pardhan, 2006).

Stimuli

The stimuli for the current study consisted of 160 videos of spoken sentences derived from the Speech Perception in Noise (SPIN) test (Kalikow et al., 1977). Eighty of these were sentences with a low constraint for acceptance (i.e. sentences with neutral contextual cues that allow for many unpredictable outcomes; e.g, “You’d been considering the geese”) and the other 80 had a high constraint for acceptance (i.e. sentences that provide sufficient contextual cues to allow predicting the final word; e.g., “We saw a flock of wild geese;” See Appendix B). These sentences were all selected from forms one through four of the SPIN test. The two sentences types are manipulated for the degree of contextual information provided to the participant, with the high constraint sentences providing sufficient contextual information to allow some anticipation of the terminal word. Conversely the low constraint sentences provide only neutral contextual information, preventing any effective anticipation. Each low constraint sentence has a terminal word matched to a high-constraint sentence (like the examples presented above). For the purposes of testing all of the sentences recorded were from these matched pairs, ensuring that variability in the terminal word between low constraint and high constraint lists cannot be considered a factor in any results.

Video recording of these stimuli took place at the Concordia Vision Labs of Concordia University. A female speaker was selected to read the sentences based upon symmetrical facial features and the absence of any distinctive and distracting facial characteristics. She was instructed to wear no make up, remove all distracting jewelry and keep her hair tied back so as to not obstruct the view of the face. This speaker was sat in a comfortable chair to minimize accidental movements during recording caused by standing. The speaker sat in front of a white projector screen to serve as a white backdrop for the recordings and was illuminated from studio lighting mounted directly below the camera to ensure the maximum degree of light exposure to all parts of the face. All attempts were made to minimize any background noise.

A *Logitech QuickCam Pro 9000* camera combined with the recording software *QuickTime v. 10.2* were used to record the stimuli. The original video was recorded at a resolution of 1280 px X 720 px with a frame rate of 29.97 fps, with the audio recorded at a rate of 48,000 Hz. To ensure the speaker could keep her head firmly centered during recording and to minimize accidental movement, the computer screen displaying the recording was faced towards the speaker and markings were placed on the screen to serve as a guide for where the speaker should keep her head situated on the screen. This allowed the speaker to ensure that her face and neck took up the majority of the screen.

Once in the optimal position the speaker was provided a list of the stimuli sentences and asked to read each one at a normal rate and without making any errors in pronunciation. All sentences were read with a flat facial expression and no sentence recordings were used if the speaker blinked at any point during the reading of the sentence. Each sentence was read three times to ensure an optimal sentence recording could be extracted. An optimal recording was one where the speaker started in a flat facial expression with her lips closed, read the sentence without errors and upon completing the sentence returned to the same flat expression with her lips closed. Recording sessions took place over two days before all of the required sentences were completed. During recording two associates supervised the session, monitoring for any undesired facial expressions, blinking or misreading of the sentences.

Once recording was complete, all video files were imported into *iMovie '11 v. 9.0.8.* All three recording takes for each sentence were reviewed to determine the optimal selection. Once determined, this sentence was marked and extracted from the main file into an individual editing file, one for each of the 160 sentences. Once there the selected sentence was trimmed down so that the recording began and ended with a neutral expression directly preceding or following any lip articulation. A still-frame was also added and displayed for 500ms at the beginning and ending of every video. This single still-frame consisted of a copy of the neutral expression of the speaker prior to opening her mouth and beginning the first lip utterance of the sentence. This was added to provide a cue for participants to anticipate the oncoming sentence rather than starting the sentences immediately at the beginning of the video. Due to the presence of some residual background noise, the "background noise reduction" audio editing tool was utilized, specifically setting reduction to 55%. Once this was complete all of the 160 videos were exported in the MV4 format with all available settings set for the highest available quality in both audio and video. The approximate length of the videos ranged from three to four seconds.

At this point audio corrections were made to the videos to ensure that the volume of each individual video file was set to a standard level. To accomplish this the *MP3Gain v. 1.2.5* software was used to apply peak normalization to the files, resulting in a standard peak volume for all video files without a loss of quality.

Once audio corrections were complete, stimulus editing then involved inserting triggers into the respective video files. These triggers are required for ERP analysis as they send a signal to the ERP system during recording that creates a mark in the participant's EEG recording. This mark can then be returned to at the analysis stage and allow observation of the unique brain activity directly following the point of interest. In the stimuli of the current study, markers were inserted at the onset of the terminal word of the sentence, as this point was where any N400 effects were predicted to occur.

To insert these triggers, all of the video files were imported into *Adobe Premiere Pro CS6 v. 6.0.0*. Once imported, each sentence was edited individually by first isolating the audio and editing this audio in the accompanying audio-editing suite: *Adobe Audition CS6 v. 5.0*. Here the right-channel of the audio for each sentence was deleted. In the EEG set up utilized for the current study the left channel was presented to the participant in both ears while the right channel was entirely sent to the EEG system. The right channel, which originally presented audio from the video, was erased and instead replaced with audio triggers for the ERP system, with the triggers inserted to coincide with specified points in the video. The triggers consist of a single tone (-18.1dB, 400Hz) that was inserted directly before the terminal word was uttered in each sentence and played for a duration of 5ms. The trigger insertion point was determined by examining the audio in *Adobe Audition CS6 v. 5.0* and placing the trigger directly before the precise point where any detectable articulation of the terminal word was heard. This tone was not heard by the participant but only used to create a marker in the EEG recording during testing. Following insertion of this trigger into the right channel, the left and right channel were reimported back into the original video file, resulting in a modified video with the sentence audio in the left channel and the ERP triggers in the right channel. Back in *Adobe Premiere Pro CS6 v. 6.0.0*, each file was then exported in the Mpeg4 file format. Each video was encoded at a resolution of 720x480 pixels and 29.97 frames per second, with audio quality encoded at a bitrate of 192kbps.

After embedding the triggers in the video files it was determined that some significant background noise was still present in the video files, a high-pitched frequency distorting the overall audio. For this reason a further audio correction was applied specifically to remove this high-pitched frequency. Each file was individually edited in *Audacity v. 2.0.3*, an audio editing suite with a specifically designed tool for high-frequency noise removal. *Audacity v. 2.0.3* removed the background noise by utilizing a section of each video where nothing was being spoken in order to establish a baseline for the background noise and then applying a filter to remove this noise from the entire file. The subsequent audio track was found to be much clearer and absent of the background noise. Following this, each audio track was reimported back in to *Adobe Premiere Pro CS6* to be reintegrated with the original video file. During this audio correction the right channel (the one containing the embedded triggers) was not modified in any way so as to preserve the triggers.

As a final step in the video editing process, each Mpeg4 file was converted to the AVI file format for compatibility with the experiment software. This final conversion was completed using *Mpeg Streamclip v. 1.9.3b8* with all settings set to leave the video and audio in their original level of quality with no form of compression. The result of this sequence was a stimuli list of 160 AVI format videos of SPIN sentences with a typical length of three to four seconds.

Videos were presented to participants on a 16.1” CRT monitor set to a resolution of 1280x1024 pixels. Videos were all presented in the center of the screen and had a width of 15.5 cm and a height of 11.5 cm. The audio was presented binaurally at an average of 65 dB using EARLINK tube ear inserts (Neuroscan, El Paso, TX, USA).

Sentences were presented in either an auditory (A) or Audiovisual (AV) condition. In the latter sentences the videos were presented to the participant in the centre of the screen but during the former the video was hidden from the participant by instructing the experiment presentation program *Inquisit 3.0* (2007) to only show the video on a single pixel in the corner of the screen. As a result, only the audio could be heard. During these A condition sentences a fixation point consisting of a small white circle was placed in the centre of the screen in place of the video

Procedure

Prior to the testing date a health and demographic questionnaire was completed with each participant over the phone to determine general demographics info and rule out any preexisting health issues implicated in EEG testing. On the testing date participants arrived, the experiment was reviewed with them and any questions were answered before ultimately informed consent was obtained. Participants were then asked to take a seat in a comfortable chair while the screening tests were administered. The experimenter then administered the screening tests of the MoCA, LNS, MNREAD, MARS Letter-Contrast Sensitivity and the PTA test. Following completion of the screening tests participants were asked to remain comfortably seated while the EEG system was set up (described in detail in the EEG Data Acquisition subsection). Once properly set up participants were fitted with EARLINK tube ear inserts (Neuroscan, El Paso, TX, USA) to isolate out any other noise and allow focusing on the audio for each sentence. Participants had their seat adjusted to ensure they were at eye-level with the screen and their eyes were at a distance of 60 cm from the screen.

The experimental task was controlled by *Inquisit 3.0* (2007). In the experiment the 80 LC and 80 HC Spin sentences were arranged to present in a consistent randomized order that ensured that no more than two low constraint or high constraint sentences were played in sequence. To ensure maximum time to orient to each new sentence, a post trial pause of three seconds was added to each sentence. Participants were assigned to one of two presentation orders: odd numbered participants had the sentences presented in four blocks (40 sentences per block) beginning with auditory and then followed by audiovisual (A, AV, A, AV) while even numbered participants had the opposite presentation (AV, A, AV, A). This manipulation was done to determine the extent or ordering-effects in presenting sentences first in either the A or AV modalities. In either presentation order the sequence of the sentences remained the same, ensuring that sentences that were presented in the A modality for half of the participants were presented in the AV modality for the other half.

Participants were instructed to attend to each sentence being presented, listening to it as one would normally listen to a speaker. Participants were further instructed to move as little as possible during the sentence presentation, to keep their eyes from wandering and to refrain from conversing with the experimenter. The experiment would then begin with the sentences being presented in sequence to the participant without requiring any input from them to advance from one sentence to the next. During the A trials participants were instructed to maintain their gaze on the fixation point and simply listen attentively to the sentences. Throughout the experiment comprehension questions were displayed to the participant about the last sentence they just heard. The frequency of these questions varied between every 5 to 10 sentences. Each comprehension question was a simple yes/no question about the previous sentence designed to ensure participants were attending adequately to each stimuli (see Appendix C). When each comprehension question was presented participants were instructed to notify the experimenter that they had a question and the experimenter then began a 45 second timer. These 45 seconds served as a brief break for participants to minimize losing attention on the sentences caused by rapid presentation. Following the 45 seconds participants were instructed to provide their answer via a USB mouse they were asked to hold in their hands. Input was provided with the left mouse button indicating an answer of “No” and the right mouse button indicating an answer of “Yes.” Twenty-four comprehension questions were presented to participants throughout the experiment.

After presentation of the first 40 sentences a new message was presented asking the participant to notify the experimenter. This message served as a warning that the participant was about to transition from one modality to the other (either A to AV or AV to A depending on presentation order). At these times a break of three minutes was provided and participants were provided a snack and drink if desired and conversed with the experimenter so as to alleviate any feelings of fatigue from the study up to that point. Any required corrections to the EEG system were also made during these times.

Following the three minutes participants were instructed to return to their original position and the experimenter initiated the next block.

Completion of all four blocks took one hour in length. Following completion participants were disconnected from the EEG system and provided facilities to wash their hair of the bio-conductive gel if desired. Finally a debriefing form was provided, participants were thanked for the time and the experiment was concluded.

EEG Data Acquisition

Data collection utilized a Biosemi ActiveTwo EEG system. In this system participants had their brain activity recorded from 64 channels, arranged in the International 10-20 system (Jasper, 1958). To control for eye movements electro-oculograms (EOGs) were placed above and below the left eye as well as at the outer canthi of both eyes. The EEG data was recorded at a sampling rate of 512Hz with a high-pass filter of .16Hz and a low-pass filter of 100Hz.

Once collected the EEG data files were converted from their original Biosemi data format to the Neuroscan continuous data format through the *Polygraphic Recording Data Exchange* program (PolyRex; Kayser, 2003). Once converted each file was opened in the Scan software (version 4.3.1; Compumedics Neuroscan, 2003) where an event file was extracting containing information on the embedded markers in each EEG file, with offset reported in seconds. This event file was then modified to create specific triggers for each sentence that would identify these sentences as either low constraint (LC) or high constraint (HC) as well as audio (A) or audiovisual (AV). Once this event file was modified, it was imported back into the EEG data file, overwriting the original event file markers.

Once the markers were updated, all data files were imported into *Brainvision Analyzer 2.0.2* (Brain Products, 2012). From there each file was inspected for time periods where no stimuli was being presented (e.g., break periods) and these time periods were marked as "bad intervals" to exclude them from subsequent analysis. Following this all data files were refined before segmentation and analysis of the data itself. A DC Detrend transformation was applied followed by an infinite impulse response (IIR) filter with a low cutoff of 1Hz and a high cutoff of 45Hz. An ocular correction ICA was then applied to all participants to correct for blinking activity throughout the EEG data. This ocular correction utilized a mean slope algorithm to detect blinking activity, utilizing the VEOG channel for vertical activity and the HEOG channel for horizontal activity, with the ICA matrix calculated specifically around the identified blinking activity.

After ocular corrections were applied to each data file, all trials (LCA, HCA, LCAV and HCAV) were segmented and an artifact rejection was applied to identify and exclude any bad electrodes that were compromised as a result of hardware errors. All files were then segmented to -100ms before and 900ms after the stimuli trigger in each sentence. For every sentence presented this stimuli trigger was directly preceding the speaking of the final word. These segments were then averaged for each participant, creating four averaged waveforms representative of the four sentence trial conditions (LCA, HCA, LCAV, HCAV). All average EEG waveforms were baseline corrected to the prestimulus period (-100ms to 0ms before the stimuli trigger). In the averaging of each trial condition a specific trial sentence was rejected if the horizontal EOG activity exceeded +/- 75 microvolts (μV) or if the general activity across any of the electrode sites exceeded +/- 100 μV. This resulted in mean of 37.61 trials per average (SD=3.57, Minimum=21, Maximum=40)

For the purposes of analysis of any present ERP component amplitude (μV), only electrode sites around the centre of the head were extracted for statistical testing. These electrode sites consisted of: Fz, F1, F2, FCz, FC1, FC2, Cz, C1, C2, CPz, CP1, Cp2, Pz, P1 and P2. Only the results of the midline sites (Fz, Fcz, Cz, Cpz, Pz) are presented in the subsequent results. To measure the amplitude (μV) of the N400 effect, the average waveform for each trial condition across all participants was extracted for mean area activity (μV) at 50ms intervals. This process involves creating a single microvolt average for the 50ms time interval specified for each participant across all four conditions. Intervals were created at the 0-50ms interval, 100-150ms, etc.. The mean area activity values from these time intervals were utilized in the subsequent statistical analysis to determine the significance of any observable negativity indicative of a possible N400 effect.

Results

In all subsequent repeated-measures ANOVAs, Greenhouse-Geisser non-sphericity corrections were applied for factors with more than two levels (Greenhouse & Geisser, 1959). Subsequent statistical reporting includes the uncorrected degrees of freedom, Greenhouse-Geisser epsilon (ε) values, corrected *p* values and mean square error (MSE) values. In each ANOVA, significant main effects are reported first followed by any significant interactions and corresponding analyses of simple effects to decompose these interactions. Relevant tables and figures are presented as required. Unless otherwise indicated, all tests reported as significant are significant at the $\alpha = .05$ level or lower.

Behavioural Results

The average success rate for the comprehension questions was 98.1% with a range of 91.7% to 100% (SD=2.89%). No participants reported any problems or difficulties with the comprehension questions. Due to consistently high accuracy rate demonstrated by participants on the comprehension questions, it was determined that all participants paid a suitable level of attention to the stimuli and their results are therefore valid for further analysis.

Electrophysiological Results

Two sets of analyses were conducted in order to investigate the variables in question. First, a repeated measures ANOVA was conducted on all of the tested participants (n=28) testing the factors of Modality (A and AV), Constraint (LC or HC), Electrode (Fz, FCz, Cz, CPz, Pz) and Time Interval (300-350ms, 350-400ms, 400-450ms, 450-500ms, 500-550ms and 550-500ms). To further investigate potential WM effects a second repeated measures ANOVA was then conducted, only utilizing participants that were classified as either low WM (n=11) or high WM (n=11). This second analysis utilized all of the same factors as above but now included the between subject factor of WM group (lowWM or highWM).

All Participants. A repeated measures ANOVA was conducted with factors Modality (A and AV), Constraint (LC or HC), Electrode (Fz, FCz, Cz, CPz, Pz) and Time Interval (300-350ms, 350-400ms, 400-450ms, 450-500ms, 500-550ms and 550-500ms). A main effect was not found for Modality ($F(1,27) = .14$, $MSE = 27.35$, $p = .71$, $\eta\rho^2 = .005$), indicating no significant difference in the ERP activity between the auditory and audiovisual modalities. A significant main effect was found for Constraint ($F(1,27) =$

17.84, $MSE = 24.81$, $p < .001$, $\eta\rho^2 = .4$), with LC sentences eliciting significantly greater negative ERP activity as compared to HC sentences (see Figure 1). A significant main effect was also found for Time ($F(5,135) = 5.72$, $MSE = 6.3$, $p = .001$, $\varepsilon = .68$, $\eta\rho^2 = .18$) but no significant main effect was found for Electrode ($F(4,108) = .34$, $MSE = 6.83$, $p = .63$, $\varepsilon = .34$, $\eta\rho^2 = .013$).

In addition to the significant main effect of Constraint, several significant interactions were found. A significant interaction was found between Constraint and Electrode ($F(4,108) = 30.95$, $MSE = 2.86$, $p < .001$, $\varepsilon = .47$, $\eta\rho^2 = .53$) demonstrating that the waveform was significantly more negative at the posterior sites for the LC sentences, as compared to the HC sentences (see Figure 2). A further significant interaction was found between Constraint and Time ($F(5,135) = 8.59$, $MSE = 6.91$, $p < .001$, $\varepsilon = .59$, $\eta\rho^2 = .24$) which revealed that the negative activity associated with the LC sentences was highest in the 450-500ms range and second highest for the 400-450ms range, while conversely the HC sentences actually yielded a trend towards baseline and some positive activity by the 550-500ms interval (See Figure 1). Finally a significant three-way interaction between Constraint, Electrode and Time ($F(20,540) = 10.2$, $MSE = .92$, $p < .001$, $\varepsilon = .23$, $\eta\rho^2 = .27$) revealing that the negativity occurring at the 400-450ms and 450-500ms intervals was occurring primarily as the posterior electrode sites (see Figure 2).

To further explore these results additional analyses were conducted on difference waves, created by subtracting the waves for the HC stimuli from the LC stimuli. The purpose of creating difference waves is that the end result should uniquely reveal any pertinent N400 effect by highlighting the specific difference between the two stimuli. For this reason, a repeated measures ANOVA was conducted using the difference wave data, with the repeated measures ANOVA utilizing the same factors aside from Constraint which due to the nature of difference waves is removed as a factor with multiple levels.

A main effect was once again not found for Modality ($F(1,27) = .16$, $MSE = 50.83$, $p = .69$, $\eta\rho^2 = .006$), indicating no significant difference in the N400 activity between the auditory and audiovisual modalities. A significant main effect was found for Time ($F(5,135) = 8.59$, $MSE = 13.83$, $p < .001$, $\varepsilon = .59$, $\eta\rho^2 = .24$) and for Electrode ($F(4,108) = 30.95$, $MSE = 5.71$, $p < .001$, $\varepsilon = .47$, $\eta\rho^2 = .53$).

In addition to these main effects, one significant interaction was found between Time and Electrode ($F(20,540) = 10.2$, $MSE = 1.84$, $p < .001$, $\varepsilon = .23$, $\eta\rho^2 = .27$), which demonstrated that there was a significant increase in negative amplitude activity in posterior electrode sites for the 400-450, 450-500, 500-550 and 550-600ms ranges, characteristic of N400 activity.

Ordering Effect Results. To determine if any significant ordering effects occurred, a similar repeated measures ANOVA was conducted with the addition of a between subject factor of Presentation Order (A-AV or AV-A). In this analysis a significant main effect was found for the between subject factor of Presentation Order ($F(1,26) = 4.48$, $MSE = 33.54$, $p = .044$, $\eta\rho^2 = .15$). Participants who were presented stimuli with the auditory block first and the audiovisual block second showed significantly lower amplitude negative activity as compared to the audiovisual first, auditory second participants (see Figure 3). No significant interactions were found with Presentation Order.

An analysis of the difference waves was also done with Presentation Order utilized as a grouping variable in order to determine if the determined ordering effects were specific to the N400 effect or were found due to other variations in electrical activity unrelated to the current experimental manipulation. To determine this the same repeated measures ANOVA as indicated above was calculated again but now using difference wave data calculated by subtracting HC sentences from LC sentences (which also removed Constraint as a factor in the analysis).

In this analysis a significant main effect was not found for the between subject factor of Presentation Order ($F(1,26) = .5$, $MSE = 50.54$, $p = .49$, $\eta\rho^2 = .02$). This result demonstrates that when specifically observing differences in electrical activity intended to reflect N400 activity, the previously determined ordering effect is no longer statistically significant (see Figure 4). No significant interactions were found with Presentation Order.

Working Memory Group Analyses. In order to further investigate the potential effect of WM differences on potential N400 ERP effects, another repeated measures ANOVA was conducted with the same within-subject factors and an additional between-subject factor of WM group (LowWM or HighWM). These groups were created based on the participants' LNS scores completed as an initial measure of individual differences in WM. As the LNS is a frequently used measure of WM, overall distribution of the WM data was observed to determine an appropriate point to separate participants into either group. A median split revealed that after excluding participants with a score of 11 or 12 (done so to avoid inappropriately classifying scores so close together as either low or high) the result was 11 LowWM and 11 HighWM participants. See Figure 5 for a breakdown of the LNS score split. Of the 11 LowWM participants seven were shown the A-AV presentation order and four were shown the AV-A order. Conversely, of the 11

HighWM participants four were shown the A-AV order and seven were shown the AV-A order.

The repeated measures ANOVA yielded a significant main effect of WM group ($F(1,20) = 4.74$, $MSE = 30.7$, $p = .042$, $\eta\rho^2 = .19$) with LowWM participants showing a greater degree of negative activity as compared to HighWM participants (see Figure 6). A subsequent interaction between Modality, Constraint, Electrode and WM Group was found to be significant ($F(4,80) = 4.84$, $MSE = 1.41$, $p = .002$, $\eta\rho^2 = .2$). Breaking down this interaction reveals that when sentences are presented in an auditory modality, participants with LowWM show little difference between either LC or HC sentences, but HighWM participants show a significant difference in electrical activity with a significantly reduced degree of negative amplitude activity for HC sentences. Conversely in the AV modality a different pattern is observed, where LowWM participants show a decreased negative amplitude for the HC sentences not observed in the A modality, while HighWM participants do not show any significant difference between constraints in the AV modality (see Figure 7).

No other interactions with the WM groups were found to be significant and no main effects were determined that were not previously found in the original repeated measures ANOVA.

Similar to the previous analyses, a difference waves analysis was also conducted to further explore these results in the context of waveforms designed to closely reflect the N400 component. Once again the difference waves were created by subtracting the HC sentence from the LC sentences and a repeated measures ANOVA was then run using WM group as the between subject factor and maintain all of the previously mentioned within subject factors with the obvious exception of Constraint.

The repeated measures ANOVA did not yield a significant main effect of WM group ($F(1,20) = .14$, $MSE = 59.62$, $p = 72$, $\eta\rho^2 = .007$) which would indicate that the N400 effect did not significantly differ between WM groups, contrary to the previous results. A significant interaction was still found however between Modality, Electrode and WM Group ($F(4,80) = 4.84$, $MSE = 8.07$, $p = .026$, $\eta\rho^2 = .2$). This interaction revealed that while the N400 effect is similar for HighWM participants in both the A and AV modalities, LowWM participants show a significantly greater N400 effect in the AV condition as compared to the A condition.

similarly (see Figure 8). No other significant interaction was determined in the difference waves analysis with the between subject factor of WM group.

Discussion

This study sought to investigate the investigate the unique interaction between the speech comprehension benefits afforded by audiovisual speech and the demands placed on working memory by sentences that manipulate the degree of contextual information provided. To investigate this, ERP analysis was utilized with specific attention paid to the N400 component, an electrophysiological indicator of the processing of semantic language information. While several studies have demonstrated the relation between the N400 component and the processing of anomalous semantic content (Kutas & Hillyard, 1980; Kutas, Neville & Holcomb, 1987), the current study utilized sentences wherein the anticipation of the final word was either facilitated by providing significant contextual cues or was unassisted by sentences with neutral cues that did not encourage any content prediction (Kalikow et al., 1977). Through presenting these sentence types in conjunction with audiovisual speech, two modalities known to assist in the early processing of speech cues (Erber, 1969), the general hypothesis was formed that audiovisual speech presentation would alleviate the increased demands on WM posed by sentences without contextual information, allowing these sentences to be processed as efficiently as their contextually-rich alternatives.

The first prediction of the current study was that, due to the established AV enhancement effect, LC sentences that were presented in the AV modality would yield significantly lower N400 components as compared to sentences in the A modality. This hypothesis was not confirmed and instead it was found that there was no significant difference in the electrophysiological activity of A or AV sentences. This result was unanticipated, but past research on AV speech provides some explanation. Previous literature has reliably demonstrated that an AV speech modality decreases the amplitude and increases the latency of early auditory processing ERPs, ultimately increasing the efficiency of early auditory processing (Frtusova et al., 2013). Based on this research it was predicted that the AV enhancement effect would generalize to later top-down language processes like semantic integration. As semantic integration requires WM resources (D'Arcy et al., 2005; Salisbury, 2004), resources which are also utilized in early auditory processing, it was hypothesized that the AV speech benefit would allow resources previously consumed in auditory processing to be redistributed to semantic processing. The result of this would be an increase in the amplitude of the N400 ERP component, with the increase being an indication of additional WM resources being utilized.

The absence of this predicted finding may be attributable to the overall high level of hearing acuity inherent to participants in the 18 to 35 years of age range. Previous research investigating the AV enhancement effect has found that while younger adults do show an AV enhancement, it is less prominent when compared to older adults tested under a similar paradigm (Winneke & Phillips, 2011). This difference was attributed to the general decline in hearing sensitivity that older adults experience (C.H.A.B.A., 1988). Because of this decline it has been theorized that older adults learn to take greater advantage of visual speech cues to augment their declining auditory speech perception and comprehension. Younger adults do also show an AV enhancement effect but by comparison the effect is less pronounced, theorized to be due to younger adults superior hearing not requiring a reliance on visual speech cues. If there is a WM benefit for later top-down processes in younger adults when presented AV information the benefit may simply be too minor to be detected.

The second major hypothesis of this study was that, consistent with previous research utilizing sentences from the SPIN test, sentences with a low constraint for acceptance would have a significantly higher amount of negative activity, indicative of a higher amplitude N400 component as compared to sentences with a high constraint for acceptance (Connolly et al., 1992). This prediction was confirmed with LC sentences yielding a significantly more negative ERP component. The significant interactions also revealed that the N400 elicited by the LC sentences were distributed in more posterior areas and primarily occurred at the 400-450 and 450-500ms ranges. These results are consistent with previous research investigating the N400 ERP component utilizing sentences that manipulate the degree of contextual information provided (D'Arcy et al., 2005; Salisbury, 2004).

The significant results for the manipulation of sentence constraint, independent of the non-significant results for modality, exemplify the process of semantic integration. Sentences from the SPIN test do not contain outright anomalous semantic information, which according to the lexical-level view of the N400, should not yield an N400 as the component is only elicited by the words that cannot be predicted (i.e. nonwords; Lau et al., 2008). Instead the semantic integration view incorporates the lexical level view but maintains that words need not be anomalous to be unpredictable, instead terminal words of a sentence can be made unpredictable simply by removing the traditional content cues we receive in everyday speech. Taking a content-rich sentences such as *"The hunter aimed at the geese"* and modifying it to have neutral content such as *"The old men talked about the geese"* still achieves the same effect of making "geese" unpredictable in the latter. The increased amplitude N400 effect occurs due to the widespread activation of semantic networks that occurs when presented with the neutral context. In everyday speech semantic integration is a constant process wherein the listener activates networks of semantic information as they listen to speech and then selectively deactivates some of those networks as new information rules out what the content of the sentence could be. If a particular sentence is modified only to provide neutral information, then this removes the ability to rule out potential anticipations and deactivate semantic networks. This increases the WM demand of processing the content of the sentence, as the automatic process of attempting to predict the final word of the sentence now must activate a much greater array of possibilities then in the case when the sentence allows some selective filtering (Collins and Loftus, 1974). The increased N400 observed in this study is therefore anticipated and consistent with the N400 effects observed in previous studies

(D'Arcy et al., 2005; Salisbury, 2004).

Due to the main effect of modality being non-significant and there being no significant interactions with modality, the hypothesis that the AV speech modality would modify the typical electrophysiological presentation of LC and HC sentences was not supported. It was anticipated that if the first hypothesis was supported and the AV modality yielded higher N400s generally as compared to A modality presentations, that specifically in the LC sentences the N400 would see a significantly greater increase in amplitude than in the HC sentences. The rationale behind this prediction centered around the semantic integration hypothesis. HC sentences, due to having an appropriate amount of contextual cues, should not be significantly demanding on WM resources to begin with and hence would not benefit from additional resources being available. LC sentences conversely are highly demanding on WM resources and so if additional resources are available due to earlier auditory processing being made more efficient it is reasonable to propose that these resources could benefit later taxing top-down language processes (Frtusova et al., 2013; Novais-Santos et al., 2007). The possible explanation for the absence of this effect is the same as the one proposed for the absence of a modality main effect: detection of the AV enhancement effect in younger adult participants may be obscured by their optimal hearing sensitivity. This explanation would require further verification as other research studies (Gordon & Allen, 2009) investigating age differences with the AV enhancement effect have not found results similar to those of Winneke and Phillips (2011). Instead these studies have found no significant difference in AV enhancement across the age groups.

While the initial hypotheses of the current study were not fully supported, further exploration of the data was conducted regarding the variable of WM. While the previous hypotheses all investigated variables that are specifically tied to WM functioning, the analysis did not specifically take into account individual variations in WM capacity. Perhaps with participants grouped based on a WM score different results might be found. It was this rationale that warranted conducting a split of participants into either low or high WM groups for the current study. This grouping was based on the LNS scores that had been previously administered to participants as a screening test for healthy cognitive functioning. Statistical analysis revealed that a median split would ultimately require scores of 11 or 12 to be excluded due to the determination that it would be unjustified to group participants with a score of 11 as low WM and participants with a score of 12 as high WM when the two scores are so close. For this reason, the current study utilized scores of 10 or lower to indicate a low WM participant and scores of 13 or higher to indicate a high WM participant, with 11 participants ultimately compromising both groups.

Dividing participants into WM groups as well as excluding those with LNS scores close to the median ultimately yielded results worthy of discussion. The main effect of WM group being significant supports the relation between WM capacity and semantic ambiguity. It was interestingly found that lowWM participants exhibited significantly more negative activity across all modalities, constraints, electrodes and times as compared to highWM participants. This result is surprising given the previous hypotheses that if WM resources were freed up in earlier processes they could be used to increase the size of the N400 effect. It should follow that participants with a high WM capacity have a great degree of resources available and therefore would distribute these resources when semantic integration is required. Instead the opposite appears to be occurring, wherein participants with a highWM capacity are able to more efficiently process both the audiovisual speech cues and the contextual speech cues, yielding lower amplitude ERP components as a result.

These results are interestingly contrary to the findings of Salisbury (2004) but are consistent with their original hypothesis. Salisbury (2004) predicted that participants with a highWM capacity would be able to more efficiently process challenging language information (yielding lower amplitude ERPs) but instead he found that his highWM group had higher amplitude ERP components compared to the lowWM group. The contradictory findings between Salisbury's (2004) findings and the current study may be explained by the WM tests utilized by Salisbury. While the current study utilized the LNS, a well-validated WM tool, Salisbury utilized tests typically more reflective of processing speed. As these tests ultimately informed the grouping of participants, the results Salisbury hoped to find may have been obscured by his WM group classification. The current study may have therefore succeeded in finding the originally anticipated results of Salisbury (2004), demonstrating the proposed processing efficiency inherent to highWM participants.

While having a significant main effect of WM group is promising in revealing the relation between WM resources and semantic integration, the most interesting result lies in the unique interaction between WM capacity, speech modality and sentence constraint. In the auditory modality, both high and low WM participants showed a similar amount of negative activity indicative of an N400 in the low constraint sentences. However, when presented with high constraint sentences, participants with a high WM capacity showed significantly less N400 activity when compared to lowWM participants. Conversely in the AV modality, low constraint sentences yielded similar activity as they did in the A modality but when presented with high constraint sentences the lowWM participants showed a similar reduction in the N400 amplitude as the highWM participants.

This significant interaction demonstrates that presenting stimuli in an AV modality can significantly modify the N400 effect but this is dependent on the WM capacity of participants. Participants with a high WM capacity appear able to distinguish between the content-rich HC sentences and the neutral LC sentences in both the A and AV modalities, taking advantage of the additional information to significantly reduce the N400 activity elicited from the LC sentences. This result reflects the findings of other studies demonstrating how the amplitude of the N400 effect will vary depending on the degree of difficulty in resolving the semantic information presented (Connolly et al., 1992). Participants with a low WM capacity however may be less able to mentally maintain the content cues provided in the HC sentences in the A modality. The result of this is that lowWM participants still exhibit some N400 activity in the A modality as they are unable to efficiently predict the terminal word of the sentence. It is important to note that lowWM participants still show some reduction in their N400 activity moving from LC to HC sentences, suggesting that they are able to take advantage of some of the contextual cues, just not to the same degree as highWM participants.

This pattern however changes when sentences are presented in the AV modality. Here the N400 effect is similar for both WM groups when presented with a LC sentence, but the reaction to HC sentences differs with lowWM participants now showing similar activity as compared to highWM participants. The results demonstrate that when speech is presented in an AV modality the addition of visual speech cues seems to allow lowWM participants to better take advantage of the contextual cues in a similar fashion to the highWM participants. Overall it appears that when participants with a lower capacity for WM are presented speech in an AV capacity they are able to utilize the available information to the same degree as participants with a high WM capacity.

This finding presents broader implications for the utility of the AV enhancement effect. Previous research (e.g., Garstecki, 1983; Walden et al., 1993; Grant & Seitz, 1998) on AV enhancement has not specifically investigated utilizing the combination of auditory and visual speech cues for top-down language processes like semantic integration. The results of this study indicate that the simple opportunity to see the individual speaking can assist in the processing of challenging language information for individuals with an overall lower WM capacity. Given the significant amount of communication in contemporary society that does not rely on face-to-face contact (i.e. telecommunications), this may result in a substantial population with lower WM capacities who have to devote significant WM resources and may in some cases struggle with processing language information. It is noteworthy that the HC sentences in this experiment are specifically designed to present contextually appropriate cues so as to allow efficient activation of semantic networks and anticipation of the final word. Despite this, participants in the lowWM group still exhibited N400 activity indicative of effortful semantic integration. Broadly speaking this indicates that AV speech presentation is not only useful to lowWM individuals in the limited context of challenging semantic content but also in regards to everyday communication. For individuals with a lower WM capacity, face-to-face communication will assist in reducing the degree of mental resources required for top-down language processes like semantic integration.

Limitations and Future Research

A significant limitation to the current study involved its use of comprehension questions to ensure sufficient attention was being paid to the stimuli sentences throughout the experiment. Specifically the comprehension questions utilized were all simple yes or no questions that only inquired about the presence or absence of key concepts in the last sentence heard. For example if the last sentence was *"Angie talked to the cameraman about the weather,"* the following question would be *"Did Angie talk to the cameraman about the traffic accident?"* Feedback from several participants indicated that these questions were too simple and did not require significant attention to answer with complete accuracy. Indeed analysis revealed that no participant got more than two comprehension questions incorrect and most answered every question completely correct. While this result might be interpreted as a positive sign that participants paid sufficient attention throughout the experiment, the consistently high success rate likely suggests that most participants found the comprehension questions easy and therefore they likely failed to serve as a reliable method of maintaining sufficient attention. While it is true that the N400 activity differences between the HC and LC sentences also indicates the participants were paying sufficient attention, this attention may have just been the minimum required to notice the differences between the sentences. Replications of this study and future variations should likely develop more challenging comprehension questions to ensure that participants are paying sufficient attention. Doing so might even have an effect on the amplitude of the ERP components, as participants are required to pay significantly greater attention in order to answer more challenging questions, with that attention benefiting the processing of the sentences' contextual cues.

A second major limitation concerned the use of the LNS as an exclusive WM measure. Specifically the LNS was originally included as a measure of individual WM capacity but the objective was not to utilize LNS scores for grouping purposes. Fortunately the LNS is a well-validated tool for assessing WM function but as the significant results of this study ultimately relied on grouping participants based on WM function it would have been beneficial to have more than one WM test in order to ensure reliable measurement and grouping. Given the fact that WM grouping was based on very small differences between scores, being able to cross-reference LNS scores with other WM measures (potentially other tests from the WAIS-IV such as the Digit-Span test) would ensure that the LNS scores could be relied on for such a critical analysis grouping. As this study has ultimately found support that audiovisual speech specifically benefits participants with a lowWM capacity, adding additional tests would only serve to add further credibility to this finding.

Another significant limitation to the current study concerns the unbalanced presentation order numbers for the WM groups. As the study was not originally intended to group participants based on their WM capacities, the study failed to evenly distribute both low and high WM participants across the two presentation orders. As a result, any analysis of presentation order effects may be unreliable. Subsequent research and continuations of the current study design will easily be able to rectify this problem by specifically controlling for which presentation order each low or high WM participant receives.

Finally, as was noted in the explanation for the modality hypothesis, a potential explanation for the non-significant modality results was that younger adults, as compared to older adults, simply do not experience as significant of an audiovisual enhancement effect. Older adults on the other hand, due to the general decline in hearing sensitivity associated with aging (C.H.A.B.A., 1988), have been found to utilize visual speech cues to a greater degree and translate this to a more pronounced AV enhancement effect. Older adults would represent an ideal participant population to sample for a replication of the current study, with the intention to determine if any significant difference could be found between the younger adult and older adult populations. The results of the current study are promising but may only scratch the surface of the relationship between WM capacity and top-down language functions. Investigating a population with an established decline in hearing sensitivity would both further elucidate the relationship between those variables and also inform on new strategies to assist comprehension in an otherwise impaired age group.

Conclusions

The current sought to investigate the relationship between AV speech presentation, semantic integration and WM. It was ultimately found that individuals with a high WM capacity could take greater advantage of contextual cues to assist in semantic integration, reducing the amplitude of the N400 effect elicited by sentences with neutral contextual information. It was further found that while participants with a low WM capacity were less effective at utilizing contextual cues to assist semantic integration (as evidenced by a higher N400 effect as compared to the highWM group), the presentation of speech in an AV modality alleviated this deficit and allowed low WM participants to take advantage of the additional language information similar to the high WM participants. These results broadly demonstrate that face-to-face communication is useful in allowing the efficient processing of language information, particularly for individuals who experience difficulties maintaining information mentally over long periods of time. This paper serves as an initial foray into linking the AV enhancement effect with top-down language processes like semantic integration and will hopefully encourage subsequent research in populations with varying WM capacities.

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Table 1

Descriptives and Screening Test Results

	Mean			Standard Deviation			Minimum			Maximum		
Group	Overall	LowWM	HighWM	Overall	LowWM	HighWM	Overall	LowWM	HighWM	Overall	LowWM	HighWM
Age	24.57	24.09	26.09	3.88	3.18	3.73	18.00	21.00	22.00	35.00	30.00	35.00
Education	16.32	16.00	17.27	1.76	1.34	1.95	14.00	15.00	14.00	20.00	19.00	20.00
MoCA	27.82	27.64	28.00	1.31	1.36	1.55	26.00	26.00	26.00	30.00	30.00	30.00
LNS	11.64	9.64	13.82	2.00	0.67	0.75	8.00	8.00	13.00	15.00	10.00	15.00
MARS (Left)	1.65	1.62	1.67	0.06	0.04	0.07	1.54	1.56	1.56	1.80	1.72	1.80
MARS (Right)	1.67	1.65	1.69	0.05	0.05	0.06	1.52	1.52	1.60	1.80	1.72	1.80
MARS (Both)	1.71	1.69	1.72	0.05	0.05	0.05	1.64	1.64	1.68	1.80	1.80	1.80
MNREAD Acuity	-0.02	-0.02	0.00	0.10	0.13	0.07	-0.18	-0.18	-0.10	0.30	0.30	0.12
MNREAD Reading Speed	166.96	168.64	165.45	28.20	31.31	28.76	120.00	120.00	120.00	200.00	200.00	200.00
PTA (Left)	9.17	9.85	8.64	4.27	4.62	4.82	0.00	0.00	1.67	16.67	16.67	15.00
PTA (Right)	8.45	9.24	8.03	3.87	3.75	4.93	1.67	5.00	1.67	15.00	15.00	15.00
PTA (Both)	8.81	9.54	8.33	3.92	4.00	4.76	1.67	2.50	1.67	15.83	15.83	14.17

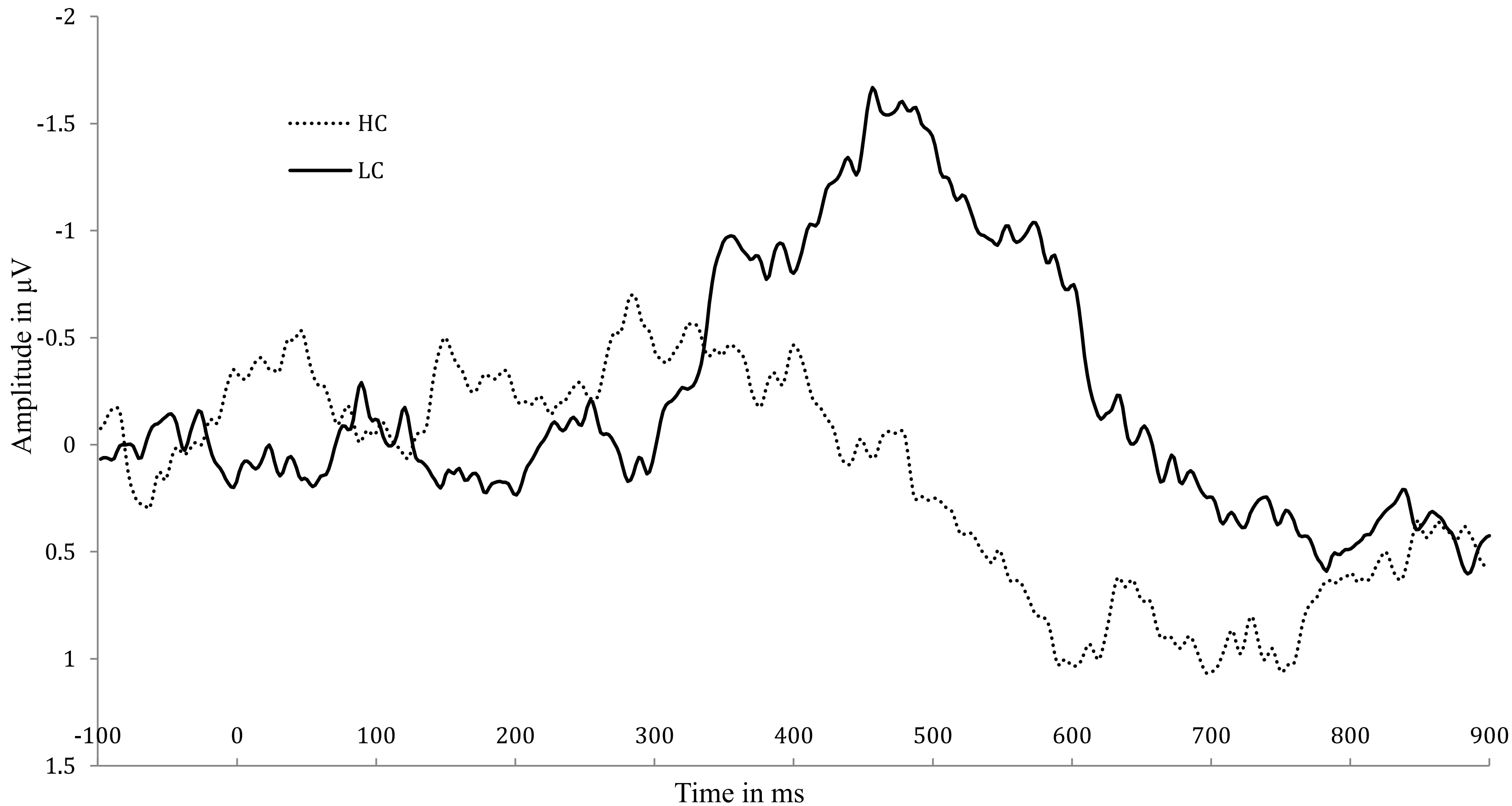

Figure 1 – LC vs. HC Sentences for all Participants (CPz electrode)

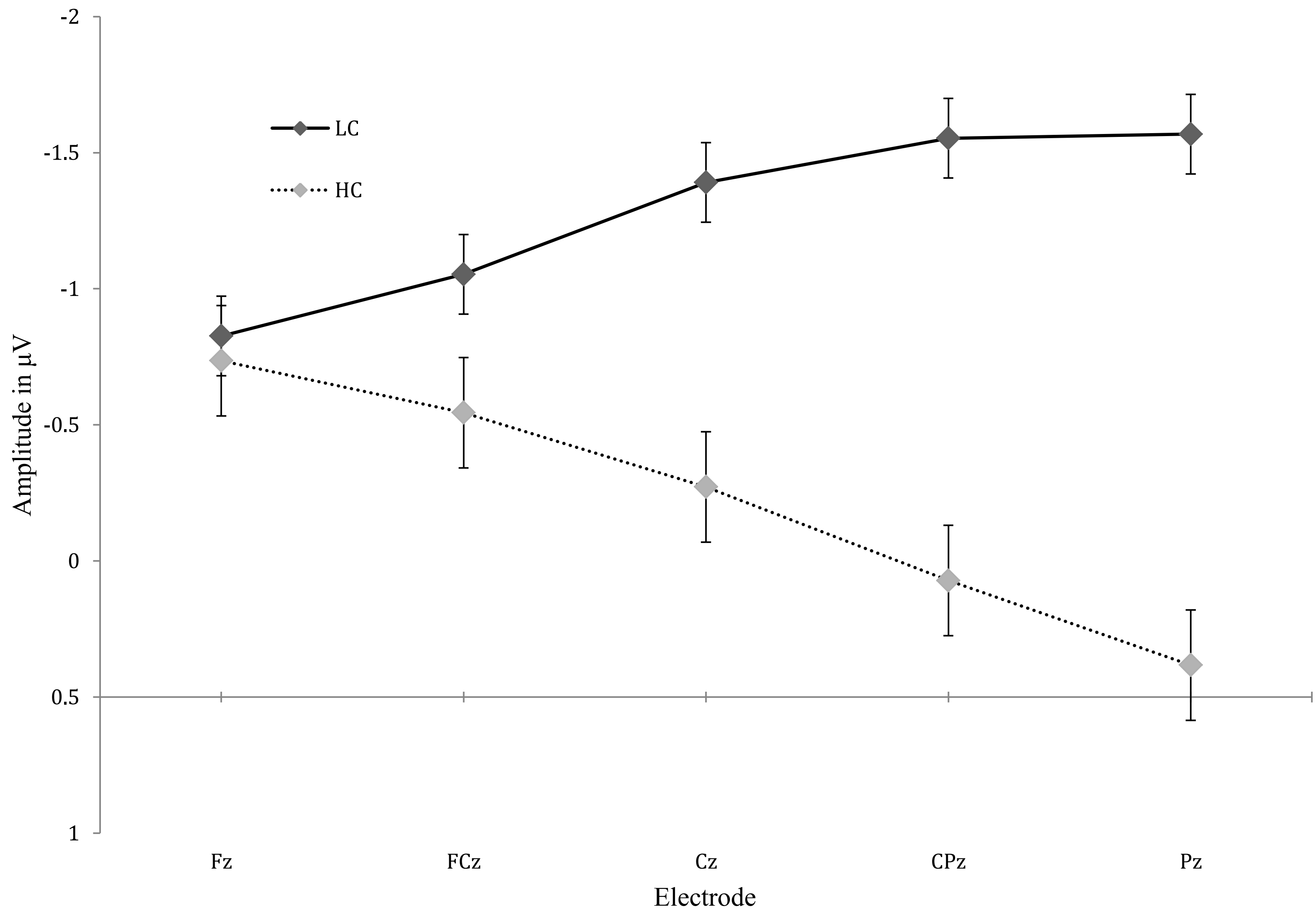

Figure 2 – Low Constraint vs. High Constraint Sentences Across Five Electrode Sites for All Participants (measured at 450-500ms interval)

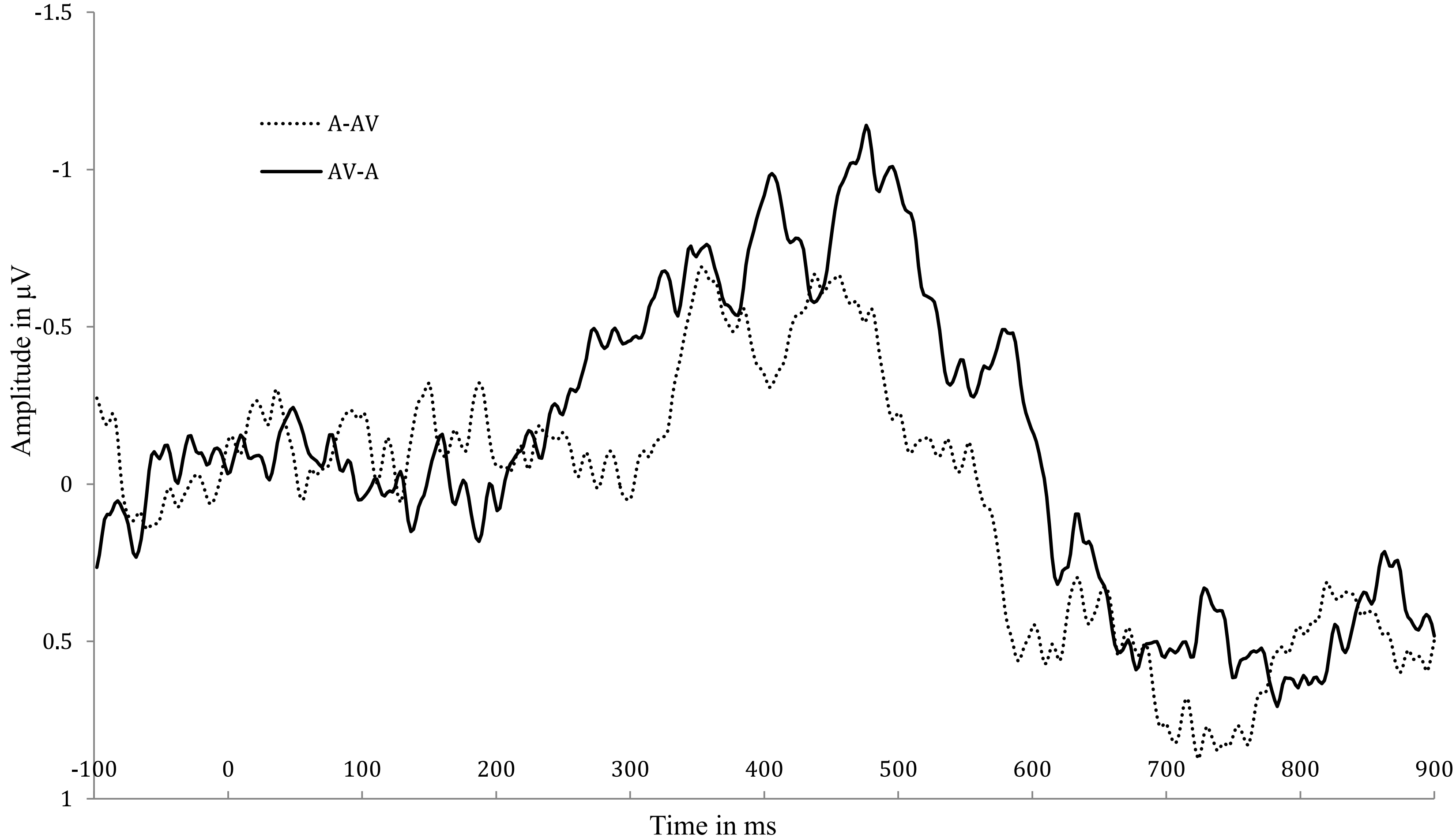

Figure 3 – Ordering Effects Across All Time Intervals for All Participants (CPz electrode)

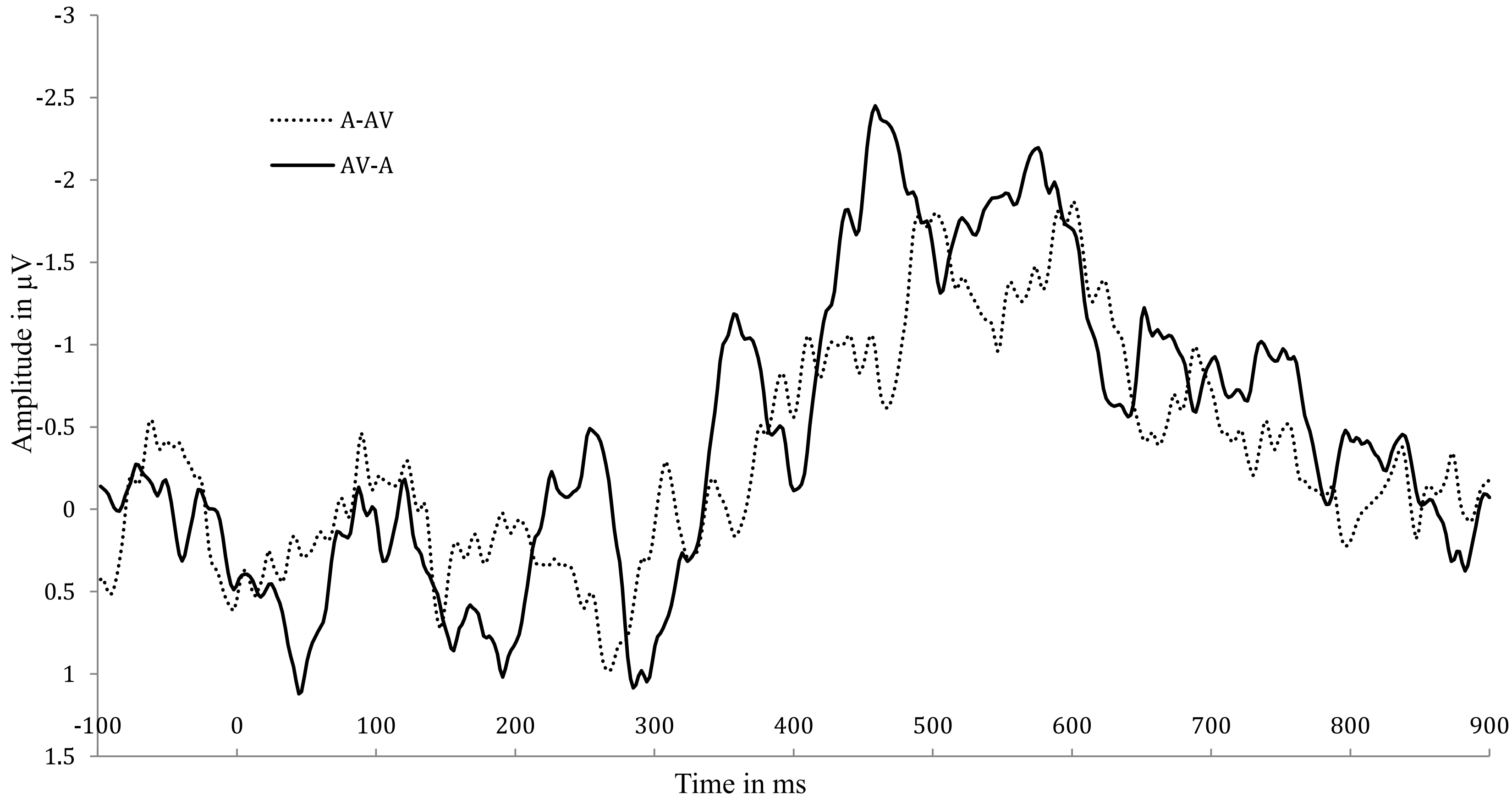

Figure 4 – Difference Wave (subtraction of HC waves from LC waves) Ordering Effects Across All Time Intervals for All Participants (CPz electrode)

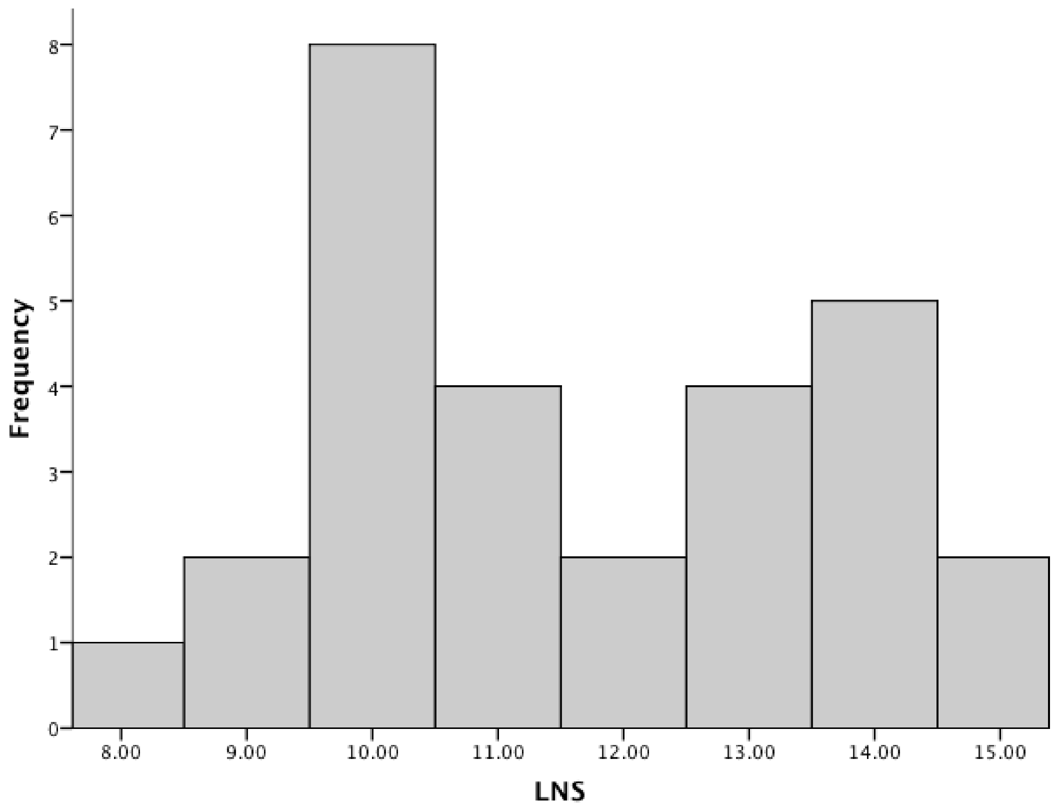

Figure 5 – Histogram of LNS Scores for All Participants (scores of 10 or lower grouped as low WM, scores of 13 or higher grouped as high WM)

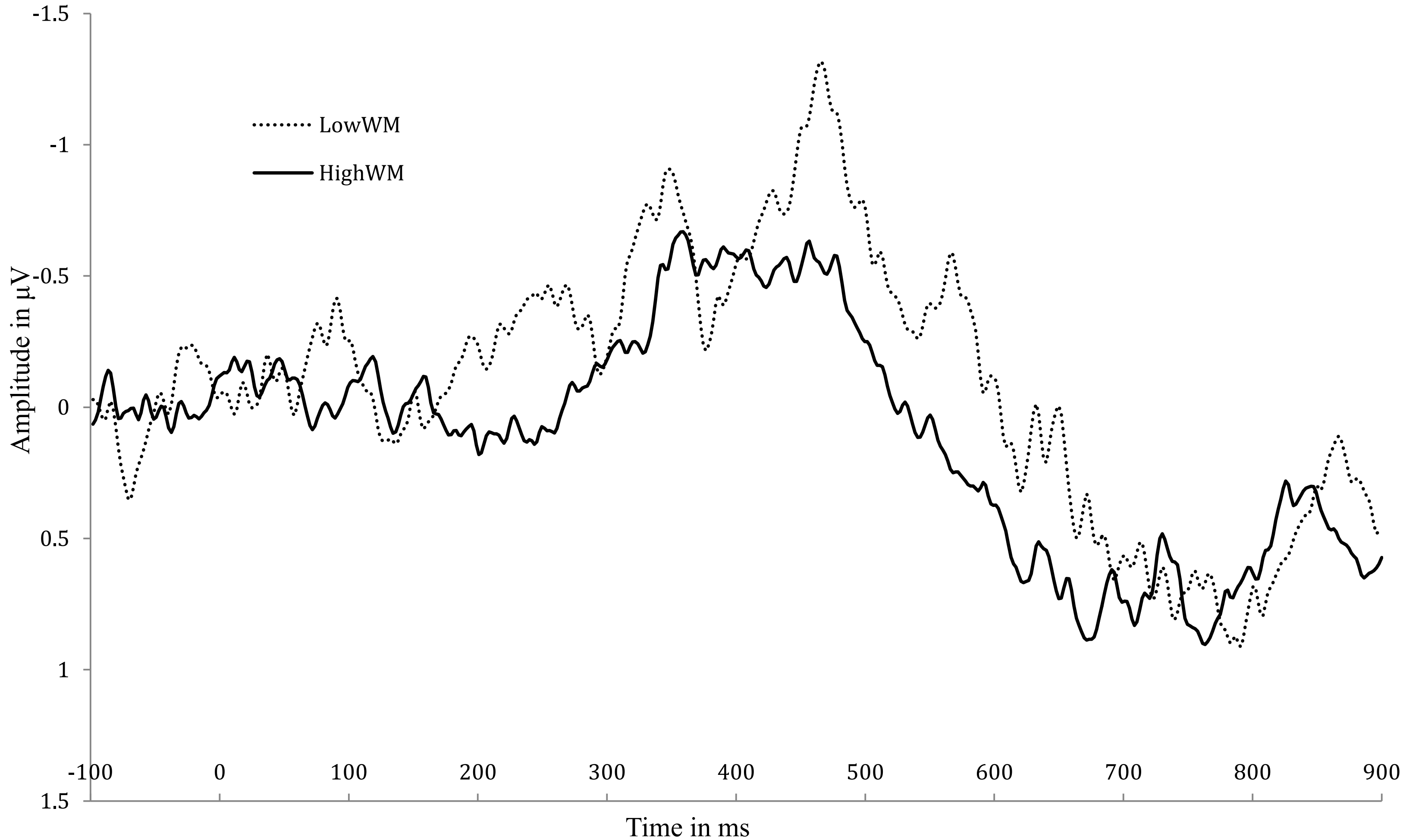

Figure 6 – LowWM vs. HighWM Across All Time Intervals (CPz electrode)

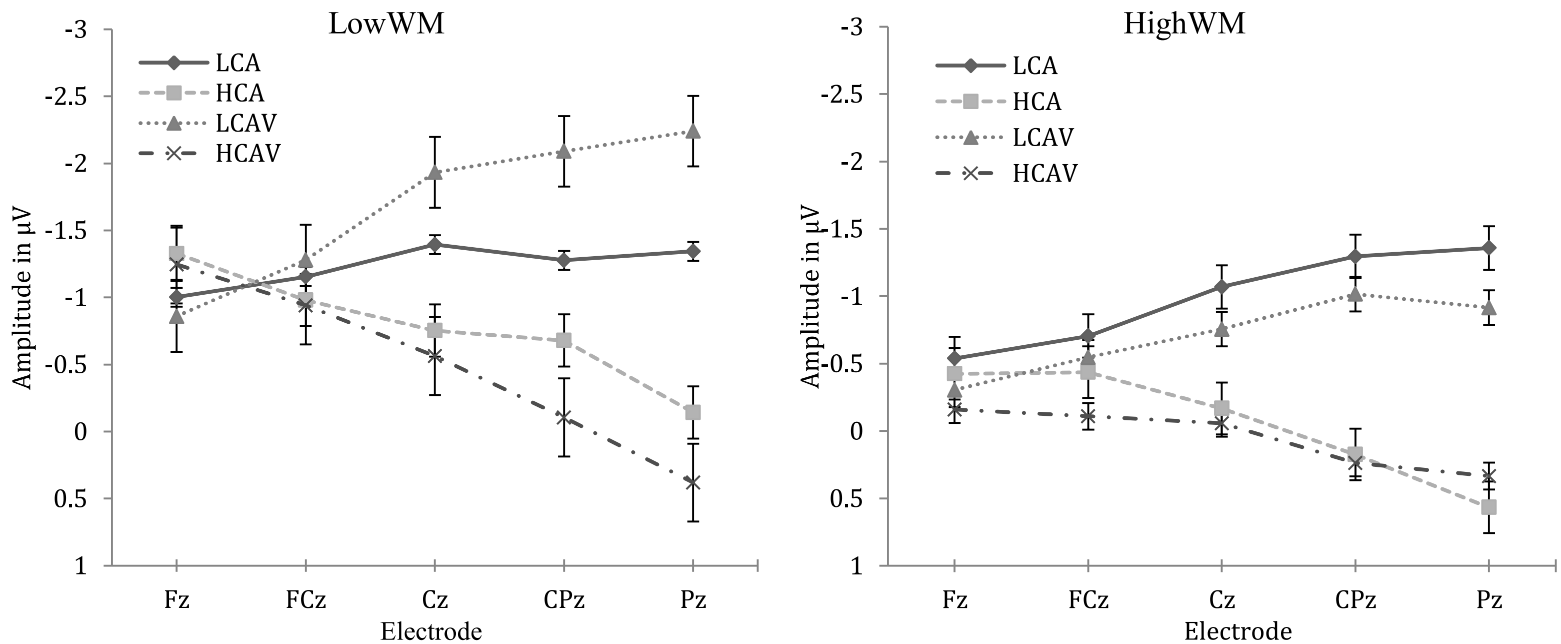

Figure 7 – Modality and Constraint (LCA, LCAV, HCA, HCAV) at Five Electrode Sites for both LowWM and HighWM Groups (measured at 450-500ms interval)

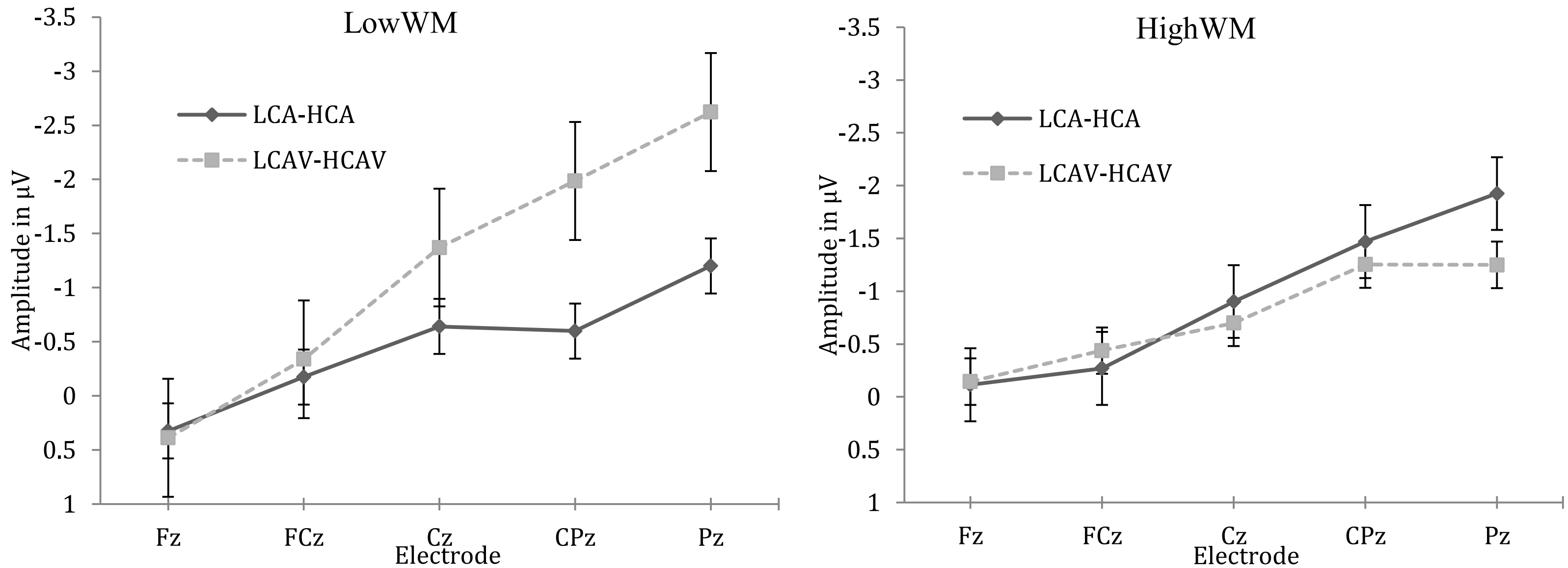

Figure 8 – Difference Waves (subtraction of HC waves from LC waves in both modalities) of Modality at Five Electrode Sites for both LowWM and HighWM Groups (measured at 450-500ms interval)

Appendix A

Id: __________ Interviewer: _____________ Date (D/M/Y): _____________

Health History Questionnaire[*]

We are interested in your personal history because it may help us to better understand the results of our study. Your answers to a few short questions will aid us in this effort. All answers will be kept strictly confidential. Thank you for your help.

Demographics:

1. Date of Birth (D/M/Y):_____________ 2. Age:_________________

3. Gender: *(circle response)* (1) Male (2) Female

4. Overall handedness: *(circle response)* (1) LEFT (2) RIGHT (3) BOTH
   Which hand do you use to write with: *(circle response)* (1) LEFT (2) RIGHT (3) BOTH
   Were you ever made to switch which hand you use for common tasks? *(circle response)* YES NO
   If YES, please elaborate: ____
   ____
   ____
   ____
   ____

5. Present marital status: *(circle response)* (1) Single – never married
   (2) Married
   (3) Separated
   (4) Divorced
   (5) Widowed
   (6) Cohabit

Language

7. Place of Birth:____

8. If not Canada, how long have you been in Canada? __________________________________

9. Languages Spoken (in order of fluency):____

10. Primary Language/Language of choice:____

11. Language at home:_____________________ 10. At work: _________________________

12. At what age did you first learn English/French? ____________________________________

13. At what age did you become fluent in it ? ______________________________________

14. How would you rate, from 1 to 5[1], your level of proficiency in the languages you speak? What percentage of time do you speak it?

[*] Questionnaire updated May 2013
[1] 1: No ability at all; 2: Very little; 3: Moderate; 4: Very good; 5: Native-like ability

Id: __________ **Interviewer:** _____________ **Date (D/M/Y):** _____________

Language	Rating (**L**istening, **R**eading, **S**peaking, **W**riting):
1. ___________________	L: ____ R: ____S: ____ W: ____ %:____
2. ___________________	L: ____ R: ____S: ____ W: ____ %:____
3. ___________________	L: ____ R: ____ S: ____W: ____ %:____
4. ___________________	L: ____ R: ____S: ____ W: ____ %:____

These questions are to be administered for studies interested in language and/or bilingualism:

6. Parents' places of birth and native languages:
mother: __________________ father: ______________________________________

Have you ever spent a long period of time in another country in which you had to communicate in a language other than your native language? Indicate these cities, languages, and the age at which you lived there:
No.

What is your primary language or language of choice? __________________________

Which languages do you speak… (and if more than one, which is primary?)
at home? ____
with close family (parents/siblings)? ____________________________________
with extended family (grandparents)? ___________________________________
with friends? ____
with yourself (e.g. when you dream)? ___________________________________

In what language(s) do you listen to the radio? Watch tv? ___________________________________
Which language(s) do you use at work (estimate percentage for each)?
At school: ____

In which language was your education?
primary________ secondary_________ cegep_________ university____________

How did you learn your second language? ____

____

15 . How many years of education do you have at this time? (i.e., what is the highest level achieved?)

1 2 3 4 5 6	7 8 9 10 11	12 13	14 15 16	17 18 19 20	21 22 23 24 25
Elementary	Secondary	Cegep	Undergrad	Graduate	Professional

16. In what field did you complete your degree? _____________________________

17. Did you skip or repeat a grade?
A) NO / YES
B) Which one (s):____

Id: __________ Interviewer: _____________ Date (D/M/Y): _____________

18. Did you have any particular difficulty with any subject in school?
    A) NO/YES
    B) Which one (s): ____

19. What is or was your main occupation? ____

20. What was your longest held occupation? ____

21. When did you retire? _________________

22. How many hours per week do you engage in physical exercise? ______________________

23. How many hours per week do you engage in a social activity (this can include interacting with members of your household)?_____________

[redacted]

Medical History

24. Do you have now, or have you had in the past -*(please circle your response)*

- Visual problems:
  A) Nearsighted / Farsighted
  B) Glasses / Contact lenses[2]
  C) Cataract: Left / Right
  D) Colour blind: NO / YES

[2] If participant usually wear contact lenses, he/she will have to wear glasses on ERP testing sessions (to prevent blinking).

Id: __________ Interviewer: _____________ Date (D/M/Y): _____________

- Trouble hearing: E) NO / YES
  F) Hearing Aid: Left / Right

25. Have you ever been unconscious[3], had a head injury or had blackouts[4]?
    A) NO / YES
    B) Cause:____
    C) Duration:____
    D) Treatment:____
    E) Outcome:____

26. Have you been seriously ill or hospitalized in the past 6 months?
    A) NO / YES
    B) Cause:____
    C) Duration:____

Do you have now, or have you had in the past (conditions susceptible or influencing cognitive functions)...

27. a) A stroke? b) [s] Transient ischemic attack (mini-stoke[5])?	NO / YES NO / YES	
28[s]. Bypass surgery?	NO / YES	
29[S] Heart disease? Pacemaker? (If yes, **OK** for testing)	NO / YES NO / YES	Nature (myocardial infarction [MI], angina, narrowing of arteries):
30 [S] High blood pressure?	NO / YES	Is it controlled? NO / YES What medication? _________________
31 [S]. High cholesterol?	NO / YES	Is it controlled? NO / YES What medication? _________________
32 [S]. a) Diabetes? b) Insulin dependent?	NO / YES	Type 1 / Type 2 Age of onset: __________________ Treatment: __________________
33. Other Surgery?	NO /YES	
34. Seizures?	NO / YES	Age Onset: ______________________ Frequency: ______________________ Cause: ______________________ Treatment: ______________________
35. Epilepsy?	NO / YES	
36. Thyroid disease?	NO / YES	
37. Frequent headaches?	NO / YES	Tension / migraine
38. Dizziness?	NO / YES	
39. Trouble walking Unsteadiness?	NO / YES NO / YES	

[3] Falling unconscious ≠ Fainting
[4] Exclude: Substantial head injury relatively recently, several concussions, & coma.
[S] Risk factors for stroke. Exclusion criterion: More than one of those factors, if older participants.
[5] Mini-stroke: symptoms less than 24 hours.
[S] Risk factors for stroke. Exclusion criterion: More than one of those factors, if older participants.

Id: __________ Interviewer: _____________ Date (D/M/Y): _____________

40. Arthritis?	NO / YES	
41. Any injuries to the lower limb? (e.g. hip, knee, ankle)	NO / YES NO / YES	
42. Serious illness (e.g. liver disease)?	NO / YES	
43. Neurological disorders[6]? (e.g. lupus, MS, Parkinson's)	NO / YES	
44. Exposure to toxic chemicals (that you know of)?	NO / YES	
45. Depression?	NO / YES	Did you seek assistance or feel the need to so? ______________________ Is it controlled? ______________________
46. Anxiety?	NO / YES	Did you seek assistance or feel the need to so? _____________________ Is it controlled? __________
47. Other psychological difficulties?	NO / YES	
48. Hormone replacement?	NO / YES	
49. Steroids?	NO / YES	

50. Medication: Please list the medication you are currently taking and any other medication that you have taken in the past year.

Type of medication		Reason for consumption	Duration of consumption and dose
A			
B			
C			
D			
E			
F			

51. Do you drink alcohol? a) YES, frequently.
b) YES, but infrequently.
c) NO.
If YES, approximately how many drinks[7] of alcohol do you have per week?___________________________________

52. Do you use non-prescription drugs such as homeopathic medications, vitamins, laxatives, syrups ?
NO / YES
If YES, which one (s): ____
How many times per week?
a) Occasionally b) 1 - 3 c) 4 - 6 d) more than 6

[6] Automatic exclusion
[7] 1 drink = 1 beer, 1 glass of wine, 1 oz of liquor. 2 drinks/day is considered moderate drinking.

Id: __________ Interviewer: _____________ Date (D/M/Y): _____________

53. Do you use non-prescription drugs for recreational purposes?

NO / YES

If yes, do you use marijuana/hashish?
NO / YES
If YES, How many times per week?
a) Occasionally b) 1 - 3 c) 4 - 6 d) more than 6

Do you use any other non-prescription drugs for recreational purposes?
NO / YES
If YES, How many times per week?
a) Occasionally b) 1 - 3 c) 4 - 6 d) more than 6
If yes, which one (s): (*participant not obliged to answer*) ________________________

Ask participant to not use drugs prior to testing (~48hr)

54. Do you smoke[S]?

NO / YES
If YES, How many packs a day (or average quantity)? _____________

55. Current problems: Are you currently troubled by any of the following[8]?

a) Concentration / Attention problems?
NO / YES
Nature: ____

b) Memory problems?
NO / YES
Nature: ____

c) Difficulties finding words?
NO / YES
Nature: ____

56) How would you rate your health? *(circle response)*

1) poor 2) fair 3) good 4) very good 5) excellent

[8] Please remind potential older participants who are interested in participating to research because of memory concerns that we do NOT provide full clinical assessments

Id: __________ **Interviewer: _____________** **Date (D/M/Y): _____________**

57) Have you participated in other studies (outside of our lab)? NO/YES

If **YES**, which lab did the study take place?

____
____
____
____
____

What was the purpose of the study (or any details about the study)?

____
____
____
____
____

When did the study take place?

____
____
____
____
____

Id: __________ Interviewer: _____________ Date (D/M/Y): _____________

<u>Participant contact information</u>:

Name: ____ _____________________ ________

Phone Number: _________________________________ _____________________________

Email: _________________________________ _____________________________________

Address ***(remind participant that this section is optional)***:

____

________________ ________________________________

________________ ______**e**________________________

Are you willing to b contacted by researchers i D . Phillips' lb for future sud ies?
NO / YES

What year will you graduate? __________________________ ________________

Can we give your contact information to other Concordia researchers (name, tel. #, email address)?
NO / YES

Source: ____

Eligibility:

- You are not eligible for this study due to ________ reasons, but you may be eligible for other studies, so we'll keep your information on file
- I need to discuss some issues with my colleagues, and I will contact you to let you know if you are eligible to participate.
- If they ask why they are ineligible:
  - We are interested in cognitive processing and certain conditions, medications, and habits interfere with cognitive processing, therefore we cannot test people who meet those criteria

Appendix B

SPIN-R Sentences

Low Constraint

#	Sentence	Original SPIN-R List
1	Miss White won't think about the CRACK.	1
2	He would think about the RAG.	1
3	The old man talked about the LUNGS.	1
4	I was considering the CROOK.	1
5	Bill might discuss the FOAM.	1
6	Nancy didn't discuss the SKIRT.	1
7	Bob has discussed the SPLASH.	1
8	Ruth hopes he heard about the HIPS.	1
9	She wants to talk about the CREW.	1
10	They had a problem with the CLIFF.	1
11	You heard Jane called about the VAN.	1
12	We could consider the FEAST.	1
13	Bill heard we asked about the HOST.	1
14	I had not thought about the GROWL.	1
15	He should know about the HUT.	1
16	I'm glad you heard about the BEND.	1
17	You're talking about the POND.	1
18	Nancy had considered the SLEEVES.	1
19	He can't consider the CRIB.	1
20	Tom discussed the HAY.	1
21	She's glad Jane asked about the DRAIN.	1
22	Bill hopes Paul heard about the MIST.	1
23	We're speaking about the TOLL.	1
24	We spoke about the KNOB.	1
25	I've spoken about the PILE.	1
26	Miss Black thought about the LAP.	2
27	Miss Black would consider the BONE.	2
28	Bob could have known about the SPOON.	2
29	He wants to talk about the RISK.	2
30	He heard they called about the LANES.	2
31	She has known about the DRUG.	2
32	I want to speak about the CRASH.	2
33	I should have considered the MAP.	2
34	Ruth must have known about the PIE.	2

35	The man should discuss the OX.	2
36	They heard I called the PET.	2
37	Bill cannot consider the DEN.	2
38	She hopes Jane called about the CALF.	2
39	Jane has a problem with the COIN.	2
40	Paul hopes she calls about the TANKS.	2
41	The girl talked about the GIN.	2
42	Mary should think about the SWORD.	2
43	Ruth could have discussed the WITS.	2
44	You had a problem with a BLUSH.	2
45	We have discussed the STEAM.	2
46	Tom is considering the CLOCK.	2
47	You should not speak about the BRAIDS.	2
48	Peter should speak about the MUGS.	2
49	He has a problem with the OATH.	2
50	Tom won't consider the SILK.	2
51	Mr White discussed the CRUISE.	3
52	Miss White thinks about the TEA.	3
53	He is thinking about the ROAR.	3
54	She's spoken about the BOMB.	3
55	You want to talk about the DITCH.	3
56	We're discussing the SHEETS.	3
57	Betty considered the BARK.	3
58	Tom discussed the SWAN.	3
59	You'd been considering the GEESE.	3
60	They were interested in the STRAP.	3
61	He could discuss the BREAD.	3
62	Jane hopes Ruth asked about the STRIPES.	3
63	Paul spoke about the PORK	3
64	Mr Smith thinks about the CAP.	3
65	We are speaking about the PRIZE.	3
66	Harry had thought about the LOGS.	3
67	Bob could consider the POLE.	3
68	Ruth has a problem with the JOINTS.	3
69	He is considering the THROAT.	3
70	We can't consider the WHEAT.	3
71	The man spoke about the CLUE.	3
72	David has discussed the DENT.	3
73	Bill heard Tom called the COACH.	3
74	Jane has spoken about the CHEST.	3
75	Mr White spoke about the FIRM.	3

76	Mary had considered the SPRAY.	4
77	The woman talked about the FROGS.	4
78	Miss Brown will speak about the GRIN.	4
79	Bill can't have considered the WHEELS.	4
80	Mr Smith spoke about the AID.	4

High Constraint

#	**Sentence**	**Original SPIN List**
1	The door was opened just a CRACK.	2
2	Wipe your greasy hands on the RAG.	2
3	The cigarette smoke filled his LUNGS.	2
4	The policemen captured the CROOK.	2
5	The cushion was filled with FOAM.	2
6	She shortened the hem on her SKIRT.	2
7	Paul hit the water with a SPLASH.	2
8	Bob stood with his hands on his HIPS.	2
9	The ship's Captain summoned his CREW.	2
10	The car drove off the steep CLIFF.	2
11	Household goods are moved in a VAN.	2
12	The wedding banquet was a FEAST.	2
13	The guests were welcomed by the HOST.	2
14	The watchdog gave a warning GROWL.	2
15	The natives built a wooden HUT.	2
16	Follow this road around the BEND.	2
17	The ducks swam around on the POND.	2
18	The sport shirt has short SLEEVES.	2
19	The baby slept in his CRIB.	2
20	The farmer baled his HAY.	2
21	Ruth poured the water down the DRAIN.	2
22	The nozzle sprays a fine MIST.	2
23	The flood took a heavy TOLL.	2
24	Unlock the door and turn the KNOB.	2
25	The sand was heaped in a PILE.	2
26	Hold the baby on your LAP.	1
27	The dog chewed on a BONE.	1
28	Stir your coffee with a SPOON.	1
29	His plan meant taking a big RISK.	1
30	The super highway had six LANES.	1
31	The doctor prescribed the DRUG.	1

32	No one was injured in the CRASH.	1
33	We're lost so let's look at the MAP.	1
34	For dessert he had apple PIE.	1
35	The plow was pulled by an OX.	1
36	My son has a dog for a PET.	1
37	They tracked the lion to his DEN.	1
38	The cow gave birth to a CALF.	1
39	Let's decide by tossing a COIN.	1
40	The war was fought with armored TANKS.	1
41	They drank a whole bottle of GIN.	1
42	He killed the dragon with his SWORD.	1
43	He was scared out of his WITS.	1
44	The rude remark made her BLUSH.	1
45	The old train was powered by STEAM.	1
46	We heard the ticking of the CLOCK.	1
47	Mary wore her hair in BRAIDS.	1
48	The beer drinkers raised their MUGS.	1
49	The witness took a solemn OATH.	1
50	The scarf was made of shiny SILK.	1
51	The steamship left on a CRUISE.	4
52	Ruth poured herself a cup of TEA.	4
53	The lion gave an angry ROAR.	4
54	The airplane dropped a BOMB.	4
55	The workers are digging a DITCH.	4
56	She made the bed with clean SHEETS.	4
57	Tree trunks are covered with BARK.	4
58	The duck swam with the white SWAN.	4
59	We saw a flock of wild GEESE.	4
60	The sandal has a broken STRAP.	4
61	Spread some butter on your BREAD.	4
62	A zebra has black and white STRIPES.	4
63	The meat from a pig is called PORK.	4
64	She wore a feather in her CAP.	4
65	Her entry should win first PRIZE.	4
66	The cabin was made of LOGS.	4
67	Raise the flag up the POLE.	4
68	Your elbows and knees are JOINTS.	4
69	I've got a cold and a sore THROAT.	4
70	The bread was made from the whole WHEAT.	4
71	The detectives searched for a CLUE.	4
72	How did your car get that DENT?	4

73	The team was trained by their COACH.	4
74	The doctor x-rayed his CHEST.	4
75	He's employed by a large FIRM.	4
76	Kill the bugs with this SPRAY.	3
77	The pond was full of croaking FROGS.	3
78	She faced them with a foolish GRIN.	3
79	A bicycle has two WHEELS.	3
80	The nurse gave him first AID.	3

Appendix C

Comprehension Questions

Sentence	**Question**	**Answer**
The car drove off the steep CLIFF.	Did the car drive into a tree?	No
The baby slept in his CRIB.	Did the baby sleep in his stroller?	No
The dog chewed on a BONE.	Did the dog chew on the furniture?	No
Stir your coffee with a SPOON.	Should you stir your coffee with a spoon?	Yes
The cigarette smoke filled his LUNGS.	Is the smoke in his lungs from a forest fire?	No
No one was injured in the CRASH.	Was anyone injured in the crash?	No
We're lost so let's look at the MAP.	Are they proposing looking at a map?	Yes
He killed the dragon with his SWORD.	Was the dragon killed with a sword?	Yes
Spread some butter on your BREAD.	Should you spread butter on the bread?	Yes
The meat from a pig is called PORK.	Is the meat called pork?	Yes
Her entry should win first PRIZE.	Should her entry be disqualified?	No
I've got a cold and a sore THROAT.	Does she have a headache?	No
He's employed by a large FIRM.	Is he employed by the grocery store?	No
She faced them with a foolish GRIN.	Does she have a foolish grin on her face?	Yes
Bill heard we asked about the HOST.	Did Bill hear that we asked about the host?	Yes
Nancy had considered the SLEEVES.	Did Nancy consider the sleeves?	Yes
He wants to talk about the RISK.	Does he want to talk about safety?	No
She has known about the DRUG.	Does she know about the fire?	No
Jane has a problem with the COIN.	Does Jane have a problem with the coin?	Yes
The girl talked about the GIN.	Is the girl talking about gin?	Yes
Tom is considering the CLOCK.	Is Tom considering the television?	No
He is thinking about the ROAR.	Was he thinking about the roar?	Yes
Betty considered the BARK.	Did Betty consider the music?	No