

## PHONOLOGICAL PROCESSING OF VISUAL-SPEECH

PHONOLOGICAL PROCESSING OF VISUAL-SPEECH:  
THE PHONOLOGICAL MAPPING NEGATIVITY (PMN) AMPLITUDE IS  
SENSITIVE TO FEATURES OF ARTICULATION

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## **Abstract**

The goal of this study was to elucidate whether articulations of visual-speech are processed phonologically, and in the same manner as auditory-speech. Phonological processing, measured through the amplitude of the Phonological Mapping Negativity (PMN), was compared across three conditions using the electroencephalogram (EEG). Planned polynomial contrasts compared conditions of related and unrelated linguistic stimuli versus a non-linguistic control stimulus. A significant Site x Condition polynomial trend at posterior sites (Pz and Oz) during the N400 time window revealed that the unrelated condition was most negative in amplitude, an N400-like deflection in the control condition reached similar negative amplitude, while the related condition was the most positive. A significant quadratic trend of PMN amplitude differentiated between the linguistic conditions and the non-linguistic control at site Fz, but did not differentiate the related and unrelated linguistic conditions from each other. These results support a conclusion that non-lexical speech-like and gurning motions of the lips are treated differently than articulations of a meaningful nature. Moreover, the PMN response patterned similarly in the linguistic conditions, compared to the non-linguistic control, indicating phonological processing. The prediction that PMN amplitude will distinguish visual-speech events congruent or incongruent to a phonologically constrained context was not supported.

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## **List of Symbols and Abbreviations**

<b>Abbreviation</b>	<b>Meaning</b>
Ag/AgCl	Silver/Silver Chloride
CMS	Common Mode Sense
CPVT	Carolina Picture Vocabulary Test
Cz	central midline electrode site
db	Decibel
DC	Direct Current
DRL	Driven Right Leg
EEG	Electroencephalogram
ERP	Event Related Potential
Fpz	frontal midline electrode site
FPS	Frames Per Second
Fz	frontal-central midline electrode site
Hz	Hertz
ICA	Independent Components Analysis

ms	Milliseconds
N100	An ERP component characterized as a negative-going deflection at approximately 100 ms post-stimulus onset
N400	An ERP component characterized as a negative-going deflection at approximately 400 ms post-stimulus onset.
Oz	occipital midline electrode site
PMN	Phonological Mapping Negativity: An ERP component characterized as a negative-going deflection at approximately 250-325 ms post-stimulus onset.
PPVT	Peabody Picture Vocabulary Test
Pz	parietal midline electrode site
SOA	Stimulus Onset Asynchrony
STG	Superior Temporal Gyrus

## **Declaration of Academic Achievement**

Angela Harrison is the primary researcher responsible for the background research, experiment design, stimuli development, participant recruitment and screening, experimenting, collation of data, analysis of data, interpretation of results, preparation of figures and graphs, and writing of this report.

Rachel Patel, third-year practicum student at the time, assisted with video recording and preparation of the stimuli. Deanna Socha, undergraduate student and contract hire, programmed the experiment using Presentation experimental software based on the specifications provided by the primary researcher. Magdalena Partyka, office manager of the Language, Memory, and Brain laboratory, assisted the primary researcher in set-up of participants during data acquisition phase of the experiment.

Dr. John F. Connolly is the supervising researcher for this study, and acted as an expert advisor on matters concerning the experiment development, implementation and interpretation of data, throughout the project.

## **Introduction**

### **Speech Perception and Phonological Processing**

The present research uses the electroencephalogram (EEG) to investigate the extent to which phonological processing can be considered a supramodal phenomenon. This exploration begins with the systematic relationship between a language and its sounds, a relationship typically encountered in auditory speech perception. Speech perception refers to the computational task of detecting, identifying, and categorizing phonemes. In other words, it encompasses our ability to distinguish meaningful patterns in the speech stream. Speech perception itself is an implicit skill which can be made overt in decision tasks involving phoneme identification, segmentation, and manipulation; it is an expression of our explicit awareness of how sounds pattern. It is a skill often measured behaviorally and is known in the literature interchangeably as phonological awareness.

Research has converged on evidence that phonological awareness is crucial to literacy acquisition (see Goswami & Bryant, 1990 for a review of this topic). Literacy instruction makes explicit the relationship between a language and its phoneme, the phonemes and its graphemes, and the phonological awareness of this relationship. Intuitively, our capacity for phonological awareness is tied to our fundamental capacity for speech perception. Indeed, for the beginning reader there is a concurrent and longitudinal association between speech perception and phonological awareness, speech perception and spelling, and speech perception and reading (Vandewalle, Boets, Ghesquiere, & Zink, 2012), suggesting it is a necessary condition for the development of

phonological representation. Although there is evidence that the relationship between speech perception and phonological processing is reciprocal, wherein each contributes unique variance to the development of the other (Rvachew, 2006), the primacy of speech perception to phonological processing is logical perspective.

In severe-profound deafness, the sounds of speech are imperceptible without significant augmentation. Even in the case of mild-moderate hearing loss there is degradation of the incoming speech signal. There is evidence that impaired speech perception impacts phonological awareness and later reading development. Students with chronic histories of otitis media, an ear infection causing conductive hearing loss, performed more poorly on measures of speech perception and phonological processing than did their peers with no such history (Nittrouer & Thuente Burton, 2005). These delays further affect literacy acquisition so that even the highest achieving deaf and hard-of-hearing students performed below proficiency on standardized measures of reading vocabulary and reading comprehension (Traxler, 2000). The role of phonological processing for students who are deaf or hard-of-hearing has a long and contentious history (see Wang, Trezek, Luckner, & Paul, 2008 and Allen, et al., 2009 for reviews of this debate). There is some evidence that people who are deaf make use of phonology during reading tasks (see Perfetti & Sandak, 2000 for a review), leading some to suggest that phonological representations might be acquired through visual articulations of the jaw, tongue, teeth, and lips in the absence of auditory cues (see Woodhouse, Hickson, & Dodd, 2009 for a review of this position). The neurophysiological and behavioural research supporting this proposal is summarized in the following sections.

## **Articulatory Perception and Phonological Processing**

Articulation is an oral-motor activity traditionally referring to our productive capacity for speech. More recent models of speech processing consider the role of articulatory gesture in speech perception (Hickok & Poeppel, 2000; 2007). The McGurk Effect (McGurk & MacDonald, 1976) nicely illustrates that misleading visual cues change our perception of a corresponding sound even when the acoustic properties remain unchanged. For example, while listening to an auditory stimulus (/ga/) paired with an incongruent visual articulation (/ba/) listeners report having heard a hybrid of the available cues (/da/). Since this seminal work, electrophysiological and neurophysiological research has demonstrated that the brain perceives sound differently during the McGurk Effect like conditions (Sams, Aulanko, Hamalainen, Lounasmaa, Lu, & Simola, 1991; Beauchamp, Nath, & Pasalar, 2010). If we consider that listening to speech activates motor areas involved during speech production, (Wilson, Saygin, Sereno, & Iacoboni, 2004) then seeing speech might activate areas of the brain known to be involved during perception. One way to evaluate this hypothesis is by examining cortical activity during speechreading tasks.

**Neurophysiological Evidence.** Speechreading refers to the ability to extract meaningful linguistic information from the speech stream, through articulatory gestures, without any auditory accompaniment. This skill is usually measured through lexical identification tasks using single words, sentences, or story contexts. The left superior temporal gyrus (STG), a region of the brain consistently implicated during tasks of auditory-speech processing (Turkeltaub & Coslett, 2010), is also implicated during tasks

of speechreading (Calvert, et al., 1997; MacSweeney, et al., 2001; Bernstein, Auer, Moore, Ponton, Don, & Singh, 2002; MacSweeney, et al., 2002; Paulesu, et al., 2003; Capek, et al., 2008). Evidence of this kind suggests there is an auditory-motor network that integrates articulatory and auditory representations of speech during typical processing (see Hickok & Poeppel, 2000 for a review).

Some explanations for auditory-motor network activation during visual-speech perception are worth exploring. On the one hand, speechreading is not a particularly natural way to process speech. One does not merely observe speakers in an everyday context but integrates seen-speech and heard-speech for a complete perceptual analysis. To what extent does auditory experience play a role in conditioning the association between articulation and acoustics? Deaf-oral participants, all of whom communicated primarily using spoken English, demonstrated no significant left temporal activation during a speechreading task (MacSweeney, et al., 2002). Variability in the involvement of the left temporal gyrus in individual participants did lead the researchers to suspect individual differences in early auditory experience as a possible explanation for this result (MacSweeney, et al., 2001). Consistent with this interpretation, STG activity in a group of post-lingual deaf participants demonstrated a negative relationship with duration of sensory deprivation (Lee, Truy, Mamou, Sappey-Mariniér, & Giraud, 2007; Suh, Lee, Kim, Chung, & Oh, 2009). In other words, recent onset deafness resulted in greater STG activation compared to those who experienced a longer duration of deafness. These results support the conclusion that auditory experience facilitates temporal lobe processing of visual-only speech. On the other hand, pre-lingual deaf participants

demonstrated auditory cortex involvement similar in concentration, but delayed in latency, as compared to their post-lingual deaf counterparts (Suh M.-W. , Lee, Kim, Chung, & Oh, 2009). In other words, regardless of the limited auditory experience of the group, auditory cortex activation was evident. These results suggest that auditory experience cannot explain the actual presence of activity in auditory processing sites.

It might be argued that articulation plays more of a central role in the perceptual experience of individuals with hearing-loss and is more relevant for scaffolding phonological representations. Dependence upon visual-speech is another explanation for auditory-motor network activation during visual-speech perception. Consistent with this interpretation, congenitally deaf-signers with limited, if any, experience with oral language showed significantly greater left lateralized STG activation than did a group of hearing controls (Capek, et al., 2008). Moreover, this activation positively correlated with speechreading skill, who the deaf group as a whole are said to perform better (Auer & Bernstein, 2007). That speechreading skill moderates the activation of left temporal gyrus during visual-speech processing has since been replicated with other deaf (Campbell & Capek, 2008) and hearing participants (Hall, Fussell, & Summerfield, 2005). The reviewed neurophysiological evidence implies that the brain processes heard-speech and seen-speech in fundamentally the same location. So too is there behavioural evidence that the brain processes these two types of speech in the same manner.

**Behavioural Evidence.** In a series of studies, deaf children performed more poorly than children of the same chronological and reading age on tasks of phonological awareness (Kyle & Harris, 2006; Kyle & Harris, 2011). This pattern is persistent (Kyle &

Harris, 2010; Kyle & Harris, 2011) and extends into adulthood (Mohammed, Campbell, MacSweeney, Barry, & Coleman, 2006). On the other hand, the deaf participants did perform at levels above chance on tasks measuring phonological awareness (Kyle & Harris, 2006) implying that phonological representations might be possible in circumstances of impoverished speech perception. Indeed, speechreading skill had correlative and predictive association to phonological awareness (Kyle & Harris, 2006) which “point(s) to speech reading as the core skill that underpins the capacity for phonological representation (Harris & Moreno, 2006, p. 197)”. It best predicted single word reading scores at beginning reading stages, accounting for 26% of the variance (Kyle & Harris, 2006), while phonological awareness itself demonstrated no association with single word reading scores. Speechreading skill ceased to associate with phonological awareness and single word reading by intermediate reading stages whereas phonological awareness began to show its own moderate, but significant, relationship with reading skills (Kyle & Harris, 2010). Although the investigators did not look at the predictive association of speechreading to phonological awareness, there were some important conclusions about this relationship made. Specifically, that “speechreading could provide the input for deaf children’s phonological representations and ... that speechreading and phonological awareness tasks are potentially tapping the same underlying abilities and representations (Kyle & Harris, 2010, p. 241)”.

The behavioural evidence supports the assertion that articulatory cues might provide an alternative means of encountering the sounds of speech while serving as a scaffold for the development of phonological representation. Speechreading skill might

serve as a comparable measure of phonological processing for the deaf during beginning reading stages, until such a time phonological awareness skills are sufficiently developed and useful for analyzing the sounds of oral language. The question remains about whether observing the sounds of speech might serve as a substitute for auditory speech perception. In other words, does it provide sufficient cues to detect, identify, and categorize phonemes and extrapolate meaningful patterns in the speech stream? The goal of the current research is to illuminate the thread of cognitive processing implied by the neurophysiological and behavioural evidence just reviewed. Specifically, this research is designed to test whether articulatory cues encountered during the task of speechreading are processed phonologically, and in the same manner as auditory speech cues.

### **Event -Related Brain Potentials (ERPs)**

The electroencephalogram (EEG) is a tool of considerable sensitivity to the cognitive processing of phonological parameters in the auditory speech stream. This technique is commonly used in studies of language processing because it offers an excellent time resolution to the order of only milliseconds. This tool amplifies and records signals generated by the brain through electrodes placed directly on the scalp. A common experimental technique elicits a neuroelectric response (known as a potential) that is temporally linked to the onset of a presented stimulus. The recorded electrophysiological response is known as an event related potential (ERP) and presumably indicates cognitive processing of the stimulus token. There are several known ERP components that are unique enough in physical character and systematic enough in sensitivity to manipulation so as to be distinguishable from other observable ERP responses. The next section will

introduce the specific ERP components relevant to the language processing tasks used in this study.

**N100.** The earliest ERP components are generally known as *exogenous* due to their sensitivity to external factors, such as stimulus parameters. The N100 is an early negative-going ERP in which the amplitude is greatest in response to intense and sudden onsets. The N100 can be recorded from different scalp sites and at differing latencies depending on the properties of the stimulus. In a direct comparison of auditory-only speech versus visual-only speech N100 amplitude was maximal at fronto-central sites an average of 136 ms post-stimulus. Whereas visual N100 amplitude was maximal at occipito-parietal sites closer to 280 ms post-stimulus onset (Besle, Fort, Claude, & Giard, 2004). The authors concluded that the gradual onset of articulation in the visual-only speech not only delayed the latency of the visual N100 but actually suppressed auditory N100 responses during audio-visual combined processing. Suppression of the amplitude in the auditory N100 during conditions of visual-speech processing (Davis, Kislyuk, Kim, & Sams, 2008) and covert speech production (Kauramaki, et al., 2010) has since been replicated. In fact, visual N100 amplitude differences have been observed to picture stimuli manipulated for auditory saliency with no actual auditory stimulus (Proverbio, D'Aneillo, Adorni, & Zani, 2011). In the current study, it is hypothesized that the N100 will be largest in amplitude to the onset of the auditory targets compared to an N100 response to the onset of articulation in the lexical and non-lexical speechreading tasks. The visual-speech and control conditions are also expected to show longer onset latencies than the auditory condition. No within condition effects are expected in N100 amplitude

due to congruency or lexical status. Results pertaining to ERP morphology (latency and amplitude) during the N100 time window will not be reported in the present paper.

**Phonological Mapping Negativity (PMN).** There are also several language-related ERP components. They characteristically have longer onset latencies because they reflect interaction with cognitive processing. As such, the later components are known as endogenous due to their sensitivity to internal cognitive factors. The ERP of most interest to the present study is referred to as the Phonological Mapping Negativity (PMN; Newman & Connolly, 2009). The PMN is thought to reflect phonological processing during heard speech (Connolly & Phillips, 1994) because the negative amplitude, measured from fronto-central sites between 270-310 ms post-stimulus, is largest in response to an unanticipated phoneme (see Steinhauer & Connolly, 2008 for a review of the literature). The paradigms known to elicit the PMN most robustly use a prime to constrain the subject's phonological expectation. For example, cloze probability sentences use context to constrain the predictability of the sentence-final word. Terminal words of sentences of low cloze probability elicit larger negative-going amplitudes than do terminal words of sentences with high-probability endings where phonological parameters go unviolated (Connolly, Stewart, & Phillips, 1990). Several studies have used cloze probability sentences to manipulate the PMN response (Connolly & Phillips, 1994; D'Arcy, Connolly, Service, Hawco, & Houlihan, 2004). Single words (Connolly, Service, D'Arcy, Kujala, & Alho, 2001; Kujala, Alho, Service, Ilmoniemi, & Connolly, 2004; Newman & Connolly, 2009) and picture primes (Connolly, Byrne, & Dywan, 1995; Desroches, Newman, & Joanisse, 2008) have also been used successfully to constrain

context in a way that elicits the PMN in a phonologically incongruent conditions.

Although the PMN does not appear to be sensitive to phonological parameters in the visual modality (Connolly, Phillips & Forbes, 1995), its responsiveness has only been tested in a reading task. Motor theories of speech perception advocate that articulatory gestures are directly related to phonetic processing and might be a more appropriate stimulus to explore the parameters of PMN responsiveness to visually-based phonological tasks (for example, Liberman & Mattingly, 1985).

**N400.** The N400 is another language related ERP component whose amplitude is sensitive to the cloze probability of sentences (Kutas & Hillyard, 1984). Similar to the PMN, the N400 is a negative going ERP response, but is sensitive to semantic violations. As would be expected by its name the N400 effect occurs around 400 ms post-stimulus at central-parietal scalp sites (Kutas & Hillyard, 1980). In addition to cloze probability primes, N400 has also been elicited to single words (Perrin & Garcia-Larrea, 2003; Bonte & Blomert, 2004) and picture primes (Stelmack & Miles, 1990; Connolly, Byrne, & Dywan, 1995). The current research used lexical picture primes as context to constrain phonological expectation. Given the lexical status of the primes, and the use of a paradigm known to elicit the N400, it is hypothesized that semantic violations observed in a task of lexical speechreading will follow the same patterns as in tasks of auditory speech. It is hypothesized that the N400 will be elicited during tasks of speechreading and largest in the condition of incongruent semantic information. Only results of ERP amplitude recorded to lexical and non-lexical speechreading stimuli will be reported in this paper.

## Summary

The current study will evaluate the responsiveness of the PMN marker of phonological processing in a standard auditory condition and compares and contrasts the morphology (including latency and amplitude) of the EEG signal to that found in a condition of lexical speechreading. It is hypothesized that phonological violations observed in a task of lexical speechreading will follow the same patterns as in tasks of auditory speech. The PMN deflection is expected to be largest in the condition of incongruent phonological information compared to a PMN elicited to the congruent condition. A control condition was introduced that consisted of non-linguistic speech-like gestures. This type of control condition is similar to those seen in other speechreading experiments (Calvert, et al., 1997; Hall, Fussell, & Summerfield, 2005; Lee, Truy, Mamou, Sappey-Marinier, & Giraud, 2007; Suh, Lee, Kim, Chung, & Oh, 2009). A PMN and N400 effect are expected in the non-linguistic condition based on a generalization that stimuli in this condition will violate phonological and semantic constraints on context. Though these stimuli are not lexical in nature, other researchers have found typical PMN and N400 responses to non-word targets (Connolly, Service, D'Arcy, Kujala, & Alho, 2001; Kujala, Alho, Service, Ilmoniemi, & Connolly, 2004; Newman & Connolly, 2009). Further to that prediction, other research as demonstrated that the auditory cortex is similarly engaged to speech-like non-linguistic events in hearing (Calvert, et al., 1997) and deaf participants (Suh, Lee, Kim, Chung, & Oh, 2009) and indicating that these events might be treated as lexical early on during processing. Only

results of the ERP amplitude recorded to the lexical and the non-lexical visual-speech stimuli will be reported in this paper.

## **Method**

### **Participants**

Ten undergraduate students of McMaster University (4 males and 6 females) ranging in age from 20-29 years old (M=23 years) participated in this study. All participants were right-handed, native English speakers, with normal or corrected to normal vision, and no history of hearing loss, or neurological or psychiatric disorders. Written informed consent was obtained from all participants prior to study commencement. Participants received payment or course credit for their participation.

### **Stimuli**

**Auditory condition.** The auditory condition was modeled from the research of Connolly, Byrne, & Dywan (1995) with some noteworthy changes to the stimuli. First, whereas Connolly et al. used the Peabody Picture Vocabulary Test-Revised (PPVT-R) the current study used an updated 4<sup>th</sup> edition (PPVT-IV). Second, unlike the black-and-white line drawings of the PPVT-R used in Connolly et al., the picture primes in the current study were coloured-line drawings of the PPVT-IV. The PPVT-IV is designed to assess the receptive vocabulary of children through to adult. The pictures used as primes for this experiment (N=72) were limited to items from appropriate to children between 2.5 to 9.0 years of age. Picture primes were repeated twice; paired once in a congruent condition and once in an incongruent condition. The target stimuli were aurally presented words

that were either congruent with the picture prime or incongruent both semantically and with regard to its initial phoneme (N=144; 72 congruent and 72 incongruent). Targets were recorded by a female native speaker of English. The audio clips were recorded, edited, and digitized using Audacity software. These stimuli varied in duration ranging from 610 ms to 1150 ms in length, resulting in an intertrial interval between 5.51 s and 6.05 s. The onset of the target word served as the trigger from which the ERPs were recorded. A full stimuli list for the auditory condition is provided in Appendix A.

Although this is a departure from the lagged order of presentation in the original Connolly et al. (1995) experiment<sup>1</sup>, modality constraints demanded by the visual condition required a sequential order of presentation be maintained for the auditory condition. A direct comparison of the two conditions could not otherwise be made. To ensure that the change in presentation did not alter the components of interest a pilot study was conducted to evaluate the ERP effects. The lagged presentation and the modified sequential paradigm were treated as two separate blocks and delivered to 6 subjects, who were not participants of the main study, during a single session. The pilot data indicated that these methodological changes had minimal effect on the morphology of the ERP. Generally, overall more negative amplitude was observed from the sequential condition (Figure 1) however, the order of presentation was not equally counterbalanced. For example, the majority of participants encountered the prime-target pairs first in the sequential block followed by the lagged block during which they encountered the same

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<sup>1</sup> In this experiment, the picture prime was presented 700 ms before the target word onset and remained on the screen for 1000 ms after target word offset.

prime-target pairs a second time. As a result subjects saw and heard each visual prime and auditory target a total of four times. It is likely that this practice effect is responsible for the observed amplitude difference between presentation protocols. It is concluded that the alteration of the paradigm presentation itself does not result in noticeably different ERP responses.

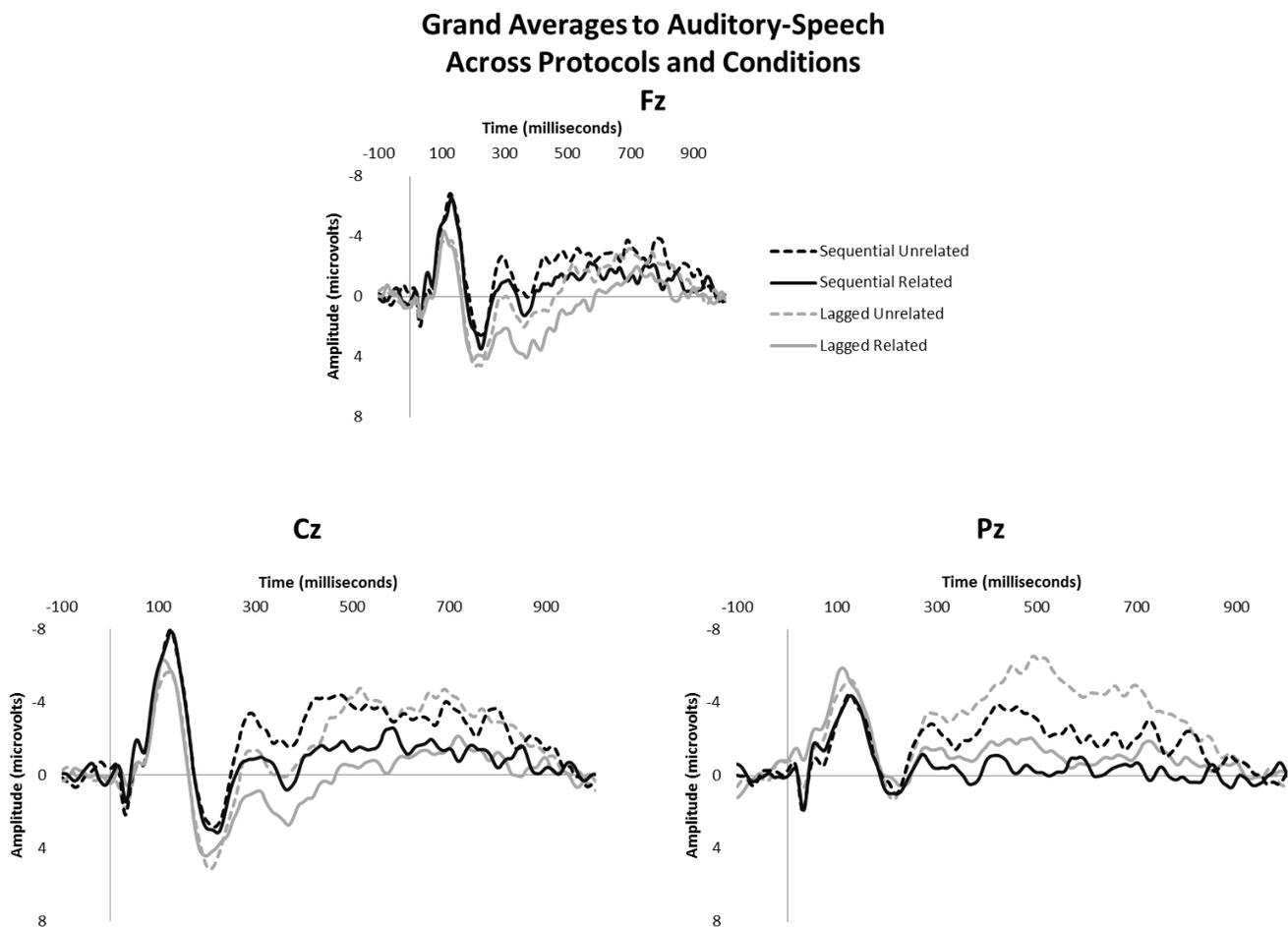


Figure 1: Grand average amplitude difference between the lagged versus sequential presentation of prime-target pairs in the auditory-speech condition across sites Fz, Cz, and Pz.

**Visual condition.** The selected black-and-white line drawn picture primes in the visual condition (N=120) are vocabulary items of the Carolina Picture Vocabulary Test (CPVT); a receptive sign language vocabulary test normed with deaf and hard of hearing children in the United States. The test is designed to assess children of 4 years through 11.5 years of age, and the picture primes selected for this experiment spanned the full age range. Primes and their targets were selected from the same test item set on the CPVT thereby ensuring consistency with the original test construction. This prime-target relationship meant that all vocabulary items served as both a prime and a target. For example, each prime was repeated three times (N=360); paired once in a congruent condition (N=120), once in an incongruent condition (N=120), and once in a non-linguistic control condition (N=120). A prime with a congruent target (*bat-bat*) also had an incongruent target (*bat-car*). This incongruent target has a congruent prime of its own (*car-car*) and its counterpart test-item was maintained as the incongruent target (*car-bat*). This meant that targets were also repeated twice; once in a congruent condition and once in an incongruent condition.

Targets in the experimental condition were video recordings of visually articulated words that were either congruent to the picture prime or incongruent both semantically and with regard to the initial phoneme. Selection of the targets was based on dissimilarity between the phonological features of the prime and its target. For example, prime words beginning with a bilabial place of articulation may have been paired with incongruent targets of a back place of articulation, or a mid place of articulation. The constraint of choosing the prime-target word pairs from the same test item of the CPVT made it

impossible to precisely control the phonological feature contrasts. However, it was always the case that a prime and its target differed by at the least one feature; place, manner, or rounding. Although some stimulus pairs differed in voicing, this feature is not well transmitted through the visual stream (Jesse & Massaro, 2010) and was not the single factor by which a pair contrasted. Similarly, number of syllables was never the single factor by which a pair differed because it is not a phonological feature inherent to the initial phoneme itself (or a property of any single phoneme). A full stimulus list for the visual experimental condition is provided in Appendix B.

Targets of the control condition were non-linguistic in nature and further subdivided into facial gestures that either looked like the onset of an articulation, but did not end as such, or a facial grimace that did not resemble an articulatory onset. These two variants of non-linguistic movement were for this analysis combined to form the non-linguistic control condition.

Target words and gestures were produced by a female, native speaker of English, and recorded with a Canon Vixia HF R200 digital camcorder at a frame rate of 29.97 frames per second (FPS). The video recordings were edited using Adobe Premiere CS5.5 using the following criterion: The most obvious articulatory onset was identified for each target, and the video was cut 1 frame (33.4ms) prior to this point. The frame before articulatory onset was then extended in length into a 700 ms still frame before the articulatory onset. This still frame was included in order to resolve any ERPs that would have been elicited in response to the onset of the video clip itself. Next, the visual offset of the target was located at the point where the final articulatory gesture was observed.

The video was cropped 4 frames after this point (133.6 ms after target completion). The audio portion of the stimulus was then extracted leaving only a visual stream of the target. These stimuli varied in duration from 1400 ms to 2000 ms in length (including the 700 ms still frame), resulting in an intertrial interval between 5.6 s and 6.2 s. The onset of the target word served as the trigger from which the ERPs were recorded.

### **Task and Procedure**

Participants were seated at a computer monitor in a dimly lit room. Auditory stimuli were presented through ear inserts at a volume comfortable for each individual. A mouse pointer was provided for recording behavioral responses. The auditory and visual conditions were treated as two separate blocks and were delivered in counterbalanced order across participants. In the auditory condition trials were pseudo randomized with the restriction that identical trial primes were separated by at least one other trial. In the visual condition the 120 primes were presented in a fixed order across three different blocks so that each prime was separated from repetition by exactly 120 trials. One of the three targets paired to each prime occurred randomly across blocks with the stipulation that each target condition would only ever occur once. In the visual condition identical trial targets were always separated by at least one other trial. In both the auditory and visual experiments the same trial condition (congruent, incongruent, or control) was not permitted to occur more than three times in a row.

Each trial began with a 700 ms presentation of the picture prime, followed by the target onset. In the visual condition, the target consisted of the 700 ms SOA of still frame followed by the visual word onset to which ERPs were recorded. In the auditory

condition, it was essential to maintain the sequential presentation determined by the modality constraints of the visual condition. Therefore the SOA in the auditory condition consisted of 700 ms of black screen followed by the onset of the auditory word onset. This procedure was to avoid any overlapping ERPs to the onset of the video itself insofar as it was the ERPs to the onset of the visual speech cues that were of interest. Connolly et al. (1995) avoided overlapping ERPs using 700 ms SOA in a similar cross-modal and cross-form priming experiment.

Participants were instructed to click, as quickly and accurately as possible, one mouse button if the spoken word was congruent to the prime and to click the other if it was incongruent. Responding hand and button (left or right) were counterbalanced. Behavioural responses were recorded for accuracy and reaction time from the target onset. In the visual condition, the response time began at articulatory onset (700 ms into the video clip). Target offset was followed by 2000 ms of black screen during which the participants were still able to respond. During the auditory event, the black screen from the 700 ms SOA was maintained to the conclusion of the response window. The failure to respond during the delineated response window was scored as an error. In each condition, a 1500 ms white fixation cross intervened between the response window and the onset of the next trial. The fixation cross was used to indicate the end of the response window and the end of the current trial.

Each block began with 4 practice trials to ensure that the participants understood the instructions of the experiment. The presentation order of the auditory and visual conditions was counterbalanced across participants. During the visual block, breaks of 15

seconds duration were interspersed after every 30 trials in order to allow participants the opportunity to relax, adjust their position, and refocus their attention. A longer break was provided between the first 180 trials and the final 180 trials, at which time the participant changed response hands. This counterbalancing strategy within the visual condition was intended to mitigate practice effects that might occur due to such a large number of trials. Another longer break was provided between the visual condition and auditory condition, which contained breaks of 15 second duration after every 36 trials. The entire experiment took approximately one hour to complete (Visual=40 minutes; Auditory=15 minutes).

### **Electroencephalogram Recording and Analysis**

EEG data were recorded continuously with a 0.01-100 Hz bandpass and digitized at 512 Hz using ActiView software from 128 scalp sites using an active Ag/AgCl electrode system (BioSemi Active Two). An additional active electrode (Common Mode Sense; CMS) and passive electrode (Driven Right Leg; DRL) were used as reference and ground, respectively. Vertical and horizontal eye movements were recorded from electrodes placed supraorbital and over the outer canthus of the left eye. Recordings were referenced offline to the average of left and right mastoids.

EEG analysis was performed offline using BrainVision Analyzer software (version 2.0). Data were digitally filtered with a bandwidth of 0.1-30 Hz (slope 24 db/octave). Ocular artifacts were corrected using an ICA algorithm. Baseline correction and DC detrend were applied, using the mean amplitude and average voltage of the pre-stimulus period (-100 to 0 ms), before offline averaging of the pre- and post-stimulus

analysis epoch (-100 to 1000 ms). Epochs with signal amplitudes in excess of 100  $\mu\text{V}$  were excluded from further analysis. Two participants were excluded from the analysis (1 male and 1 female); one because of technical problems and the other because of excessive artifact. Though 128 channels were used during data recording, the current results analysis reports only a selection of five standard midline channels; Fpz, Fz, Cz, Pz, and Oz.

## **Results**

### **Behavioural Analysis & Results**

In the visual-speech condition, frequency of correct responses was calculated and percentages reported for each condition (Figure 2). For the non-linguistic control condition, participants correctly identified the prime-target relationship with 99.5% accuracy, whereas only 0.2% was incorrectly identified and 0.3% was calculated as misses (no response). For the linguistic conditions, participants correctly identified the related targets as congruent 90.2% of the time. Incorrect identification of the related prime-targets as incongruent occurred 9.7% of the time (0.1% misses were calculated as no responses). Unrelated targets were correctly identified as incongruent 95.7% of the time and incorrectly identified as congruent 3.8% (0.5% misses were calculated as no responses). Arguably should run simply ANOVA (one-way) on these accuracy judgments.

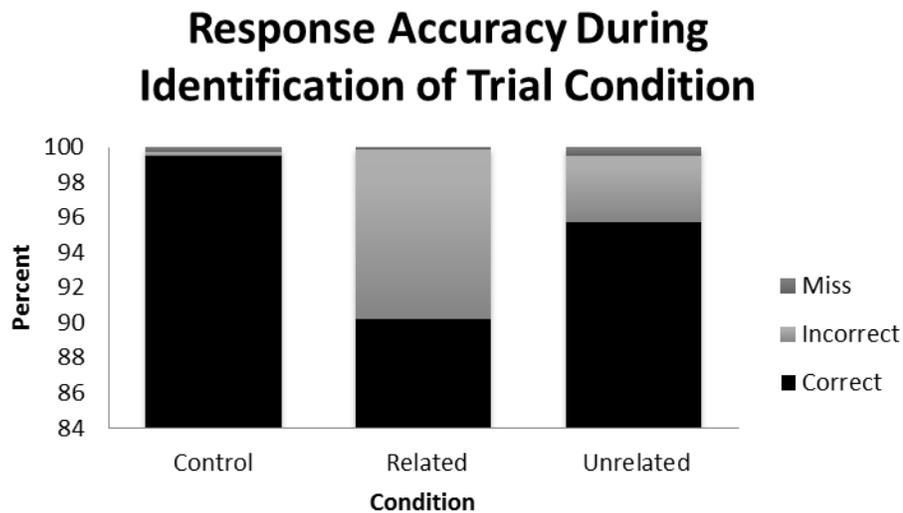


Figure 2: Percentages of correct, incorrect and no responses during the visual-speech condition. Responses represent the participant's identification of the trial type for the prime-target pair as a match (unrelated), or as a mismatch (related and control).

A repeated-measures ANOVA was calculated to compare participant reaction times during identification of prime-target trials across conditions. Mean reaction times for identifying prime-target pairs were technically not normally distributed for the non-linguistic control condition,  $D(951)=.097$ ,  $P<.001$ , and both the linguistic related,  $D(951)=.091$ ,  $p<.001$ , and linguistic unrelated conditions,  $D(951)=.089$ ,  $P<.001$ . However, the sample size is large ( $N=951$ ) and the significant results are likely due to small deviations from normal. Observing the distribution plots (Figure 3), only a slight positivity in skewness and kurtosis is observable. Based on these observations, small deviations from a normal distribution are not believed to have biased the outcomes of the statistical procedures applied to the data, but related results should nonetheless be interpreted with some caution.

### Normality Plots for Response Latencies Across Conditions

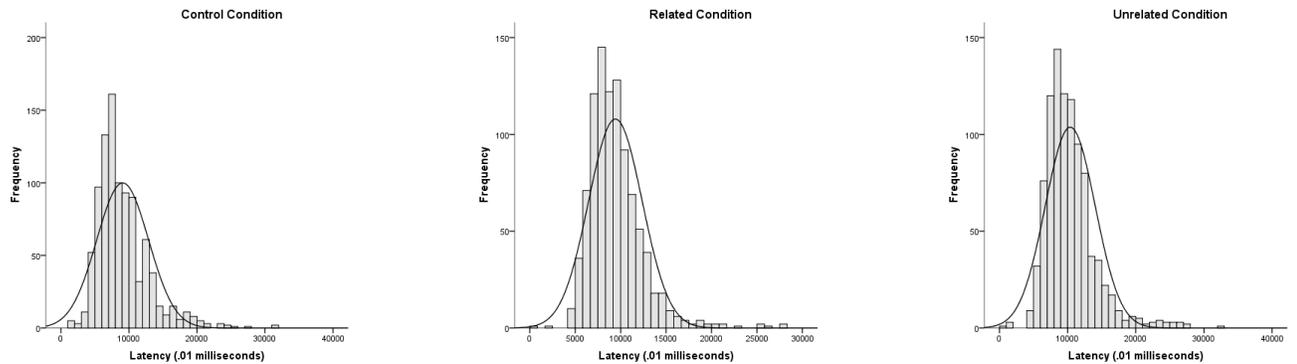


Figure 3: Frequency distribution of response reaction time in the non-linguistic control condition, and the linguistic related and unrelated conditions during visual-speech.

Mauchly's test indicated that the assumption of sphericity had been violated,  $\chi^2(2)=25.1$ ,  $p<.05$ , therefore multivariate tests are reported ( $\epsilon=.975$ ). The Pillai's Trace test shows a main effect of reaction time,  $V=0.11$ ,  $F(2, 949)=60.06$ ,  $p<.001$ . *Post hoc* pairwise comparisons, with Bonferroni correction applied, found that reaction times differed between all three groups; reaction times were smaller to the prime-target pairs in the non-linguistic control condition ( $M=902.4$ ,  $SD=12.2$ ) than to the related linguistic condition ( $M=942$ ,  $SD=9.59$ ,  $p<.05$ ) and to the unrelated linguistic condition ( $M=1038.92$ ,  $SD=11.92$ ,  $p<.001$ ). There was also a significant difference in reaction times between the two linguistic conditions; participant responses to the unrelated condition were significantly larger than responses to the related condition ( $p<.001$ ) (Figure 4). It should be noted that the assumption of normality was violated in these data and the results should be interpreted with some caution.

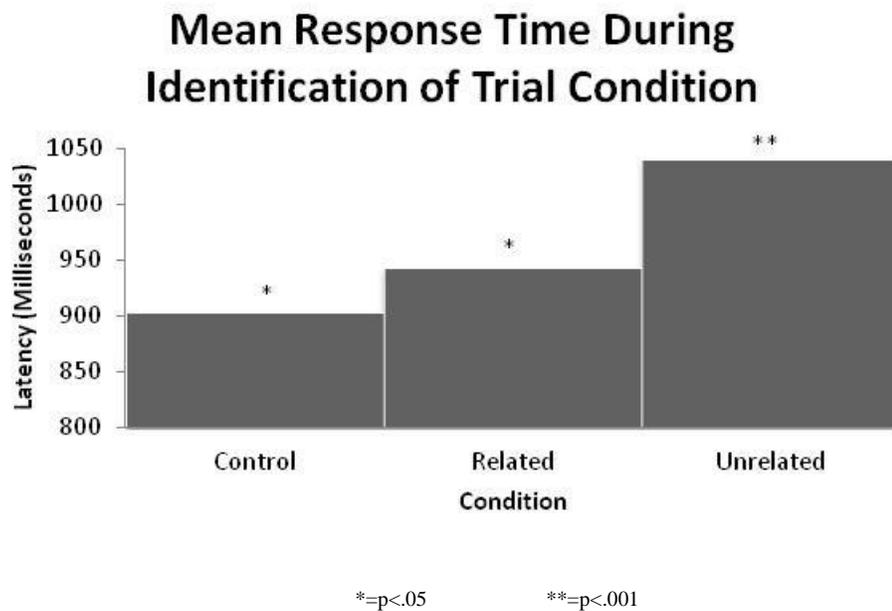


Figure 4: Mean response time by condition during the visual-speech. Responses represent the participant's identification of the trial type for the prime-target pair as a match (Unrelated), or as a mismatch (Related and Control).

### Electrophysiological Analysis

Grand average waveforms (see Figure 5) indicated that the N100 component peaked closer to 200 ms in contrast to the N100 typically observed in the literature (see Discussion for explanation and relevance). As a result, mean peak amplitude for the remaining eight participants (N=8; 3 male and 5 female) was identified later than it would be in the standard auditory paradigm; PMN was identified as the most negative peak between 300-400 ms and N400 between 400-600 ms.

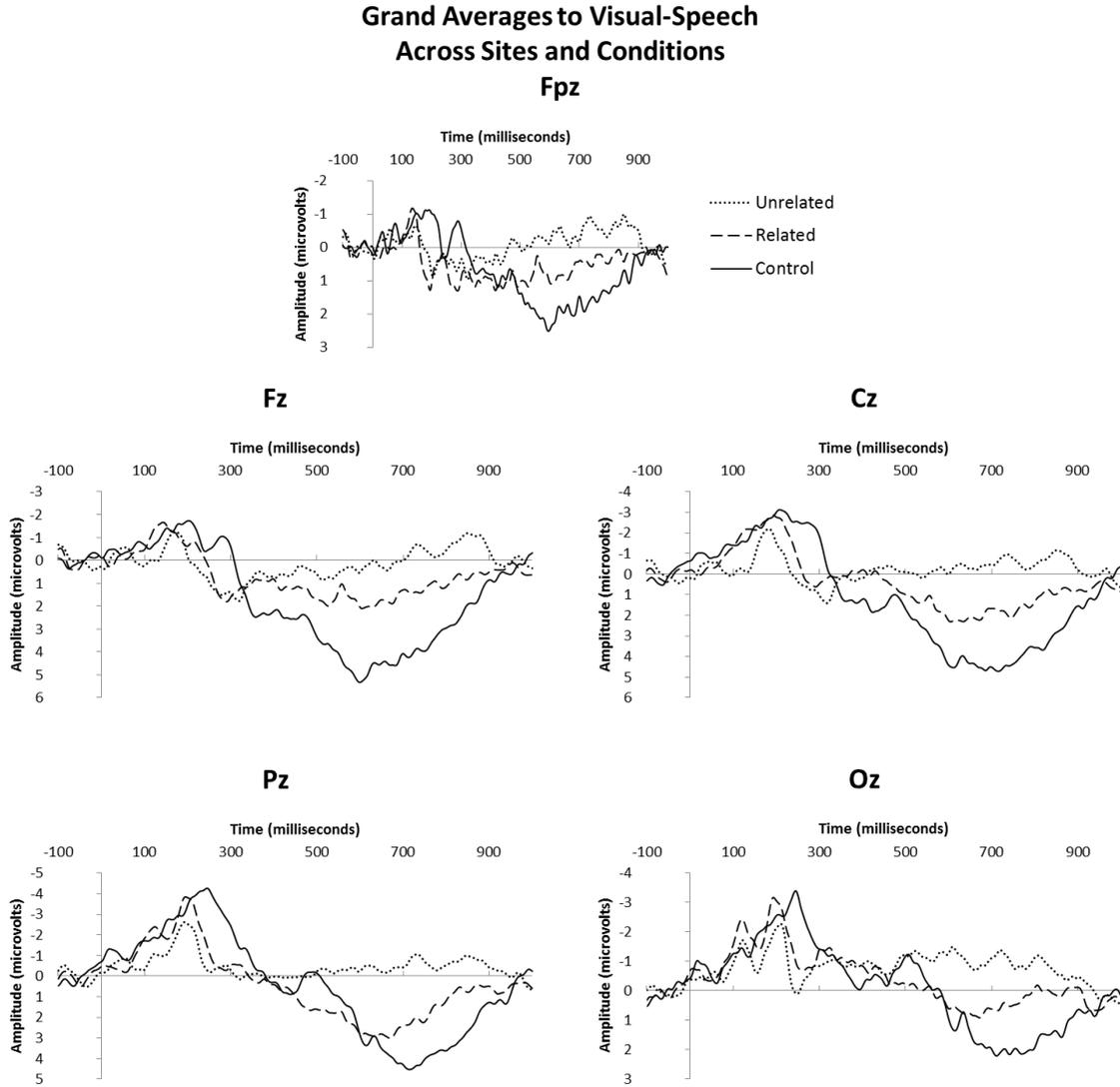


Figure 5: Grand average evoked potentials to the visual-speech condition across sites and conditions.

## Electrophysiological Results

**PMN.** A repeated-measures ANOVA was conducted to examine the effects of Condition (3 levels: Unrelated, Related, and Control) and electrode site (5 levels: Fpz, Fz, Cz, Pz, and Oz) on amplitude in the time windows for the PMN. There was a main effect

of site on amplitude in the PMN condition,  $F(4, 28)=3.42$ ,  $p<.05$ . Planned contrasts comparing the mean amplitude of each site against the main effect of the Condition (the mean amplitude across all sites;  $M=-0.04$ ,  $SE=0.33$ ) found amplitude of the PMN was significantly more negative at site Oz ( $M=-1.22$ ,  $SE=0.47$ ),  $F(1, 7)=6.59$ ,  $p<.05$  (one-tailed),  $\text{partial-}\eta^2=.49$ , and more positive at site Fz ( $M=0.95$ ,  $SE=0.53$ ),  $F(1, 7)=5.75$ ,  $p<.05$  (one-tailed),  $\text{partial-}\eta^2=.45$ . Posterior sites were generally negative in amplitude and anterior sites were generally positive with Oz and Fz being the most extreme negative and positive sites, respectively (Figure 6).

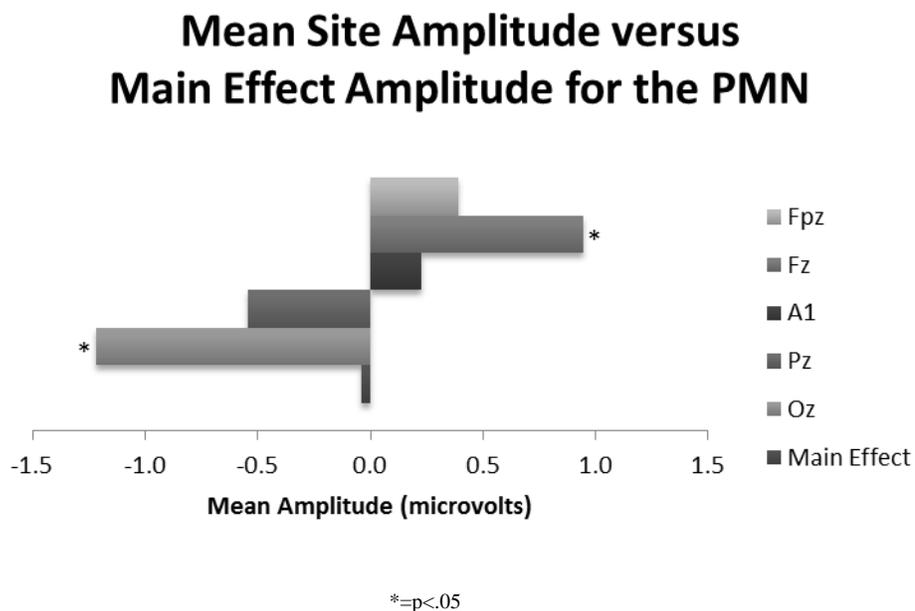


Figure 6: Main effect of site compared to the mean of the overall main effect during the PMN time window.

No main effects of Condition or interaction effects of Site x Condition were found in the univariate analysis. However, in a planned polynomial contrast, a significant Site x Condition linear trend at Pz was found,  $F(1, 7)=13.57$ ,  $p<.05$  (one-tailed),  $\text{partial-}\eta^2=.66$

and a significant quadratic trend at Fz was observed,  $F(1, 7)=10.69$ ,  $p<.05$  (one-tailed), partial- $\eta^2=.60$ . PMN amplitude in the non-linguistic control condition demonstrated a larger negativity ( $M=-.93$ ,  $SE=.94$ ) at site Pz than did either of the linguistic conditions (Figure 7). The PMN amplitude in the unrelated condition demonstrated a larger negativity ( $M=-.68$ ,  $SE=.62$ ) than did the related condition at site Pz ( $M=-.03$ ,  $SE=.56$ ). At site Fz the ERP activity in the PMN latency window during both of the linguistic conditions demonstrated larger negativities than during the non-linguistic control condition ( $M=1.76$ ,  $Se=.65$ ). The linguistic conditions themselves did not differ in amplitude (Unrelated  $M=.51$ ,  $Se=.90$ ; Related  $M=.58$ ,  $SE=.67$ ).

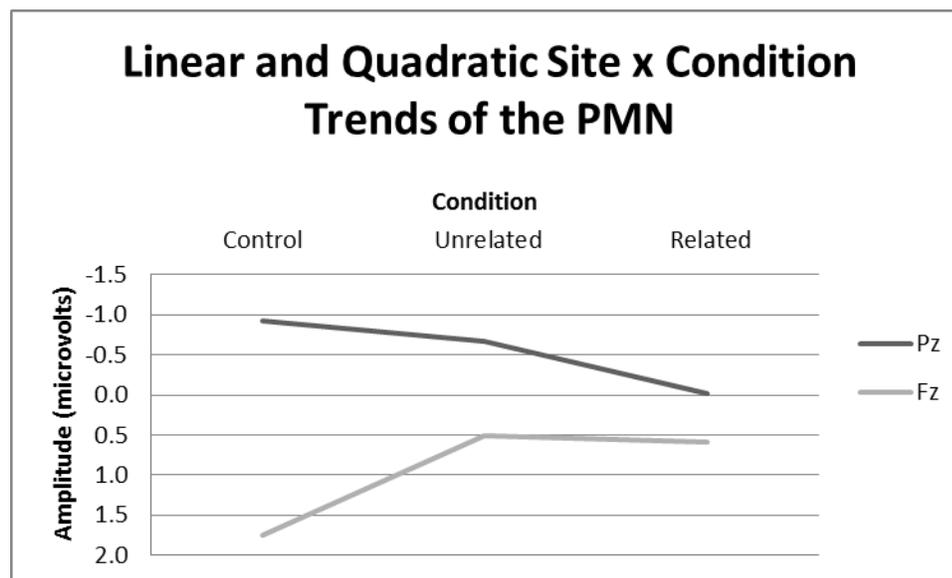


Figure 7: Site x Condition linear and quadratic trends of the PMN time window at sites Pz and Fz across conditions.

As can be seen from the grand average waveform at site Pz (refer to Figure 5), the control condition appears to have a small negativity riding on an unresolved N100 which can be seen more clearly at frontal sites (Cz, Fz, Fpz). At these more anterior sites this

accompanying and confounding negativity resolved before the PMN window, but did not do so at the more posterior Pz site. It is this component that was scored as the largest peak and likely produced the significant linear trend at this particular site. It is unlikely that this trend reflects the true pattern of these results. In support of this perspective, a marked positivity directly follows, until the control condition matches the related condition in positivity while heading into the N400 time window. This can be seen from the grand average waveforms across conditions, including at site Fz. In fact, the non-linguistic control condition appears to be treated entirely differently than the linguistic conditions during this time window and this difference is exaggerated at the frontal-central site (Fz) where the significant quadratic trend relates to the positive deflection in that condition during that time frame. This quadratic trend nicely describes the true patterns of these data.

**N400.** A repeated-measures ANOVA was conducted to examine the effects of Condition (3 levels: Unrelated, Related, and Control) and electrode site (5 levels: Fpz, Fz, Cz, Pz, and Oz) on amplitude in the time windows for the N400. The Kolmogorov-Smirnov test of normality found that amplitudes at Fpz in the control condition,  $D(8)=.340$ ,  $p<.01$ , and site Cz in the related condition,  $D(8)=.291$ ,  $p<.05$ , were not normally distributed. All other site amplitudes met the assumption of normality. Mauchly's test indicated that the assumption of sphericity was violated for the main effect of site,  $\chi^2(9)=19.18$ ,  $p<.05$ , therefore the degrees of freedom were corrected using Greenhouse-Geisser estimations of sphericity ( $\epsilon=.43$ ). All other conditions met sphericity assumptions. No significant main effects of Site or Condition were found in the

univariate analysis. However, a planned polynomial contrast revealed a significant quadratic trend by Condition,  $F(1, 7)=6.64$ ,  $p<.05$ ,  $\text{partial-}\eta^2=.49$ . There is a clear trend of a larger negative N400 amplitude in the unrelated linguistic condition ( $M=-.517$ ,  $SE=.54$ ) (Figure 8) than either the related linguistic ( $M=.57$ ,  $Se=.44$ ) or non-linguistic control condition ( $M=.83$ ,  $SE=.62$ ).

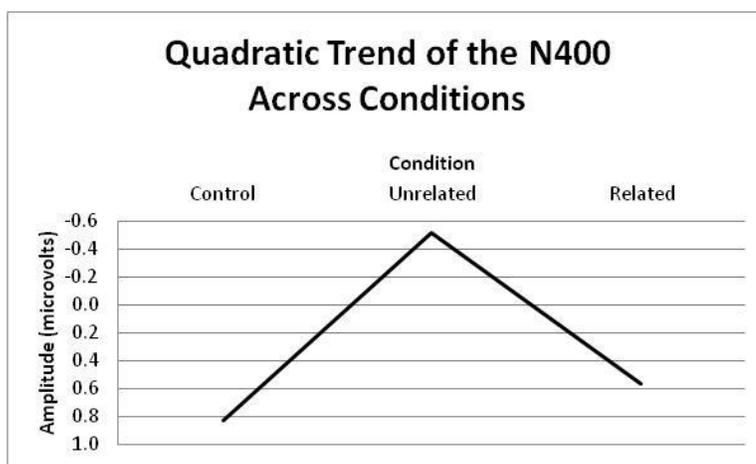


Figure 8: Quadratic trend of the N400 time window across conditions.

A significant Site x Condition quadratic trend,  $F(1, 7)=10.14$ ,  $p<.05$ ,  $\text{partial-}\eta^2=.60$  at site Fz, linear trend at Pz,  $F(1, 7)=16.76$ ,  $p<.01$ ,  $\text{partial-}\eta^2=.71$ , and quadratic trend at Oz,  $F(1, 7)=7.39$ ,  $p<.05$ ,  $\text{partial-}\eta^2=.51$  further breaks down the aforementioned effect of Condition. There is larger negative amplitude of the N400 in the unrelated linguistic condition across sites (Figure 9). Amplitude of the N400 during the non-linguistic control condition is more similar at posterior sites (Oz, Pz). The more anterior site (Fz) is the source of the quadratic trend observed (Figure 8). Referring to the grand averages (Figure 5), it can be seen that an N400-like deflection at sites Oz and Pz

becomes progressively smaller as it moves forward to more anterior sites over the scalp.

These trends also appear to nicely describe the true patterns of these data.

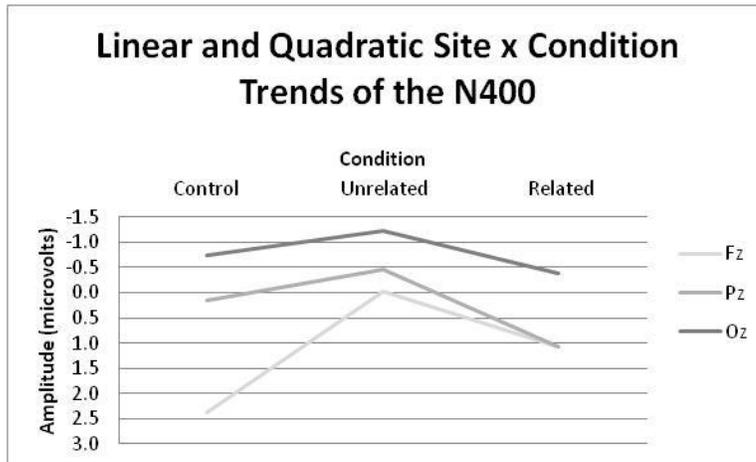


Figure 9: Linear Site x Condition trend of N400 amplitude at site Pz and Quadratic Site x Condition trends of the N400 amplitude at sites Fz and Oz.

## Discussion

### Electrophysiological Analysis

**N100.** An observable trend of a later N100 latency during the visual-speech condition was not tested statistically. Though conclusions cannot be drawn based on this trend, they are in line with the results of Besle, Fort, Claude, & Giard (2004) who found an average peak latency equivalent of 280 ms during a visual-speech condition. These authors suggested that it was the progressive onset of an articulation influencing a gradual N100 response in the global ERP signal. The N100 latency of the present study was not as late as that reported by Besle et al. (2004), but the stimuli constructions were different to a degree. In the Besle et al. (2004) experiment a closed mouth still frame was followed with six frames of faint lip movements culminating in opening of the mouth

(synchronized with the onset of the 7<sup>th</sup> frame). In the present study, 700 ms of still frame was followed by the sudden onset of the first most salient mouth movement of the phoneme. For some stimuli this was mouth opening, but for other phonemes (bilabial, for instance) it corresponded to detectible features appropriate to the articulation, such as lip protrusion. Therefore the more progressive changes were substituted for a more abrupt visual energy change and likely facilitated a stronger N100 onset with a shorter latency.

**PMN.** The PMN is known to have a frontal-central distribution and is characterized by negative going deflection most robust to incongruent phonological information (Connolly & Phillips, 1994; Connolly, Byrne, & Dywan, 1995; Connolly, Service, D'Arcy, Kujala, & Alho, 2001; Newman & Connolly, 2009). Some of the results from the present study corroborate these observations. For instance, at site Fz the amplitude of the PMN component demonstrated a significant quadratic trend. A specific positive-going deflection of the control condition characterized this trend. Though this positivity was not predicted, this response separated the control condition from the negative amplitude characterizing the PMN during both of the linguistic conditions. These results imply that articulations of the non-linguistic control condition were treated fundamentally differently than were the articulations of the linguistic conditions. These results are consistent with research observing negative amplitude differences to violations of phonological constraints. Contrary to predictions, the PMN amplitude did not differ between the related and unrelated linguistic conditions at any of the analyzed sites (Fpz, Fz, Cz, Pz, and Oz). Looking at the grand average waveforms at site Cz, the trough to peak PMN deflection is larger in the unrelated condition than in the related condition.

This difference is not borne out statistically because the deflection does not exceed the actual amplitude of the related condition. Instead, it appears to have not been able to overcome the effects of the larger P2 positivity that it is emerging from.

**N400.** The N400 is characterized by a negative-going deflection most robust to incongruent semantic information and can be differentiated from the PMN based on its more central-parietal distribution (Connolly, Service, D'Arcy, Kujala, & Alho, 2001; Kujala, Alho, Service, Ilmoniemi, & Connolly, 2004; Newman & Connolly, 2009). Consistent with predictions, the N400 component demonstrated a significant quadratic trend of larger negative amplitude responding to the unrelated linguistic condition. At posterior sites (Pz and Oz) significant Site x Condition polynomial trends defined a three-way separation of N400 amplitude between the conditions. The non-linguistic control condition demonstrated an N400-like negative deflection reaching similar amplitudes to the unrelated linguistic condition. The N400 amplitude of the related linguistic condition remained more positive. The N400-like negativity of the control condition can be seen most clearly at posterior sites whereby a positive-going ERP can be seen to strongly deflect to a negative-going response in the N400 time window. These data are consistent with N400-like responses seen to words and non-word stimuli alike (Connolly, Service, D'Arcy, Kujala, & Alho, 2001; Kujala, Alho, Service, Ilmoniemi, & Connolly, 2004; Newman & Connolly, 2009).

## **Behavioural Analysis**

Response accuracy was generally very high across conditions, indicating that the task demands were easily met. Participants were quickest and most accurate at identifying the non-linguistic control condition compared to either of the linguistic conditions. These reaction time data are consistent with the outcomes of other research comparing reaction times during identification of speechreading versus facial gurning events (Lee, Truy, Mamou, Sappey-Marini er, & Giraud, 2007). Though mean response time was shorter in the related than the unrelated linguistic condition, accuracy was lower during prime-target trials of this condition. Nearly 10% of the related prime-target pairs were incorrectly judged as incongruent and were behaviourally miscategorized. Incongruent judgments are conditions under which we would expect to see a PMN. Though the number of incorrectly judged trials may appear trivial, speechreading skill interacts with auditory cortex involvement during visual-speech tasks, and presumably impacts phonological processing (Campbell & Capek, 2008; Capek, et al., 2008; Hall, Fussell, & Summerfield, 2005; Lee, Truy, Mamou, Sappey-Marini er, & Giraud, 2007; Suh, Lee, Kim, Chung, & Oh, 2009). Behavioural evidence demonstrates that vocabulary correlates with and predicts speechreading skill (Kyle & Harris, 2006; (Kyle & Harris, 2011; Kyle & Harris, 2010; Mohammed, Campbell, MacSweeney, Barry, & Coleman, 2006). Moreover, vocabulary interacts with the saliency of the PMN component (Connolly, Byrne, & Dywan, 1995). Ambiguity during priming may not have been inconsequential to the observed PMN amplitudes during the related and unrelated linguistic conditions.

## **General Discussion**

This experiment was designed to assess the plausibility that articulations can be processed phonologically, and in the same manner as auditory speech. Phonology and lexical status were the two main features manipulated between the non-linguistic control and experimental speechreading conditions. As far as the implications of phonology, the electrophysiological and behavioural results support the notion that phonological status may have been used to inform behavioural responses. For instance, the mean response time of the control condition was 902 ms, which is less than the average duration of the non-linguistic articulation events themselves (1068 ms). Participants did not wait until the end of the clip to decide that the articulation event was non-linguistic and they were very accurate in their decisions (99.5%). The electrophysiological results during the PMN time window also support a conclusion that these non-linguistic movements were not treated as phonological events. The results support the conclusion that speech-like gestures and facial gurnings are not processed phonologically. Future analysis of these data will separate the two types of non-linguistic control stimuli to validate that both are processed in the same manner.

As far as considering the implications of lexical status, if the articulations were interpreted as lexical during the control condition then one would predict that the N400 would be characterized by a negative-going deflection due to violation of contextual constraints. Indeed the Site x Condition polynomial trends did reveal a large N400 amplitude deflection at posterior sites (Pz and Oz) during the control condition. Given that these events could not have been interpreted lexically, what should be made of this

finding? Intuitively, it can be argued that regardless of its lexical status, the stimulus event violated the participant's semantic expectancy and in turn produced large amplitude N400. These results are in line with evidence that non-word targets, of no lexical content, similarly produce a large N400 negative amplitude (Connolly, Service, D'Arcy, Kujala, & Alho, 2001; Kujala, Alho, Service, Ilmoniemi, & Connolly, 2004; Coch, Grossi, Skendzel, & Neville, 2005; Newman & Connolly, 2009) and corroborate other evidence that N400 is reflective of meaning processing in a more general sense (see Kutas & Federmeier, 2011).

In conclusion, the results of the present study suggest that articulations of visual-speech are processed phonologically, and in the same manner as auditory-speech. These conclusions are drawn from evidence that non-linguistic speech-like gestures and gurning movements are dissociated from articulations of a linguistic nature during the phonological processing PMN time window. The non-significant amplitude difference of the PMN during conditions of related and unrelated visual-speech may be the result of context ambiguity so that future data acquisitions will seek to eliminate the vocabulary confound. Alternatively, the non-significant amplitude difference of the PMN during the linguistic conditions may be due to a lack of power to detect this more subtle amplitude difference. In order to address this possibility, future data analysis will utilize amplitude detection of a spatial area rather than single electrode sites. A comparison of the PMN response during auditory-speech versus visual-speech will be conducted to further elucidate the question of whether these two forms of speech are processed in fundamentally the same manner while topographic and dipole modeling will be used to

corroborate neurophysiological evidence of processing in the same location of the brain.

Altogether these findings suggest that visual-speech is processed linguistically, to the extent that the PMN and N400 characterize linguistic processing similarly in both auditory and visual modalities.

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### Appendix A: Stimuli List of the Auditory-Speech Condition

Prime - Target

1. ball - card	25. peeking - taking	49. fly - house
2. dog - bed	26. ruler - wing	50. painting - buying
3. spoon - fish	27. tunnel - muddy	51. farm - moon
4. foot - baby	28. branch - flute	52. penguin - straw
5. duck - book	29. envelope - lizard	53. gift - brother
6. banana - wheel	30. diamond - circus	54. feather - corn
7. shoe - chair	31. calendar - egg	55. cobweb - shell
8. cup - box	32. buckle - tank	56. elbow - paper
9. eating - knocking	33. sawing - getting	57. juggling - clapping
10. bus - kite	34. picking - dirtying	58. fountain - house
11. flower - bird	35. target - button	59. net - hook
12. mouth - school	36. dripping - spelling	60. shoulder - garbage
13. pencil - juice	37. knight - children	61. dressing - feeding
14. cookie - money	38. delivering - hugging	62. roof - soap
15. drum - bag	39. cactus - balloon	63. chef - paint
16. turtle - car	40. dentist - robin	64. squash - mountain
17. red - boat	41. floating - making	65. ax - triangle
18. jumping - climbing	42. claw - flag	66. flamingo - brain
19. carrot - sister	43. violin - scissors	67. chimney - wolf
20. reading - walking	44. group - rice	68. hyena - fan
21. toe - window	45. globe - hospital	69. plumber - drawing
22. belt - purse	46. vehicle - people	70. river - coffee
23. timer - flood	47. catching - calling	71. trunk - shower
24. vase - water	48. harp - watch	72. bloom - friend

## Appendix B: Stimuli List of the Visual-Speech Condition

### Prime – Target Pairs

- |     |                     |     |                      |
|-----|---------------------|-----|----------------------|
| 1.  | rabbit - star       | 31. | arrow - bowl         |
| 2.  | spider - telephone  | 32. | caterpillar - fish   |
| 3.  | plane - cake        | 33. | city - mountain      |
| 4.  | house - plant       | 34. | hospital - church    |
| 5.  | chicken - butterfly | 35. | sad - piano          |
| 6.  | camera -baseball    | 36. | soldier - barber     |
| 7.  | tree - book         | 37. | orange - grapes      |
| 8.  | paper - watch       | 38. | tiger - elephant     |
| 9.  | eat - teach         | 39. | bridge - wood        |
| 10. | light - boat        | 40. | mouse - snake        |
| 11. | barn - river        | 41. | tornado - rain       |
| 12. | pig dog             | 42. | winter - hammer      |
| 13. | butter – cup        | 43. | needle - ruler       |
| 14. | cat - bee           | 44. | cage - television    |
| 15. | pen - candle        | 45. | basket - coat        |
| 16. | sandwich - pants    | 46. | eagle - bear         |
| 17. | sit - hit           | 47. | jail - restaurant    |
| 18. | walk - sleep        | 48. | jar - bed            |
| 19. | perfume - chair     | 49. | knife - spoon        |
| 20. | box - glasses       | 50. | glue - picture       |
| 21. | towel - shoe        | 51. | dance - catch        |
| 22. | mailbox - jug       | 52. | peach - vitamin      |
| 23. | fight - bounce      | 53. | football - horseshoe |
| 24. | witch - farmer      | 54. | license - clock      |
| 25. | letter - carve      | 55. | couch - table        |
| 26. | hamburger - banana  | 56. | salad - bread        |
| 27. | purse - lamp        | 57. | kitchen - stairs     |
| 28. | policeman - dentist | 58. | castle - shower      |
| 29. | bottle - lock       | 59. | ambulance - train    |
| 30. | snail - bird        | 60. | coach - baby         |

## **Appendix C: Recruitment Script**

Study Name: A study of speech processing in the brain

Description: Theories of auditory processing must take into account the influence of visual cues in the perception of sounds. This is also true of theories of speech processing. There is evidence that visual only speech, with acoustic cues removed, activates temporal lobe in hearing and deaf subjects. Although temporal lobe is usually implicated in the processing of auditory stimuli like heard speech, it must now be considered that temporal lobe is responsive to language stimuli regardless of the modality of presentation. In this study, we want to investigate the nature of brain responses to certain types of auditory and visual speech stimuli. To that end, we will be recording your brain activity (that is, your electroencephalographic (EEG) responses) while you listen to and watch someone speaking words.

Eligibility: No hearing problems or history of neurological or psychiatric disorder. Not currently taking medications acting on central nervous system (antidepressants, anxiolytics, anti-epileptics, etc). Native speaker of English. Right-handed. 20-35 years.

Duration: 120 minutes

Preparation: Be well rested with a full night's sleep. Do not consume drugs or alcohol for 12 hours prior to the experiment. Wear glasses instead of contacts. Clean your face and hair (do not use conditioner). Do not wear face creams or make-up.

Compensation: \$20 or 2 hrs course credit

Researcher: Angela Harrison

Email: [harriav2@mcmaster.ca](mailto:harriav2@mcmaster.ca)

### Appendix D: Health Screening Questionnaire

Study # \_\_\_\_\_ Participant code: \_\_\_\_\_ Date of birth: \_\_\_\_\_ Test date: \_\_\_\_\_

Handedness: Right Left Ambidextrous Sex: Male Female

Highest level of education: \_\_\_\_\_

Languages in order of fluency: 1. \_\_\_\_\_ 2. \_\_\_\_\_ 3. \_\_\_\_\_ 4. \_\_\_\_\_

If English is not your first language: How old were you when you learned English? \_\_\_\_\_

If you were not born in Canada: How old were you when you moved to Canada? \_\_\_\_\_

History of substance abuse: \_\_\_\_\_

Is your hearing and vision normal? Yes No

If not, please describe: \_\_\_\_\_

Have you ever had any perceptual (colour blindness) learning or language problems? Yes No

If yes, please describe (age, length, recovery): \_\_\_\_\_

Have you ever had any neurological, psychological or psychiatric problems? Yes No

If yes, please describe (age, length, recovery): \_\_\_\_\_

Have you ever had a head injury, seizures, coordination problems or major surgeries? Yes No

If yes, please describe (age, length, recovery): \_\_\_\_\_

Have you ever lost consciousness, had any fainting spells, paralysis or dizziness? Yes No

If yes, when and for how long? \_\_\_\_\_

Are you presently taking any medication? Yes No

If yes, which one(s)? \_\_\_\_\_

Do you consume the following?

	Yes/No	How often?
Alcohol		
Cigarettes		
Drugs		

Have you recently taken any medication? Yes No

If yes, which one(s), and when? \_\_\_\_\_

Have you consumed any alcohol or drugs in the last 24 hours? Yes No

If yes, please specify: \_\_\_\_\_

Have you consumed any drugs in the last 7 days? Yes No

If yes, please specify: \_\_\_\_\_

Please rate your current state of alertness: - 1 2 3 4 5 +

How many hours did you sleep last night? : \_\_\_\_\_

### Appendix E: EDINBURGH HANDEDNESS INVENTORY

Please indicate your preference in the use of hands in the following activities by listing the “+” in the appropriate columns. When the preference is so strong that you would never try to use the other hand unless absolutely forced to, list “++”. If, in any case you really are indifferent, put “+” in both columns.

Some of the activities require both hands. In these cases, the part of the task or object, for which the preference is warranted is indicated in brackets.

Please try to answer all the questions, and only leave the column blank if you have no experience at all of the object of the task.

#	Task	Left	Right
1	Writing		
2.	Drawing		
3.	Throwing		
4.	Scissors		
5.	Toothbrush		
6.	Knife (without fork)		
7.	Spoon		
8.	Broom (upper hand)		
9.	Striking match (match)		
10.	Opening box (lid)		

Score = (Total left \_\_\_\_\_ + Total right \_\_\_\_\_) \* 100 = \_\_\_\_\_

## **Appendix F: E-mail Correspondences**

Hi,

Thank you for your interest in my thesis study. In a nutshell, the study involves the measurement of your brain waves through a non-invasive procedure. To assess your eligibility for the study, you will need to come into the lab to fill out a short questionnaire that should take about 15 minutes. The lab is located in TSH 610. Please let me know when you will be available to come in on [Insert time here].

If none of these times are convenient for you, let me know and we can schedule for another time.

Upon review of the questionnaires, I will contact you again with details of the study procedures. If you have any questions before then, feel free to contact me.

Thanks!

---

Dear Participant,

Thank you for your interest in our study. After careful considerations of your health and language background, we would like to invite you back to run the experiment. Please read the following details carefully to ensure your understanding of the experimental procedures and preparation.

### **The experiment**

The study involves the use of the electroencealogram (EEG) which measures brainwaves. During the study, electrodes will be connected to your scalp via an electrode cap. Water-soluble gel will be applied to your scalp to improve conductivity. Measurements will be recorded as you read sentences on the monitor in front of you. The procedure is very safe, non-invasive, and painless. If you have any questions or concerns, please feel free to contact me.

### **How to prepare for the experiment**

Avoid alcohol/nicotine/caffeine the night before (and on the day of) the experiment in order to get sufficient sleep. Make sure you sleep early in the evening. Fatigue and restlessness may distort brainwaves.

Wash your hair on the morning of the session and avoid using hair products and makeup as they may affect the conductivity of the equipment. Do not wear any make up (including foundation), hair products, or conditioner. If you wear corrective lenses, wear glasses instead of contact

lenses. It would minimize your blinking during the experiment. Make sure you are dressed comfortably in layered clothing so that you can easily adjust for your comfort in the lab. It is important to maintain a steady body temperature to reduce muscle activity caused by sweating/shivering.

Please keep your phone turned off for the duration of the study, and make sure you have gone to the washroom beforehand. It is not possible to leave the room in the middle of the study.

Shampoo and towel will be provided following the study for clean up. If you prefer, please bring your own hair brush. You may also decide to wash your hair at home if you prefer.

**Date/Location**

The location of the Language, Memory and Brain Lab is in Togo Salmon Hall 610. When you exit the elevator doors on the 6th floor, turn left, and the lab is located on the right side of the hallway.

**Your appointment is scheduled for: [Date @ Time]**

**Compensation**

You will be given 2 hours course credit or \$20 for your participation. The approximate duration of the experiment is 2 hours.

**Contact**

Angela Harrison  
harriav2@mcmaster.ca

---

Dear Participant,

I am emailing you to remind you regarding your appointment tomorrow, [date @ time]

It is important that you are well rested at the time of your appointment so please take the time to sleep early tonight! Get at least 8 hours of sleep.

Wash your hair in the morning, and make sure to not apply any hair products, conditioner and make-up, or any sort of lotion on your head and face, respectively. Our lab tends to be a little warm so please dress in layers so you will be comfortable. If you wear corrective lenses, do not wear contacts - wear glasses instead.

We will request that you turn off your phone for the duration of the experiment, and make sure you have gone to the washroom beforehand. Feel free to bring a water bottle or a book for the duration of the set up.

Again, the location of the lab is TSH 610/611. If you have any questions, please feel free to contact me.

See you tomorrow!

## **Appendix G: Letter of Information**

### **A Study of Speech Processing in the Brain**

Principal Investigator: Dr. John Connolly  
Department of Linguistics and Languages  
McMaster University  
Hamilton, Ontario, Canada  
(905) 525-9140 ext. 27095  
jconnol@mcmaster.ca

Student / Co-Investigator: Angela Harrison, B.Sc. (M.Sc. candidate)  
Department of Linguistics and Languages  
McMaster University  
Hamilton, Ontario, Canada  
(905) 973-6757  
harriav2@mcmaster.ca

#### **Purpose of the Study**

In this study, we want to investigate the nature of brain responses to certain types of auditory and visual speech stimuli. To that end, we will be recording your brain activity (that is, your electroencephalographic (EEG) responses) while you listen to and watch someone speaking words.

#### **What will happen during the study?**

In order to ensure the quality of the EEG recordings, you will first be asked to fill out a questionnaire of personal information. Certain neurological or psychiatric conditions, hearing problems, past head injuries, as well as medications that act on the central nervous system may prevent your participation in this study, since these factors may interfere with the data recorded.

EEG recordings will be made using traditional caps or nets that contain sensors capable of recording brain electrical activity. Caps will be secured to your head with the straps and additional sensors will be placed above and to the side (over the outer canthi) of one or both eyes in order to record eye movements including blinking. Recording the electrooculogram (EOG) is important too when recording the EEG because blinking and other eye movements can interfere with and produce artifacts in the EEG signal. EOG recording enables the removal of such artifact. In order to obtain good quality EEG recordings it is important to lightly abrade the scalp and/or apply medical-grade alcohol at

the recording site so that surface oils and associated skin conductivity do not interfere with the recordings. In addition, an electrolyte (an electrically conductive jelly-like substance) must be inserted under each electrode to enable good quality recording. Finally, surgical tape (i.e., tape that does not “pull” at the skin as much as regular tape) must be used to hold in place those sensors placed around the eyes. A trained experimenter will attach and remove all sensors and the cap.

During the study, words will be presented to you through headphones or by silent video during two separate tasks. Before each task you will be given instructions. During both tasks you will be asked to make a response by pressing a button. There are no right or wrong answers so you should not be worried if you have difficulty with some of the test items.

In total, the experiment should take about 2 hours.

### **Potential Harms, Risks or Discomforts:**

The EEG recordings and behavioural tasks do not carry any risk. However, the placement of sensors requires the application of a conductive gel on the scalp, as well as cleaning of the areas of the face where sensors are applied. Cleaning of the skin is done with an alcohol pad and an abrasive paste. These procedures may cause a slight sensation of cold or very light scratching. Some of the conductive jelly will remain in your hair after the sensors have been removed. In addition, in order to obtain valid EEG recordings, many stimulus presentations are necessary. This requires you to sit still and pay attention for extended periods, which may cause some fatigue or discomfort. Stimulus presentation will be stopped at regular intervals in order to allow you to relax between parts of the experiment.

You may find the screening questions about your medical history and drug use to probe sensitive areas. We need to ask you these questions to find out whether you are eligible to take part in the study. The form will not have your name on it and will not be shared with anyone else.

### **Potential Benefits**

There will be no direct benefits to you for participating in the study beyond the payment received. However, your participation will contribute to the advancement of our understanding of how the brain responds to various types of speech information, which will ultimately aid in the development of tools that will help patients with dyslexia or deafness.

**Compensation:**

You may choose two hours course credit or financial compensation at a rate of \$10/ hour.

**Confidentiality:**

All personal information gathered during the experiment will be kept strictly confidential. You will only be identified by a number. Only the principal investigator and student investigator will have access to your name, as well as any other personal or identifying information that you provide. No publication or scientific communication resulting from the study will contain any identifying information. Personal data will be stored in a locked file cabinet or on a password-protected hard drive for a duration of 7 years, after which they will be destroyed. Data that has been made anonymous will be conserved indefinitely because they retain their scientific value and may be of use in analyses subsequent to the present study.

**Participation:**

Participation in this study is completely voluntary. You may choose to withdraw at any time without consequence or prejudice. You will not need to justify the decision to withdraw. If you withdraw, your data will be destroyed unless you indicate otherwise, but you will still receive financial compensation or partial course credit.

**Information About the Study Results:**

You may obtain information about the results of the study by contacting either the principal investigator or the student investigator listed on the first page of this form.

**Information about Participating as a Study Subject:**

If you have questions or require more information about the study itself, please contact the principal investigator or the student investigator listed on the first page of this form.

This study has been reviewed and approved by the McMaster Research Ethics Board. If you have concerns or questions about your rights as a participant or about the way the study is conducted, you may contact:

McMaster Research Ethics Board Secretariat  
Telephone: (905) 525-9140 ext. 23142  
c/o Office of Research Services  
E-mail: [ethicsoffice@mcmaster.ca](mailto:ethicsoffice@mcmaster.ca)

### **Appendix H: Consent**

I have read the information presented in the information letter about a study being conducted by Dr. John Connolly and Angela Harrison, BSc, of McMaster University. I have had the opportunity to ask questions about my involvement in this study, and to receive any additional details I wanted to know about the study. I understand that I may withdraw from the study at any time, if I choose to do so, and I agree to participate in this study. I have been given a copy of this form.

---

Name of Participant

---

Signature

---

Date

## **Appendix I: Debriefing Interview**

**Participant #** \_\_\_\_\_

- How did you find the auditory task? Were you able to focus/follow it?
- How did you find the visual task? Were you able to focus/follow it?
- Which of the two tasks did you find easier?
- Regarding the harder task, what did you find difficult about the task?
- Did you develop any strategies during the tasks?
  - **Auditory**
  
  - **Visual**
- How did repetition of the pictures aid your performance, if at all?:
- Do you have any past experience with lip reading? Are you good at it?
- Were any of the stimuli unclear? Did you encounter any difficulties/distractions?
- Are you more of a visual or auditory learner/person?
- Is there anything that could have been changed to help you perform better
- Do you have any further questions?