You Can't See Me: Searching for Evidence of Unconscious Semantic Processing in an Inattentional Blindness Paradigm

---

A Thesis

Presented to

The Division of Philosophy, Religion, Psychology, and Linguistics

Reed College

In Partial Fulfillment

of the Requirements for the Degree

Bachelor of Arts

Juliette Tripier

May 2018

Approved for the Division

(Psychology)

____

Enriqueta Canseco-Gonzalez, Ph. D.

Acknowledgments

First and foremost: thank you to my advisor, Enriqueta Canseco-Gonzalez, for your endless patience, guidance, wisdom, and encouragement as we weathered the storm of this thesis process.

Thank you to Michael Pitts and the SCALP Lab (especially Camille and Kevin). I am so fortunate to have been part of such a curious and passionate group of scientists, and my thesis would not have been possible without your help and support.

Thank you to Cecile, roommate, partner in crime, and best friend extraordinaire, for four years of abundant joy, art, music, and gently simmering sauces. Your friendship has touched me profoundly and brought so much color and light into my life. Thank you for building a warm and beautiful home with me, and for navigating not only the thesis process but the entire Reed experience by my side.

Thank you to Annabelle, my absolute bean. Thank you for your invaluable help with the design of my stimuli, O all-powerful deity of Adobe Illustrator. But more importantly, thank you for being the Bill to my Ted since our first day at Reed. I am so glad you knocked on my door that day. I had never experienced such unconditional, overwhelming love in my life before meeting you, but I can no longer imagine a life without it.

Thank you to Shira, for all those hours spent in your thesis office and on various balconies, bouncing ideas back and forth and discussing psychology until our throats were dry. Thank you for all the frenzied dancing, opera singing, reality television, and impromptu balloon-based workouts during our darkest hours. I am so incredibly lucky to have you as a friend.

Thank you to The Adventure Group – Cecile, Shira, Mauricio, Taylor, Ian, and Simué. Our weekly meetings provided a much-needed break from the thesis process, and I am so glad this ragtag band of adventurers became a council of almighty gods. We have built a nation, lost a leader, and lost our faith. Now we stand at the precipice of our own universe, restrained only by our own imaginations. Let us go forth, my friends, and eat the world.

Thank you to the greatest band on earth, Honda Cynic – Taylor, Ian, Cecile, and Katie. Thank you for filling my life with music and most excellent Satisfaction mashups. I am honored to know you all and to have played alongside you.

Finally, thank you to my family – Mom, Dad, Felix, and Etienne. Thank you for helping me become the person I am today. Thank you for all your support throughout the four most challenging years of my life. Thank you for giving me the strength and courage to continue when it feels as if there is nothing left ahead of me, and for continually reminding me that in the darkest of times there is always light to be found. I hope to make you all proud.

Table of Contents

List of Figures

Abstract

The following thesis attempted to find evidence of semantic processing in the absence of conscious awareness and attention. In the first and second phases of the experiment, participants completed a difficult color-discrimination task while a grid of false fonts was presented in the center of the display. While participants fixated on the distractor stimuli, 200 pairs of semantically related and unrelated words were presented embedded within the false font grid. Inattentional blindness to the word stimuli was successfully induced in over half of participants. Participants received a questionnaire at the end of the first phase which alerted them to the presence of the word stimuli. In the third phase, participants were instructed to ignore the distractor stimuli and attend solely to the words. Tentative visual analysis of ERPs (with a small number of participants) showed no evidence of an N400 effect (larger negativity to unrelated than related target words) in the first and second phases in both aware and unaware participants, but a clear N400 response to unrelated target words in the third phase. These results suggest that awareness and some degree of attention are required for semantic processing. There also seems to be a consistent difference in ERPs to false font trials and ERPs to word trials across all participants and phases, indicating there may be some unconscious orthographic processing taking place. If similar results with a larger sample size are found, it would suggest that, although semantic processing requires both attention and awareness, orthographic processing can occur unconsciously and automatically.

Chapter 1: Introduction

Consciousness is the window through which we see the world, and we often take for granted that we have conscious access to every part of our perceptual experience. However, this assumption is incorrect. For one, salient stimuli often go undetected in real-world situations, from the relatively inconsequential, such as leaving the house without one's keys despite having passed by them moments before, to the devastating and fatal, like failing to notice a pedestrian crossing the street while driving and causing a collision. For another, a number of complex intermediary processes occur between the moment our eyes settle on a stimulus and the moment we become consciously aware of it. We have no access to the details of these processes; we only have access to the output, to the sensation of awareness of the stimulus as a whole. Therefore, there is a difference between that which is perceptually analyzed by the brain and the output of the analysis that we have conscious access to. Defining what type and amount of information we can consciously access, and which types are processed unconsciously, is difficult to do experimentally; we must find a way to extract information that subjects have, but cannot report. This study attempts to determine how comprehensively the brain can extract information from visual word stimuli in the absence of conscious awareness through the analysis of differential event-related potentials (ERPs) evoked by word and nonword tokens in an inattentional blindness paradigm.

In this chapter I will review the N400 effect, a neural response that provides a rough index of semantic processing, followed by an overview of how electrophysiological measures can be used to answer experimental questions, focusing on previous studies that have investigated unconscious processing using electrophysiological measures (EEG). Then, I will present an exposition of three commonly used experimental paradigms in determining which steps of semantic processing can occur in the absence of awareness and which cannot. Finally, I will elaborate on my own research question.

1.1 An Overview of EEGs and the N400 Effect

1.1.1 What Is An EEG?

Information is transmitted in the brain through the flow of ions, which produce small changes in voltage as they move across neuronal membranes. In a single neuron, this change is too small to be detected non-invasively, but neighborhoods of neurons can produce electrical fields large enough to be measured through the scalp. The electroencephalogram (EEG) involves placing electrodes on the scalp to measure the fluctuations in voltage of neuronal neighborhoods across time (Kutas & Van Petten, 1994).

EEG, unlike other forms of brain imaging such as the fMRI, have excellent temporal resolution and provide a direct, instant measure of neuronal activity. However, due to the non-invasive nature of the procedure and therefore the distance of the electrode from the brain, they have poor spatial resolution and can only provide a general approximation of where in the brain a given process takes place (Luck, 2014).

1.1.2 What Is An ERP?

Event-related brain potentials, or ERPs, are composed of postsynaptic potentials (PSPs). PSPs occur when ions flow across neuronal membranes. In a single cell, a PSP cannot be detected from the scalp, as it is too small and cannot be picked up by a distant electrode through the noise generated by the neurons surrounding it. However, when thousands of similarly-oriented neurons generate PSPs at once, the overall change in voltage can be picked up by a scalp electrode (Luck, 2014). By time-locking EEG activity to the onset of a stimulus (or any other event), we can experimentally identify which conditions lead to the presence or absence of a change in voltage across a large family of neurons. The term ERP, therefore, refers to this change in voltage across a large group of neurons that is reliably elicited by a particular event. The change in voltage that occurs during an ERP is generally small compared to the overall activity of the brain, and the specific change in negativity or positivity is subject to variation across trials, so in order to experimentally isolate an ERP, researchers must present the subjects with many (often hundreds) of trials and average their data across trials in order to cancel out the noise and isolate the signal (or the change in voltage associated with the particular event).

1.1.3 What Is The N400 Effect?

The first description of an N400 response was put forth by Kutas & Hillyard in 1980. They had subjects read sentences presented one word at a time and found that semantically incongruous endings (e.g. "I take my coffee with cream and *dog*") caused a negative wave around 400 msec post-final word when compared to congruous endings (e.g. "I take my coffee with cream and *sugar*"), which elicited more positive responses. Since then, researchers have found that this positive wave elicited by entirely predictable final words is by and large the exception: that is, most words elicit an N400 response, although the amplitude and latency of said N400 varies widely. The largest, most robust N400 is generated by a word that violates the pre-established semantic context, regardless of the word's position within a sentence. This N400 emerges about 200ms from the presentation of the critical word and peaks between 300 and 400ms (Kutas & Van Petten, 1994).

Scientists have continued to make strides in identifying under which specific conditions the N400 is elicited. N400 amplitude has been found to be highly correlated with cloze probability, which corresponds to what percentage of individuals would continue a sentence fragment with the word in question. For instance, with the sentence "The roast beef is in the ___", the word *oven* has a much higher cloze probability than the word *spaceship.* The N400 effect is modulated by both word frequency and predictability. It is not elicited by any given anomaly - the anomaly must reflect a violation in expected meaning, and the N400 will not be elicited by a syntactic violation. N400 effects are found among pairs of words, not just sentences, as we will see in the studies mentioned in the following sections. N400s can even be observed across modalities, as line drawings, pictures, and faces have all been found to elicit an N400 when they violate the context created by tokens or sentence contexts that precede them (Kutas & Federmeier, 2011).

Overall, the N400 does not specifically index unexpected semantic information. It is a broader neural signature that seems to index the processing of meaning and the violation of an established context.

1.2 Attentional Blink, Masked Primes, and Inattentional Blindness Paradigms

Researchers have not yet reached a consensus on which levels correspond to automatic, unconscious processing and which levels require attention or awareness. Semantic processing is more complex and extensive than simply distinguishing between a letter form and a non-letter form, and may require some level of conscious activity. The critical component of determining whether or not semantic processing requires attention and/or awareness is finding a way to present stimuli in the absence of attention and/or awareness. In what follows, I describe three of the experimental paradigms that have achieved this goal in different ways.

1.2.1 Attentional Blink

The first paradigm is the attentional blink method. In the attentional blink paradigm, subjects are presented with a rapid stream of visual stimuli (also referred to as Rapid Serial Visual Presentation, or RSVP). Subjects are instructed to identify a target stimulus within the stream of distractors. Crucially, subjects are unable to report a probe stimulus presented after the target if it appears within a certain time window - generally between 180 to 500ms after the presentation of the target stimulus (Raymond & Shapiro, et al. 1992). If the interval between the target and probe stimuli is shorter or longer than 180-500ms, subjects have no trouble identifying the probe stimulus. It is possible that this “attentional blink” arises because the subjects’ attentional resources are still occupied by the target stimulus when the probe stimulus is presented, causing the probe stimulus to go unnoticed.

One of the seminal studies in the field of unconscious semantic processing was conducted by Luck, Vogel, & Shapiro in 1996 using this paradigm. At the beginning of each trial, a priming word (e.g. READ) was presented which created the semantic context for that given trial. The stimuli the subjects were instructed to report was a target stimulus consisting of a string of repeated numerals (e.g. 7777777) and a probe stimulus (a word), both embedded within the rapid visual stream of distractor items (strings of consonants). The target stimulus preceded the probe stimulus by 1-7 distractor items. The probe stimulus was either semantically related (e.g. BOOK) or semantically unrelated (e.g. SYRUP) to the priming word presented before the RSVP. They found that the semantically unrelated probe words presented during the attentional blink window (when the target and probe stimuli were separated by 3 distractor items, corresponding to a 249ms interval) elicited an N400 effect (when compared with the semantically related probe words), indexing a semantic mismatch, even when subjects could not report having seen the probe word immediately following the trial. This was interpreted as the result of unconscious semantic processing, and they concluded that semantic processing can occur in the absence of awareness.

Since then, many replications have been conducted across different modalities and experimental paradigms, and the findings have been somewhat mixed. For instance, in one study, both missed and recognized primes elicited an N400 in subjects while identifying a target among a rapid stream of distractors (Rolke, Heil, Streb, & Hennighausen, 2001). However, a study from Batterink, Karns, Yamada, and Neville conducted in 2010 employing a similar paradigm failed to find this effect. Subjects were presented with a priming word at the beginning of the trial, and then were to identify two targets embedded in the visual stream, referred to as T1 and T2. T1 consisted of a number written in letters and flanked by Xs to create a seven-letter string (e.g. XTHREEX), while T2 consisted of a word flanked by #s (e.g. #NURSE#). The researchers found that when T2 was semantically unrelated to the priming word, it elicited an N400 compared to trials where T2 was semantically related to the priming word - *but only when subjects were able to correctly report the targets*. In "missed" trials, where subjects could not report the targets, the semantically unrelated T2 failed to elicit an N400. This finding, in contrast with Luck, Vogel, & Shapiro (1996), suggests that the N400 is reflecting a controlled, post-lexical process, and therefore the semantic features of a word cannot be accessed unless the word has reached conscious awareness. However, Batterink et al. still identified a small, statistically insignificant N400-like effect in these missed trials, suggesting there may have been semantic activation on some level, although it was inconsistent across subjects. Overall, research using attentional blink paradigms has produced contradictory results, and the possibility remains that the "hidden" stimuli are consciously processed in some way, but are not stored in memory, and therefore go unreported. This is supported by the fact that the probe word targets are correctly identified by participants at a fairly high rate, suggesting that the "hidden" stimuli are not as hidden as we may think.

1.2.2 Masked Prime

The masked prime paradigm is similar to the attentional blink paradigm, but employs slightly different methods. In a masked prime paradigm, the target stimulus is preceded by a priming stimulus that is "masked" from conscious awareness by being "sandwiched" between two patterned masks. In a typical masked prime study, the primes are either congruent or incongruent with the target stimulus; for instance, in an odd-even number categorization study with an even target (such as the number 4), a "congruent" prime would be an even number, whereas an "incongruent" prime would be an odd number. If the prime is being unconsciously processed, there should be a difference between trials with incongruent primes and trials with congruent primes, whether it be in terms of reaction times, accuracy, neuronal activation, or some other measure (Ulrich, Hoenig, Gron, & Kiefer, 2013).

A study employing a masked prime paradigm in a semantic context (presenting number stimuli in word form, e.g. "ONE") was conducted by Dehaene, Naccache, Le Clec'H, Koechlin, and Mueller in 1998. Subjects were instructed to attend to the visual stream and identify a numeric target. They were to press one button if the target number that appeared was greater than 5, and a different button if it was smaller than 5. Unbeknownst to them, each target was preceded by a masked prime, which could also be either larger or smaller than 5. The researchers found a priming effect wherein subjects exhibited faster response times in congruent trials (trials where the target and prime were both on the same side of 5) than in incongruent trials (where the target and prime were on opposite sides of 5), a result that could only be possible if the masked primes were being unconsciously processed. The researchers argued that their results reflect unconscious semantic processing, in part because they independently varied the notations used for both the prime and target numbers, presenting them either as arabic digits or written words (e.g. 1 or ONE). The notation of the numbers had no effect on the amount of priming that occurred. In addition, the priming effect remained statistically significant even after removing trials with repeated numbers from the analysis, indicating that the priming effect was due to the semantic similarity of the numbers and not simply to a word repetition effect. This study provides good evidence for some level of deeper processing occurring unconsciously, although it involves the categorization of numbers rather than the relatedness of words and, therefore, is approaching semantic processing from a different direction than Luck's study.

1.2.3 Inattentional Blindness

In contrast with attentional blink and masked prime paradigms, where the target and probe stimuli are presented in succession, the inattentional blindness paradigm presents both critical and distractor stimuli simultaneously. This paradigm exploits our limited attentional capacity by introducing an attentionally demanding task such that the critical stimuli will often go entirely unnoticed, even if presented at the center of the screen. Inattentional blindness, unlike attentional blink and masking, presents the critical stimuli in full view, ensuring that the unawareness is due to lack of attention directed at the stimulus, rather than induced by insufficient sensory input. Furthermore, inattentional blindness paradigms are not limited to visual stimuli; some studies have employed auditory stimuli in "inattentional deafness" experiments (Macdonald & Lavie, 2011). Inattentional blindness studies also create the opportunity to employ "no report" paradigms - subjects are instructed to focus on and report stimuli related to the distractor task, which is irrelevant to the critical (unattended) stimuli. As mentioned above, in attentional blink studies subjects report whether or not they saw the probe stimulus embedded in the visual stream, but under these conditions it is still possible that a stimulus that went unreported was indeed seen by the participant, but failed to be stored in memory. In contrast, in inattentional blindness studies, subjects do not need to report awareness of the critical stimulus during the trials. When using the recording of brain electrical activity (EEG), subjects do not need to make any kind of overt response whatsoever - their EEG data in aware and unaware conditions can be compared to each other directly, eliminating the conflation of aware and unaware processes with processes related to the report that are inherent in a report-based paradigm.

One of the most effective ways to directly compare brain responses between aware and unaware conditions is to split the experiment into three experimental phases. In the first phase, subjects are repeatedly exposed to a critical stimulus while attending to a distractor task. In this phase, participants are spontaneously aware or unaware of the critical stimuli. After this phase, the subjects' awareness is assessed with a questionnaire. In the second phase, all subjects are now aware of the critical stimuli as a result of the questionnaire, but continue to attend to the distractor task. After this phase, they complete another awareness assessment. In the final phase, subjects are then instructed to attend solely to a task involving the critical stimuli, while ignoring the distractor task. With this three-phase paradigm, three different conditions can be directly compared, both within and across participants: First, we have a condition where there is no awareness of the critical stimuli and no attention directed towards them (at least in some of the participants), then a second condition with awareness of the critical stimuli but only partial attention directed towards them (as the participants were able to report seeing word stimuli after phase 2, there must have been some degree of attention), and finally, a third condition with awareness of the critical stimuli and with full attention toward them. This, coupled with the no report paradigm and the fact that the critical stimuli are in full view rather than masked, makes the inattentional blindness paradigm ripe for investigating semantic processing under both aware and unaware conditions.

Some studies have found evidence for unconscious semantic processing using inattentional blindness paradigms. For example, a study by Schnuerch, Gibbons, Kreitz, and Memmert (2016) found that the meanings of unnoticed objects interfered with the classification of objects that were actively being attended to. The distractor stimuli consisted of an array of hash marks arranged in a circle around a central grid of randomly selected letters (Ws, Xs, and Ys). During the critical phase, one of the hash marks in the array was replaced with a numeral, and subjects were instructed to classify the numeral as either smaller or larger than 5 - similar to Dehaene et al. (1998). During the target phase, in some trials, some of the characters in the central array were replaced with a numeral that was consistent across trials - i.e., randomly selected characters were replaced with the numeral 8. The researchers found that reaction time was significantly reduced in trials where the numeral in the central array and the numeral in the hash mark array fell on the same side of 5, indicating some kind of facilitation effect. This effect was preserved even when the target stimulus that replaced the hash mark was a written number as opposed to an arabic numeral. The fact that unnoticed, unattended stimuli facilitated categorization of the target numeral indicates that semantic processing is contingent on neither awareness nor attention, supporting Luck's (1996) findings.

One recent study that failed to find evidence for unconscious semantic processing using this three-phase, no report inattentional blindness paradigm was conducted by Schelonka, Graulty, Canseco-Gonzalez, & Pitts in 2017. In the first and second phase, subjects attended to a complex task involving detecting disks of different luminance rotating around concentric ovals while words, consonant strings, or scrambled lines were presented in the center of the display. During the third phase, participants ignored the disks and were instructed to detect when animal words were presented on the center of the display. The researchers found that the words and consonant strings elicited more negative ERPs than the scrambled lines across all phases, indicating a level of unconscious orthographic processing. However, ERPs elicited by the words were not significantly different from those elicited by the consonant strings in the first phase in unaware participants (but were significantly different from each other in all other phases and in aware participants in the first phase), indicating that under unaware, inattentive conditions, the brain is not significantly differentiating between valid word forms and consonant strings.

Not only are the data inconclusive across paradigms, but they are inconclusive within paradigms as well. It appears that small factors such as the modality of the stimuli and the nature of the distractor task can affect whether or not one will find an N400 effect across conditions of awareness.

1.4 Research Question

In the following study, I attempted to find evidence of unconscious semantic processing using a three-phase, no-report inattentional blindness paradigm and an ERP procedure. In the first phase, subjects attended to a color-discrimination distractor task while false fonts or words are presented simultaneously. Subjects in this phase were be either unaware or spontaneously aware of the word stimuli. After this phase, subjects received a questionnaire assessing their awareness of the critical (false font and word) stimuli. In the second phase, all subjects were now aware of the critical stimuli, but continued to attend to the distractor task, as in the first phase. They received a questionnaire at the end of this phase as well, in order to ensure all subjects were aware of the words in this condition. In the final phase, subjects were instructed to attend solely to the critical stimuli, ignoring the distractor task. I compared ERPs elicited across different conditions of attention and awareness, both within subjects across phases and across unaware and spontaneously aware subjects.

If both attention and awareness are required for semantic processing, in the third phase and the third phase alone I expected to find a larger N400 elicited by word stimuli that are preceded by a semantically unrelated word stimuli. If awareness, but only partial attention, is required for semantic processing, I expected to find a similar N400 effect in the second and third phase in unaware participants, and across all three phases in participants who are spontaneously aware. Finally, if Luck et al. (1996) is correct in stating that semantic processing can occur in the absence of both awareness and attention, I expected to find an N400 effect across all three phases and in aware and unaware participants alike.

Chapter 2: Methods

2.1 Participants

Eight healthy adults (mean age = 20.8 years, 6 female) with no history of neurological condition participated in the experiment. Three participants were rejected after analysis due to excessive artifacts, leaving five participants in the final sample. All participants reported normal or corrected-to-normal vision. As an incentive for participation, participants received four to six psychology department lottery tickets, each worth a chance to win a $50 Amazon gift card. The number of lottery tickets received was determined by the length of time it took to complete the experiment, with each ticket corresponding to a half hour of the participant's time. All participants gave informed written consent prior to the beginning of the experiment, and all experimental procedures were approved by the Reed College Institutional Review Board (IRB).

2.2 Stimuli

Three different sets of stimuli were used in this experiment: a set of circles for the distractor task, a set of 26 false fonts, and a set of 300 words. Five sets of circles, initially created in Adobe Illustrator, were repurposed from Mack & Rock (1998) and Koukoutchos (2016) for this experiment. Each circle was bisected vertically, with one half colored green and one half colored red, with four circles in each trial and one circle located in each corner of the display per trial. The placement of each color varied according to set; in one set, all circles had the red half on the left and the green half on the right. In the four remaining sets, one of the circles was the "odd one out", with the left half colored green and the right half colored red. The specific location of the "odd one out" distinguished the four sets from one another.

The set of false fonts was created in Adobe Illustrator. There were 26 false font characters, each corresponding to a letter of the Roman alphabet. Each character was created by manipulating pre-existing letters until they were unrecognizable, including changing orientations, adding and removing line segments, and merging the component parts of two different letters. The false font stimuli were carefully designed to closely resemble the Latin alphabet in order to effectively "hide" the word stimuli within the grid, but to be dissimilar enough to block any attempt at semantic processing of the false fonts themselves. Line thickness and amount of white space around each character was controlled in order to ensure that the characters would be properly sized and spaced once called into the grid (see Figure 2.1 for an example of the grid and circle stimuli).

The word stimuli were selected based on their relatively high frequency of use in American English and on their length. All word stimuli were 4-7 characters long and created in Google Draw with Arial, the same font used to create the false fonts. The words were divided into two categories, encompassing 200 "A" (or prime) words and 100 "B" (or target) words. The words were then paired up such that 2 A words were assigned to each B word, with one A word being semantically related to the B word and one A word being semantically unrelated. Importantly, the order of the words in the series was carefully arranged such that each target word was presented twice per phase, with one instance of each target word (e.g. "nurse") being preceded by a semantically related prime word (e.g. "doctor"), and one instance of the *same word* ("nurse") being preceded by a semantically unrelated prime word (e.g. "chair").

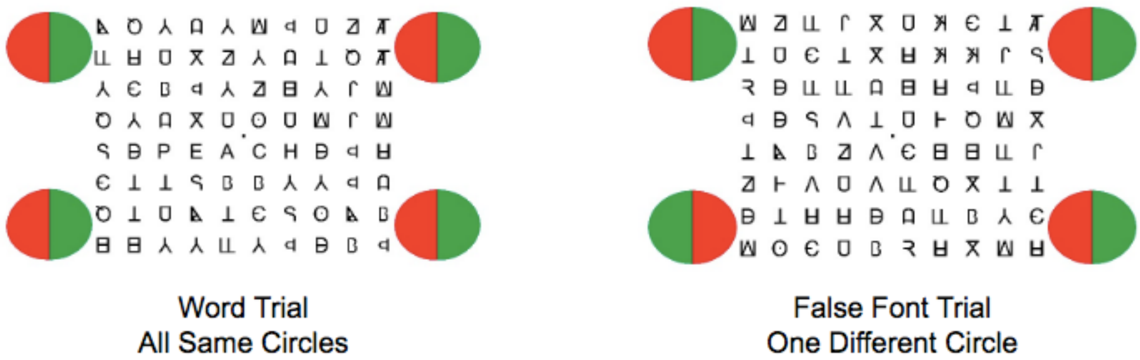

Figure 2.1 Example Stimuli
The left image shows an example of a word trial (the word "PEACH" embedded in the false font grid) and a set of identical circles. The right image shows an example of a false font trial and a set of circles containing a different circle (bottom right circle).

Semantic relatedness between the words of a pair was assessed using Wu & Palmer (WUP) values from WordNet, which index relatedness based off of the position and distance of words relative to one another within a set of synonyms. All related pairs had a WUP value of 0.6 or higher, and all unrelated pairs had a WUP value of 0.4 or lower.

Stimulus presentation, as well as behavioral responses, were controlled and recorded using Presentation software (Neurobehavioral Systems, Albany, CA).

2.3 Procedure

Participants sat approximately 75 cm from a computer screen in a sound-attenuated booth during the EEG session, which lasted about 150 minutes (including a 30-40 minute capping time). Participants were told they were being tested on a difficult same/different visual discrimination task to determine if all four circles presented in a very brief display were identical or if one was different from the rest. Using a standard keyboard, participants pressed the left arrow key using their right index finger to indicate whether all circles were identical, and the right arrow key with their right middle finger to indicate whether one of the circles was different.

The experiment was divided into three phases, preceded by a practice phase. Participants were given one practice block of 20 trials in order to ensure they understood the task at hand. The criterion for passing on to the experimental portion was at least 60% accuracy on the circle task; participants who failed to achieve 60% accuracy after 20 trials received additional blocks until the criterion was achieved. During this practice phase, the circles were always accompanied by false fonts, and the false font grid never contained words.

For each experimental trial, a set of circles and the font grid appeared together for 300 ms, with the font grid and a fixation point located in the center of the screen. On 66% of trials, a string of false fonts occupied the space directly above the fixation point in the center of the screen. On the other 33% of trials, words 4 to 7 characters long were instead presented above the fixation point, replacing the false fonts. On 50% of the word trials, the word presented was semantically related to the word preceding it, and in the other 50% of the word trials, the word presented was semantically unrelated to the word preceding it. The order of trials was pseudo-randomized to ensure that there were 50% of each type of trial. Within a given pair of A and B words, the word trials were separated by 1-2 false font trials (see Figure 2.2 for a visual of the stimulus sequence; see Appendix A for the full list of word pairs).

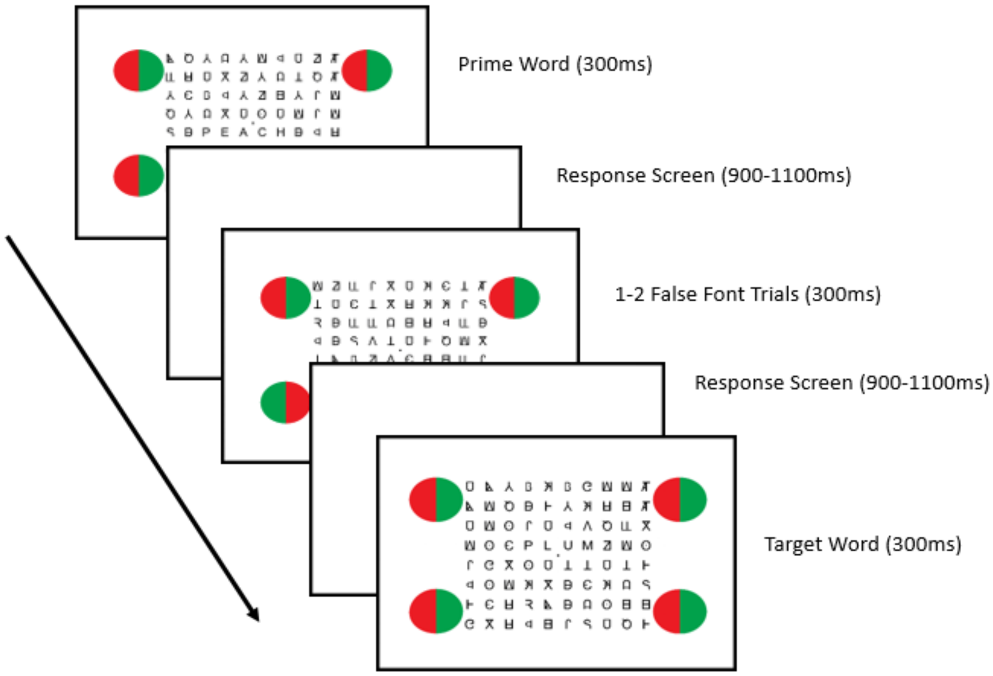

Figure 2.2 Stimulus Sequence

Stimulus sequence for a single word pair: prime word (word A), response screen, 1-2 false font trials with a response screen after each, and target word (word B). The pairs of words themselves are separated by 2-3 false font trials (not pictured).

The two word trials in each pair were separated from each other by 2-3 false font trials. Each trial was separated by a blank response screen consisting only of a fixation point, with its duration randomly jittered from 900-1100 ms. There were approximately 120 trials per block and 10 blocks in each phase, with a short break in between each block. In each phase, there were about 1200 trials, 400 of which contained word stimuli. In sum, each phase had 200 prime-target word pairs, 100 of which were semantically related (e.g. "PEACH" and "PLUM") and 100 of which were semantically unrelated (e.g. "SHOE" and "MEAT"), for a total of 200 target word trials in each phase. There were also approximately 800 trials that had only false fonts accompanying the circles, with no word stimuli embedded within the grid.

In the first phase of the experiment, participants were instructed to attend to the circle task. At the end of this phase, participants completed a questionnaire consisting of a nonspecific question: "Did you notice anything unusual during this phase?" followed by some examples of items they may or may not have noticed, some of which were actually present in the experiment and some of which were foils to ensure the participants were truly noticing the stimuli (See Appendix B for the full questionnaire; note that participants were presented with visual examples of both the words and the different types of foil stimuli). Based on their responses to this first questionnaire, we determined whether participants were unaware of the word stimuli in this first phase, or were spontaneously aware of the words by virtue of having noticed them during the task.

In the second phase, all participants were now aware of the false font/word stimuli due to the questionnaire, but continued to attend to the circle task. Participants completed the same questionnaire at the end of this phase as well, in order to ensure that our assumption of them having noticed the words was true.

In the third and final phase, participants were instructed to attend to the false font/word stimuli instead of the circles. Their task was to indicate whether or not they had seen a word in each trial. They were to press the left arrow key using their right index finger to indicate "yes" and the right arrow key using their right middle finger to indicate "no". There was no questionnaire at the end of this phase.

2.4 EEG Methods and Analysis

Electrical activity was recorded non-invasively using a 64-channel electrode cap (BrainVision). An electrode placed on the left mastoid was used as the on-line reference. Additional electrodes were placed lateral and adjacent to the right and the left eye in order to detect horizontal eye movements, and under the left eye to detect blinks. Electrode impedance was kept below 5 kΩ and electrode signals were amplified by BrainVision amplifiers. Trials with artefacts such as eye blinks and eye movements were discarded. Electrode signals were sampled at a 500hz rate, and filtered on-line to allow signals with a range of .03-100 hz. ERPs were time-locked to the onset of the circle and font grid stimuli and baseline corrected using a -200ms to 0ms baseline and later low-pass filtered off-line at 25 hZ for visual analysis.

The main comparison of interest was the difference in ERP amplitude elicited by word trials that were semantically related vs. those elicited by words unrelated to the preceding word trial in the 300-500 ms time window (representing an N400 effect), compared across participants and across phases. It is important to remember that the same identical words were used in related and unrelated pairs. Therefore, any observed differences can only be due to the degree of semantic relatedness.

In addition, ERP responses to the false fonts, semantically related words, and semantically unrelated words were compared across all 3 phases in order to isolate components related to awareness, orthographic processing, and semantic processing. The first phase among non-noticers involves neither attention nor awareness, while for noticers involves awareness but only partial attention. The second phase, for all participants, involves awareness and only partial attention. Finally, the third phase involves both awareness and attention for all participants, and the word stimuli are directly task-relevant. Therefore, differences between the first and second phase can be linked to awareness as a factor, while differences between the second and third phase can be linked to attention and task relevance.

Chapter 3: Results

3.1 Behavioral Data

3.1.1 Questionnaire Data

Participants were placed into aware (noticer) and unaware (inattentionally blind) groups according to their responses on the questionnaire issued after the first phase. The questionnaire (see Appendix B for the full questionnaire) included two open-ended questions intended to non-specifically probe for knowledge of the word stimuli, as well as two questions which asked participants to rate both their confidence in having seen different types of stimuli (including words, consonant strings, number strings, and a foil of brightly colored shapes) and how frequently they saw the aforementioned stimuli on a 5-point scale. In order to be considered unaware, participants could not mention words in the open-ended questions, and had to rate their confidence in having seen words during the phase at a 3 (representing "Uncertain") out of 5 or lower.

Of the eight participants that completed the study, three spontaneously noticed the words during the first phase; all of these participants rated their confidence in having seen the word stimuli at a 5 of 5, and two of the three provided examples of word tokens in the open-ended questions. Of the five unaware participants that completed the study, two reported seeing letters in the open-ended question following the first phase, but both of those participants rated their confidence in having seen words at a 2 (confident I did not see it). After analysis, two of the participants in the aware group and one of the participants in the unaware group were rejected due to excessive artifacts, leaving a final total of one aware participant and four unaware participants. Although the final sample has a disproportionately higher number of unaware participants than aware participants, the initial sample suggests that inattentional blindness was indeed successfully induced in over half (62.5%) of participants.

3.1.2 Task Performance

Performance on the circle task was consistently above chance and generally high across phases and groups (noticers vs. non-noticers), although there was some variation between individual participants (min = 69.50%, max = 91.13%; see Figures 3.1 and 3.2 for full results). Subjects showed a trend towards improving in accuracy between phase 1 (M = 79.46%) and phase 2 (M = 82.12%), although due to low n statistical significance cannot be evaluated. Because the stimuli are identical between phases, this trend towards improvement can likely be attributed to practice rather than differences between phases. Reaction times were very similar between phase 1 (M = 252.23 ms) and phase 2 (M = 251.39 ms). Overall, it seems that awareness of words during the circle task does not affect reaction times and likely does not affect accuracy.

All participants showed higher accuracy in the word/no-word task in the third phase compared to their performance on the circle task (M = 89.64%). This result is to be expected, as the word task involves directing one's attention at a central stimulus rather than four peripheral stimuli and is therefore easier. Reaction times were slower than in the circle task (M = 261.5318). The slower reaction times in this condition are inconsistent with past studies, which found significantly faster reaction times in the word task compared to the circle task (Koukoutchos, 2016). The pattern found in this study may be due to the fact that the letter forms in the word stimuli were highly similar to the false fonts, making them more difficult to distinguish at high speeds. However, this degree of similarity makes the word stimuli less likely to be noticed during the first and second phases, which is critical to obtaining high rates of inattentional blindness.

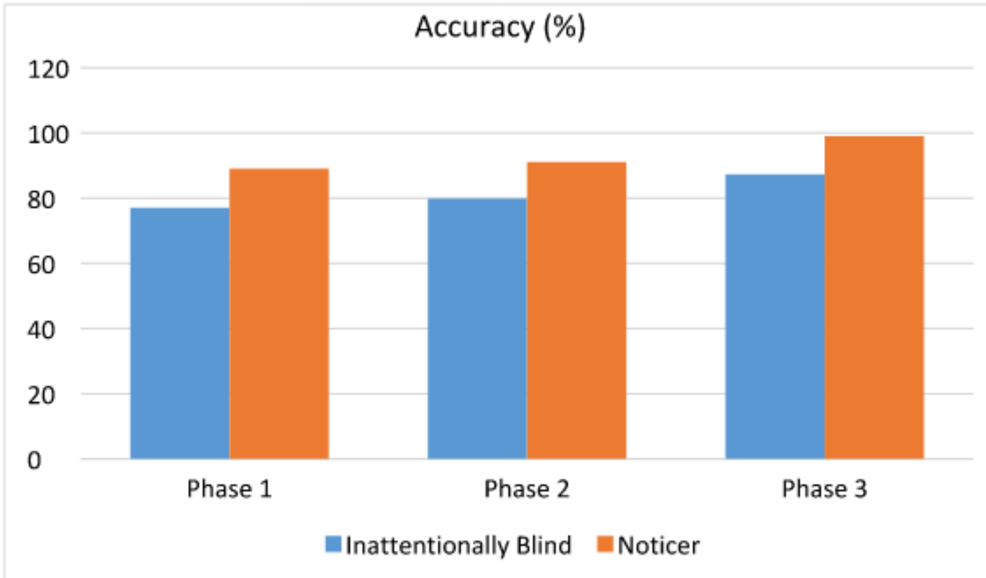

Figure 3.1 Task Accuracy

Accuracy (%) for the circle task in phases one and two and the word/no-word task in phase three.

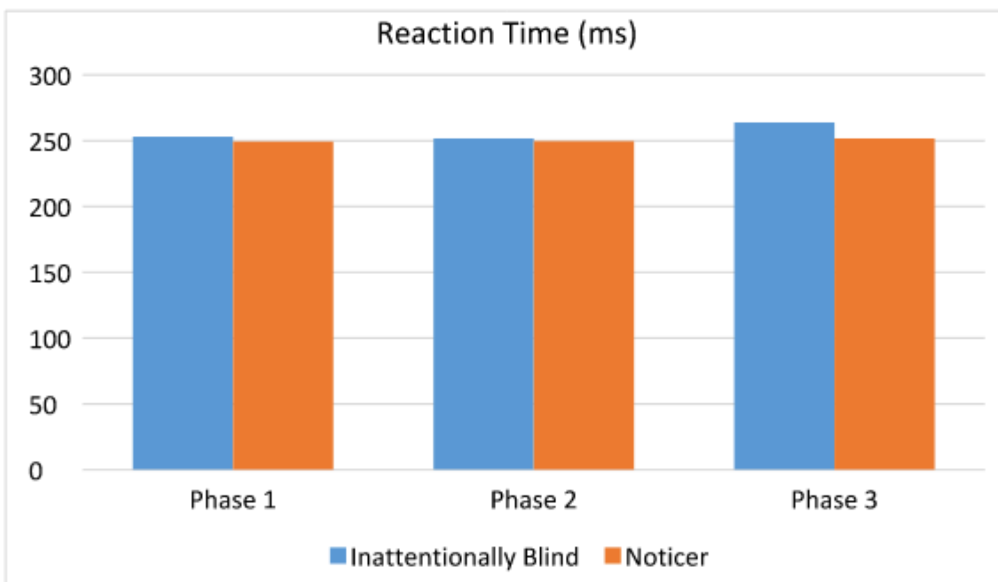

Figure 3.2 Task Reaction Times

Reaction times (in ms) for the circle task in phases one and two and the word/no-word task in phase three.

3.2 Electrophysiological Data

Due to low *n*, the analysis of the electrophysiological data is limited to trends based on visual observations. The inattentionally blind group contains four participants, while the aware group contains one. ERPs were time-locked to the onset of their respective stimuli as follows: related word ERPs locked to the appearance of a semantically related target word, unrelated word ERPs locked to the appearance of a semantically unrelated target word, and false font ERPs locked to the appearance of the second false font trial after the presentation of each pair of word stimuli.

3.2.1 N400 Observations

The N400 effect is characterized by a negativity that peaks around 400ms post-stimulus onset, generally localized centro-parietally (Luck, 2014). After a visual review of ERPs at all electrode sites, electrode Pz was selected for ERP comparisons, as it showed the clearest waves across all participants and phases. Figure 3.3 shows grand averages of the four unaware participants at Pz elicited by the three types of stimuli. Figure 3.4 shows individual averages of the single aware participants at Pz elicited by the three types of stimuli.

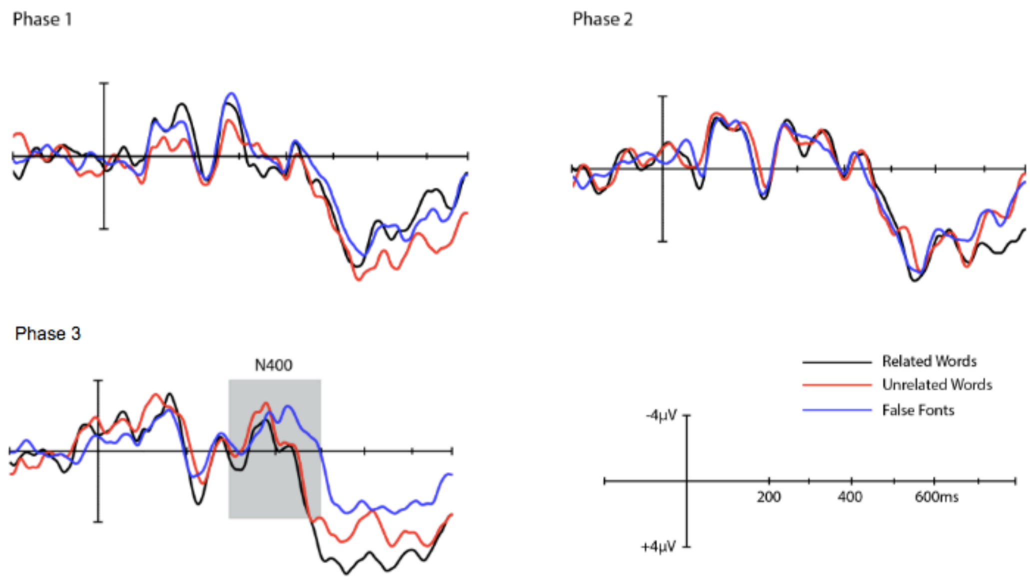

Figure 3.3 ERPs for Inattentionally Blind Participants
Grand averages for related word trials, unrelated word trials, and false font trials for inattentionally blind participants across all three phases from 200ms before stimulus onset to 800ms post-presentation, on electrode Pz.

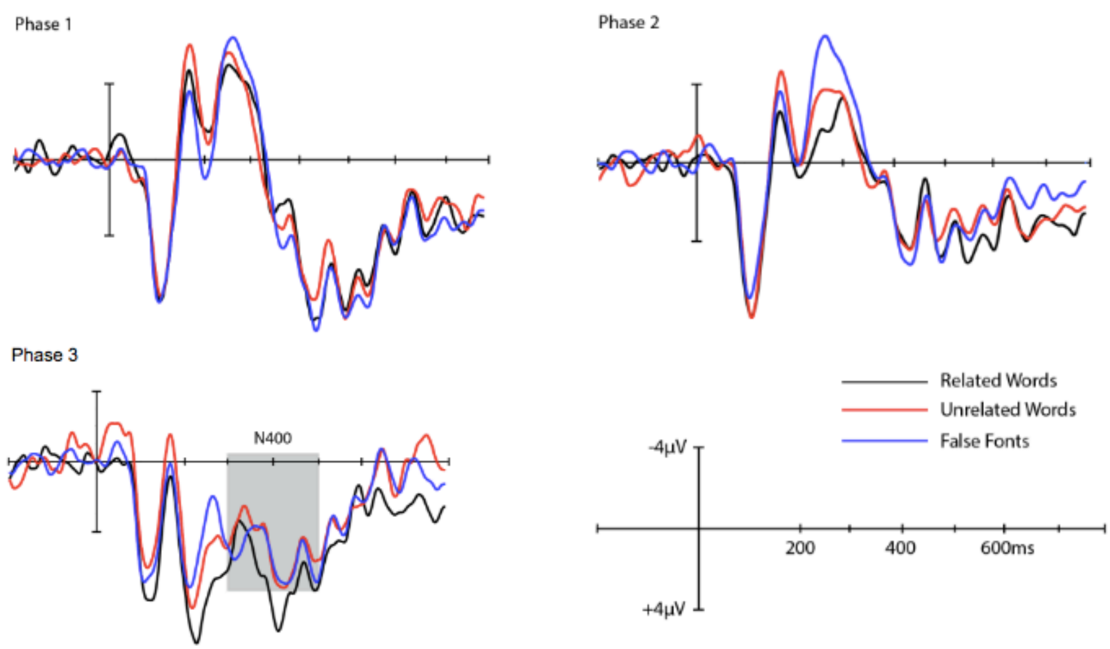

Figure 3.4 ERPs for Noticer
Grand averages for related word trials, unrelated word trials, and false font trials for the non-intentionally blind participant across all three phases from 200ms before stimulus onset to 800ms post-presentation, based on electrode Pz.

Visual inspection of the ERP data indicates the N400 effect is only elicited in the third phase across both aware and unaware participants. There is no evidence of an N400 effect in the first and second phases across aware and unaware participants alike; the unrelated words do not elicit a stronger negativity relative to the related words at the 400ms mark. The aware participant shows a clear, robust N400 effect in the third phase, while the unaware participants show a much smaller but still evident N400 effect.

The data from mean amplitude inspection supports the pattern suggested by the visual inspection (see figure 3.5 for mean amplitude data). Across phases 1 and 2, both noticers and non-noticers demonstrated miniscule differences in mean amplitude between related and unrelated words in the 300-500ms window post-target word presentation. These differences were never larger than $\pm 0.2 \mu V$, and were inconsistent with regards to whether the unrelated words elicited more negative responses than the related words. However, in the third phase, both noticers and non-noticers demonstrated clear differences in amplitude between related and unrelated words. In both groups, unrelated words (M = -0.04 in the inattentionally blind group, 4.83 for the noticer) elicited noticeably more negative amplitudes than related words (M = 0.67 in the inattentionally blind group, 6.42 for the noticer).

Inattentionally Blind		Phase 1	Phase 2	Phase 3
	Related	0.69	-0.45	0.67
	Unrelated	0.55	-0.21	-0.04
Noticer				
	Related	3.88	1.34	6.42
	Unrelated	3.98	1.57	4.83

Figure 3.5 Mean Amplitude Data
Average amplitude values (measured in μV) for each group of subjects from 300-500ms post-stimulus onset, based on electrode Pz.

3.2.2 Word Trials and False Font Trials

In order to explore the orthographic effect previously reported by Schelonka et al. (2017), we examined differences between ERP responses elicited by word trials versus those elicited by false font trials. Figure 3.5 shows grand averages for false font and word trials collapsed across all subjects at electrode Pz.

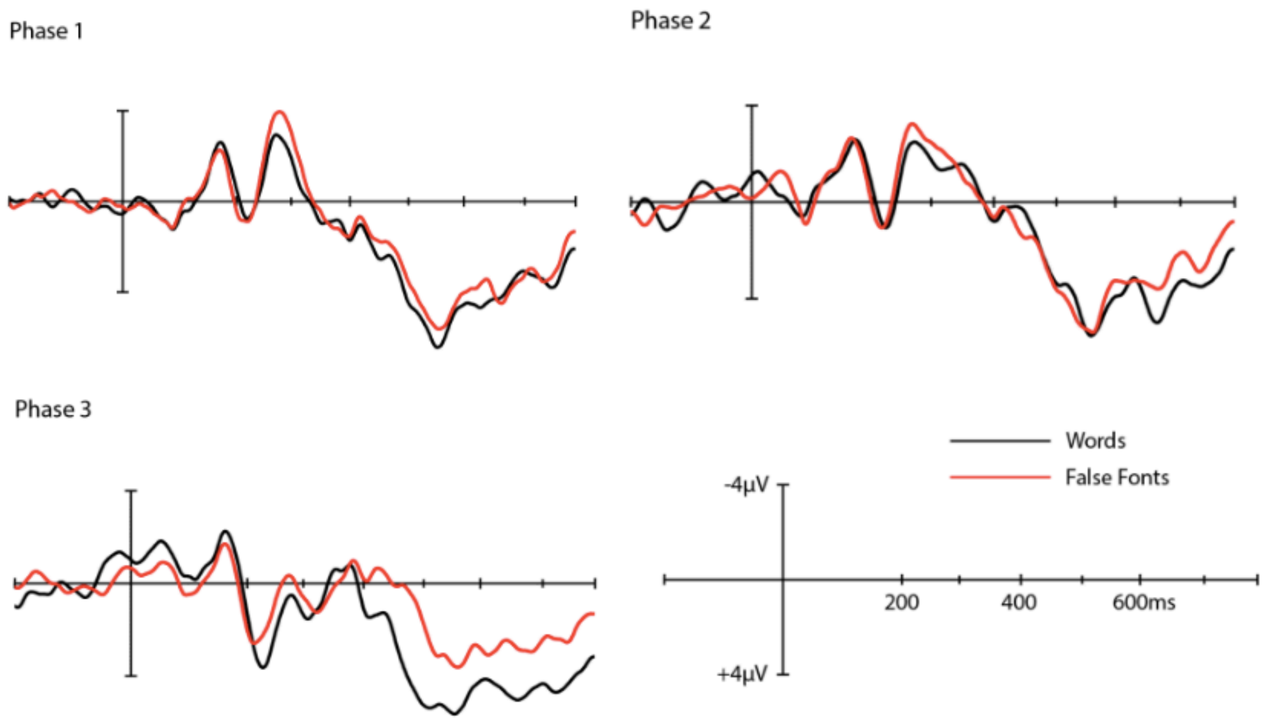

Figure 3.6 ERPs to Word Trials vs. False Font Trials
Grand averages for word trials and false font trials collapsed across participant groups, based on electrode Pz.

There appears to be a difference between ERPs elicited by word stimuli and false font stimuli in all three phases. Notably, false font trials seem to elicit a more negative peak relative to word trials at around 250-300ms across all three phases. This negativity may indicate some level of unconscious orthographic processing, as false fonts and words appear to elicit different peaks in the first and second phases, even in a largely inattentionally blind sample. The negativity is temporally consistent with Schelonka et al.'s findings, which reported a difference between responses to word forms and scrambled line stimuli between 200 and 280ms. However, in the first phase of the current study, this effect may have been carried by the single participant that noticed the words during this phase. More data are necessary before confirming that this effect appears even in unaware conditions.

3.2.3 The P300 Effect

In the third phase, a clear P3 wave for the word stimuli relative to the false fonts is present (see Figure 3.6). The P3 effect is commonly elicited more than 300ms post-stimulus onset and is characterized by a positive-going wave in response to the process of stimulus categorization, in particular uncommon stimuli relevant to the task at hand. (Luck, 2014). This P3 wave is congruent with our expectations, as the word stimuli were task-relevant targets in the third phase and therefore likely to produce such an effect.

Chapter Four: Discussion

4.1 Main Findings

The results of this study suggest that awareness and at least some level of attention are required for semantic processing within an inattentional blindness paradigm. In the first phase, participants were either unaware or spontaneously aware of the word stimuli and attended solely to the circle stimuli. Neither the spontaneously aware nor the unaware participants showed evidence of an N400 effect in this phase, through visual inspection or comparison of mean amplitudes. This pattern continued in the second phase, where participants continued to pay attention to the circle stimuli and were aware of the word stimuli by virtue of having completed the post-phase 1 questionnaire. This finding is surprising, given that prior studies on the N400 have found N400 effects in conditions of awareness with only partial attention (Luck, Vogel, & Shapiro, 1996). Performance on the circle task was far above chance for all participants in both phases 1 and 2, indicating that their attention was successfully diverted enough from the word stimuli to perform well. Notably, the aware participant had higher accuracy in all three phases than any other participant, including those that were rejected due to excessive artifacts, suggesting that failure to properly attend to the circle stimuli was not the reason this participant spontaneously noticed the word stimuli.

In the third phase, where all participants were aware of and attended to the word stimuli, clear N400 effects were observed in both groups of participants for the semantically unrelated target words, both through visual inspection and through comparison of mean amplitudes. A fairly large P3 wave was also elicited by the task-relevant word stimuli in this phase, as expected.

Finally, comparisons between a grand average of all responses to word trials and a grand average of all responses to false font trials indicated there may be some evidence of unconscious orthographic processing. At around 250-300ms post-stimulus onset, false font trials consistently elicited a stronger negativity relative to word trials across all three phases, including during inattentional blindness. This pattern is supported by the fact that previous studies have located similar orthographic effects in the same time window (Schelonka et al., 2017). Due to low *n* and somewhat noisy data, it is difficult to draw conclusions, but this pattern of data suggests the brain may differentiate between word stimuli and non-word non-letter stimuli in the absence of both awareness and attention.

4.2 General Discussion

Overall, these results fail to support Luck, Vogel, & Shapiro's conclusion that semantic processing can occur in the absence of both attention and awareness. The only clear evidence of semantic processing in this study occurred in the third phase, where participants were both aware of and explicitly attending to the word stimuli. However, this study found a pattern of data which suggests some level of unconscious orthographic processing, which is in keeping with previous research (Schelonka et al., 2017). The present data supports previous researchers' hypotheses that the N400 reflects a controlled, postlexical process that requires attention and some degree of awareness (Batterink, Karns, Yamada, & Neville, 2010); however, it seems the brain is able to distinguish between word stimuli and non-graphemic, letter-like stimuli unconsciously. If the lack of N400 to semantically unrelated probe words in the first two experiments continued with a larger pool of subjects, along with the differences in responses to the false font and word stimuli, this would be more conclusive evidence that unconscious semantic processing does not occur in this paradigm (but unconscious orthographic processing may occur). Consequently, if the study were continued with a larger pool of subjects and an N400 effect to the unrelated words were found in phase 1 across both groups of subjects, this would provide evidence that semantic processing can occur in the absence of both awareness and attention within this paradigm. If the N400 effect were found in phase 1 in the aware subjects alone, and in both groups of subjects in phase 2, this would provide evidence that semantic processing involving networks of interconnected definitions can occur in conditions of partial attention without awareness, at least within the inattentional blindness paradigm.

The results of this study, in combination with prior research that has failed to replicate Luck, Vogel, & Shapiro's findings, also suggest that the experimental paradigm used has an effect on whether or not semantic meanings are able to be processed unconsciously. Luck, Vogel, & Shapiro utilized an attentional blink paradigm in which the prime word was clearly visible and unmasked, while the probe word was blocked from conscious perception by virtue of being embedded in a rapid visual stream within a certain time window after the onset of the target stimulus. The probe word was presented in the center of the screen where the participants were directing their attention; the probe word was clearly and easily perceived when not located in the attentional blink interval (180-500ms following the onset of the target stimulus). It is therefore possible that the probe word may be processed in some way, but unable to be encoded into memory because the subject's attentional resources are devoted to the first target stimulus. In my experimental paradigm, both the prime and target words were hidden within the false font grid while participants explicitly directed their attention towards the periphery. It may be that these differences in experimental paradigm is part of why my study was unable to replicate Luck, Vogel, & Shapiro's findings. Other studies that have successfully found evidence of unconscious semantic processing within an inattentional blindness study paradigm have approached the concept of semantics from a different angle than mine. For instance, Schnuerch, Gibbons, Kreitz, and Memmert (2016) found evidence of an unconscious facilitation effect when hidden number stimuli fell on the same side of 5 as the target number during a numeric categorization task. Their idea of semantic relatedness hinged on the position of numbers relative to one another in the linear progression of numbers, whereas in my study (as well as in Luck, Vogel, & Shapiro's), semantic relatedness has to do with the position of words relative to one another in a dense, complex semantic network of interconnected nodes. Therefore, both the experimental paradigm in use and the exact definition of semantic relatedness may have some bearing on whether or not unconscious semantic processing will occur.

4.2.1 Limitations and Future Directions

The most obvious limitation of this study is the low sample size. Statistical analyses could not be conducted as only five participants were included in the final sample. Only one participant in the final sample was aware of the word stimuli in the first phase, so this condition may not have yielded representative data. In order to draw real conclusions, there should be at least twelve participants in each group. The present data provides some interesting patterns of data, but substantial claims cannot be staked on such a small foundation.

Based on rates of inattentional blindness in previous studies, about half of participants were expected to be spontaneously aware of the word stimuli in the first phase. In this study, three of eight participants spontaneously noticed the word stimuli in the first phase; however, of those three, one participant experienced a programming error which impaired her ability to focus on the circles, and it is likely that she noticed the words because of this. It seems that something about the design of the study is inducing inattentional blindness at high rates, complicating the interpretation of the data as there is an unequal number of noticers and non-noticers. It is likely a combination of the fact that the false font alphabet strongly resembles the Latin alphabet when viewed for very short periods of time and that the circle task was quite difficult. Any future replications should run a large number of subjects in order to attain enough non-inattentionally blind subjects. Previous studies employing inattentional blindness paradigms have struggled to attain a high enough rate of inattentional blindness, so the current task and stimuli should be retained, as they produce a large amount of inattentionally blind subjects.

Future studies may wish to conduct unconscious semantic processing experiments that manipulate the experimental paradigm in use. This could be accomplished by creating a study consisting of an inattentional blindness experiment and an attentional blink experiment, with both experiments containing identical priming and probe stimuli. With the right level of experimental control, a study such as this could address whether unconscious semantic processing is more likely to be induced by an attentional blink paradigm rather than an inattentional blindness paradigm. If such a study did find evidence of an N400 elicited by semantically unrelated words in conditions of no awareness and no attention in the attentional blink paradigm, but not in the inattentional blindness paradigm, it would suggest that the semantic processing taking place in the attentional blink experiment stems from how the stimulus is presented rather than the capabilities of the brain writ large.

Conclusion

Thanks to a very demanding attentional task, inattentional blindness to word stimuli was successfully induced in over half of participants, despite the words appearing directly above or below the fixation point hundreds of times. We failed to find any evidence of an N400 in either aware or unaware participants during the first or second phases of the experiment. Due to a small pool of subjects, statistical analysis could not be conducted, but visual inspection of ERPs showed a clear N400 effect to semantically unrelated target words in the third phase, where the words were both attended to and task-relevant, showing that our semantic relatedness manipulation worked as expected. There was also a visually observed difference between ERPs elicited by false font and word stimuli which was consistent across all three phases and both groups of subjects. This indicates there may be unconscious orthographic processing occurring. This study should be extended with a larger subject pool in order to conduct proper statistical analysis and further explore these findings. If these findings stood with more participants, they would stand in contrast to Schnuerch et al (2016), indicating that researchers should come to a consensus on the exact definition of semantic processing, as the processing of relatedness between concrete nouns would appear to require different conditions of attention and awareness than the processing of relatedness between number-based stimuli.

Appendix A: Complete List of Word Pairs

Related Pairs

1	CREAM / SUGAR	28	BIKE / WHEEL
2	DOCTOR / NURSE	29	APPLE / ORANGE
3	MOUSE / CHEESE	30	SWEETS / CANDY
4	SCHOOL / DESK	31	HAIR / COMB
5	TURTLE / SHELL	32	BREAD / TOAST
6	ROOF / HOUSE	33	HAMMER / NAIL
7	PAGE / BOOK	34	BOYS / GIRLS
8	FLAKE / SNOW	35	LOVE / HATE
9	ANKLE / FOOT	36	LEMON / LIME
10	CIRCLE / SQUARE	37	STAR / PLANET
11	EYES / NOSE	38	CROWN / KING
12	HORSE / BARN	39	LAKE / POOL
13	SHOWER / SOAP	40	PAINT / BRUSH
14	GLASS / BOTTLE	41	LEGS / KNEE
15	BABY / ADULT	42	BRAIN / SKULL
16	CALF / COWS	43	SONG / MUSIC
17	MILK / CEREAL	44	WALK / HIKE
18	FORK / KNIFE	45	FINGER / HAND
19	FLOOR / CARPET	46	PHONE / CALL
20	LEAF / TWIG	47	DINNER / LUNCH
21	RIVER / WATER	48	RICE / WHEAT
22	PRISON / JAIL	49	SOCK / SHOE
23	DRINK / JUICE	50	LOCK / KEYS
24	BURN / FIRE	51	BIRD / WING
25	CAKE / PIES	52	PISTOL / BULLET
26	TREE / BRANCH	53	CLOUD / RAIN
27	LIPS / TEETH	54	SUMMER / WINTER

55 PLANE / TRAVEL
56 MUSEUM / GALLERY
57 BEER / WINE
58 SINK / TOWEL
59 GIFT / PRESENT
60 PILLOW / BLANKET
61 WINDOW / DRAPES
62 PENCIL / ERASER
63 METER / INCH
64 GLOVES / MITTEN
65 COUGH / SNEEZE
66 GHOST / MONSTER
67 MOON / PHASE
68 WITCH / WIZARD
69 MOUTH / TONGUE
70 WASP / HORNET
71 HONEY / BEES
72 KETCHUP / MUSTARD
73 FLOWER / PETAL
74 FATHER / MOTHER
75 SISTER / BROTHER
76 PEACH / PLUM
77 CROW / RAVEN
78 FISH / SHARK
79 CHICKEN / ROOSTER
80 MOVIE / FILM
81 PORK / BEEF
82 GUITAR / DRUMS
83 PLANT / CACTUS
84 LETTER / STAMP
85 SWEATER / COAT
86 BULB / LAMP
87 MONEY / COIN
88 MEAL / FOOD
89 TRACK / TRAIN
90 SHIRT / PANTS
91 SCARF / NECK
92 NEEDLE / THREAD
93 SOFA / COUCH
94 WATCH / CLOCK
95 CAMP / TENT
96 JEANS / DENIM
97 FIDDLE / VIOLIN
98 TRUMPET / TUBA
99 BOAT / SHIP
100 TUNA / SALMON

Unrelated Pairs

1 SIREN / SUGAR
2 CREEK / NURSE
3 BULL / CHEESE
4 DREAM / DESK
5 MAIL / SHELL
6 CARAMEL / HOUSE
7 JELLY / BOOK
8 SURGEON / SNOW
9 SEED / FOOT
10 POPPY / SQUARE
11 COOKIE / NOSE
12 LIQUID / BARN
13 SNAIL / SOAP
14 TENNIS / BOTTLE
15 PENNY / ADULT
16 COAST / COWS
17 CITY / CEREAL
18 POSTER / KNIFE
19 TIDE / CARPET
20 SPACE / TWIG
21 TRUNK / WATER
22 SQUID / JAIL
23 NIGHT / JUICE
24 BONE / FIRE
25 DESERT / PIES
26 QUEEN / BRANCH
27 TIGHTS / TEETH
28 CORN / WHEEL
29 JOKE / ORANGE
30 CLONE / CANDY
31 HEART / COMB
32 COMPASS / TOAST
33 BREEZE / NAIL
34 WEEK / GIRLS
35 ROOM / HATE
36 PARTY / LIME
37 GAME / PLANET
38 MONTH / KING
39 WORD / POOL
40 TEAM / BRUSH
41 PARENT / KNEE
42 SUIT / SKULL
43 WOOD / MUSIC
44 BELL / HIKE
45 STREET / HAND
46 SAND / CALL
47 ISLAND / LUNCH
48 SEAL / WHEAT
49 MEAT / SHOE
50 SOCCER / KEYS
51 BEARD / WING
52 TAIL / BULLET
53 YARN / RAIN
54 CAMEL / WINTER
55 DAISY / TRAVEL
56 SOIL / GALLERY
57 ENGINE / WINE
58 PEEL / TOWEL
59 BOWL / PRESENT
60 SHADOW / BLANKET

61 PIZZA / DRAPES
62 FROWN / ERASER
63 BANK / INCH
64 VOICE / MITTEN
65 LETTUCE / SNEEZE
66 BLUSH / MONSTER
67 SODA / PHASE
68 KISS / WIZARD
69 YEAR / TONGUE
70 CRIB / HORNET
71 BUTTER / BEES
72 ANGER / MUSTARD
73 HORROR / PETAL
74 COMEDY / MOTHER
75 TREAT / BROTHER
76 BLOOD / PLUM
77 BALLET / RAVEN
78 LUCK / SHARK
79 TRUTH / ROOSTER
80 FEAR / FILM
81 DANCE / BEEF
82 SLEEP / DRUMS
83 PEACE / CACTUS
84 CELERY / STAMP
85 THRILL / COAT
86 SHEEP / LAMP
87 BANANA / COIN
88 CELLO / FOOD
89 BACON / TRAIN
90 PAPER / PANTS
91 BRICK / NECK
92 CABBAGE / THREAD
93 BADGE / COUCH
94 VINEGAR / CLOCK
95 SMILE / TENT
96 SALT / DENIM
97 ADVICE / VIOLIN
98 HAIL / TUBA
99 LUNG / SHIP
100 TRAFFIC / SALMON

Appendix B: End-of-Phase Questionnaire

Phase: (circle one) 1 2 3
Subject:
Date:

1. Some participants were randomly assigned to a condition in which items other than the circles and random symbols appeared on the screen. Did you notice anything other than the circles and random symbols while you were completing the task? If so, please describe below. Be as detailed as possible. If not, please indicate that.

2. If you did notice items other than the circles and symbols, at what point in the phase did you notice them?

3. The researcher will show you several items onscreen. Please indicate, using the scales provided below, how confident you are in having seen each item, and how frequently you saw them.

How confident are you that you saw the following items?
1 = very confident I did not see it
2 = confident I did not see it
3 = uncertain
4 = confident I saw it
5 = very confident I saw it

CONSONANTS	1	2	3	4	5
NUMBERS	1	2	3	4	5
WORDS	1	2	3	4	5
SQUARES	1	2	3	4	5

How frequently did you see each of the following items?
1 = never
2 = rarely (less than 10 times)
3 = infrequently (10-50 times)
4 = frequently (50-100 times)
5 = very frequently (over 100 times)

CONSONANTS	1	2	3	4	5
NUMBERS	1	2	3	4	5
WORDS	1	2	3	4	5
SQUARES	1	2	3	4	5

4. If you have any other comments about the phase or experiment, feel free to write them below.

Bibliography

Batterink, L., Karns, C. M., Yamada, Y., & Neville, H. (2010). The role of awareness in semantic and syntactic processing: An ERP attentional blink study. *Journal Of Cognitive Neuroscience*, 22(11), 2514-2529.

Dehaene, S., Naccache, L., Le Clec'H, G., Koechlin, E., Mueller, M., Dehaene-Lambertz, G., & ... Le Bihan, D. (1998). Imaging unconscious semantic priming. *Nature*, 395(6702), 597-600.

Kutas, M. & Van Petten, C. (1994). Psycholinguistics Electrified: Event-Related Brain Potential Investigation. Ann Arbor, Michigan: Academic Press.

Kutas, M. & Federmeier, K. (2010). Thirty Years and Counting: Finding Meaning in the N400 Component of the Event-Related Brain Potential (ERP). *Annu. Rev. Psychol*., 62, 14.1-14.27.

Luck, S.J., Vogel, E.K., & Shapiro, K.L. (1996). Word meanings can be accessed but not reported during the attentional blink. *Nature*, 383(6601), 616-618.

Luck, S.J., (2014). An Introduction to the Event-Related Potential Technique, Second Edition. Cambridge, Massachusetts: MIT Press.

Macdonald, J. P., & Lavie, N. (2011). Visual perceptual load induces inattentional deafness. *Attention, Perception, & Psychophysics*, 73(6), 1780-1789. doi:10.3758/s13414-011-0144-4

Mack, A., & Rock, I. (1998). Inattentional blindness. Cambridge, MA, US: The MIT Press.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink?. *Journal Of Experimental Psychology: Human Perception And Performance*, 18(3), 849-860.

Rolke, B., Heil, M., Streb, J., & Hennighausen, E. (2001). Missed prime words within the attentional blink evoke an N400 semantic priming effect. *Psychophysiology*, 38(2), 165-174.

Schelonka, K., Graulty, C., Canseco-Gonzalez, E., & Pitts, M. A. (2017). ERP signatures of conscious and unconscious word and letter perception in an inattentional blindness paradigm. *Consciousness and Cognition*, 54, 56-71.

Schnuerch, R., Kreitz, C., Gibbons, H., & Memmert, D. (2016). Not quite so blind: Semantic processing despite inattentional blindness. *Journal Of Experimental Psychology: Human Perception And Performance*, 42(4), 459-463.

Ulrich, M., Hoenig, K., Grön, G., & Kiefer, M. (2013). Brain activation during masked and unmasked semantic priming: Commonalities and differences. *Journal Of Cognitive Neuroscience*, 25(12), 2216-2229.