Examining Activation of Lexical and Semantic Representations Without Intention: Evidence from Event-Related Potentials

by

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A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

in

SPEECH-LANGUAGE PATHOLOGY

DEPARTMENT OF COMMUNICATION SCIENCES AND DISORDERS

University of Alberta

Abstract

Background. According to dual-route models of reading, there are two pathways with which words can be read: an orthographic-lexical pathway used to read familiar regular words and exception (EXC) words, and a grapheme-to-phoneme-conversion (GPC)-sublexical pathway used to read unfamiliar regular words, pseudohomophones (PHs), and nonwords. A recent debate in the reading literature has centered on whether individuals access lexical and semantic representations of letter strings similarly depending on which reading pathway is used. This has been explored via the Stroop paradigm (Stroop, 1935/1992), in which participants name the font colours of words while ignoring what the words say (i.e., reading without intention). We extend previous research by measuring an event-related potential (ERP), the N400, a brain waveform that has been suggested to be involved in the processing of semantic information.

Method. The present study explored lexical-semantic access while participants read without intention, using four different types of stimuli that forced readers to use the orthographic-lexical or GPC-sublexical pathways. The experiment examined twenty-four neurologically normal individuals. The amplitude and latency of the N400 were measured using electroencephalography (EEG), and response time and error rate were also measured behaviourally.

Results. In the behavioural data, evidence was found of a significant Stroop effect whereby readers were faster to identify the colour of congruent letter strings compared to incongruent letter strings. In the ERP data, the N400 was found as hypothesized. However, contrary to previous findings in the N400 literature, congruent trials exhibited greater negative peak amplitudes then incongruent trials in several different time windows.

Conclusions: Both the behavioural data and the finding of an N400 suggest that individuals access lexical and semantic representations without intention regardless of the reading pathway being used. As literacy and the ability to read play a large role in Western society, the results of the current study have important implications as they provide new information on how orthographic-lexical and GPC-sublexical reading processes operate in skilled readers, with possible ramifications for individuals with reading impairments. Thus, the results have theoretical implications not only for cognitive models of reading, but also for improving our understanding of how to help people with developmental and acquired reading disorders.

Keywords: Stroop, sublexical, lexical, electroencephalography, N400, reading

Preface

This thesis is an original work by Kathryn Faith Anton. The experiment conducted for this thesis received research ethics approval from the Research Ethics Office at the University of Alberta, Project Name "Examining Activation of Lexical and Semantic Representations Without Intention: Evidence from Event-Related Potentials", Study ID MS2_Pro00044338, February 18, 2014.

Additionally, I am also listed as an author in one of the journal articles cited in this thesis and published as Anton, K. F., Gould, L., and Borowsky, R. (2014). Activation of lexical and semantic representations without intention along GPC-sublexical and orthographic-lexical reading pathways in a Stroop paradigm. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *40*(3), 623-644. doi:10.1037/a0035154. In this work, which served as my undergraduate thesis project, I was responsible for data collection, analysis, and manuscript composition. Both R. Borowsky and L. Gould assisted with the statistical analysis and edited the manuscript. R. Borowsky was the supervising author and developed the idea for the project.

Lastly, part of this thesis may be modified and submitted to a journal for publication. My role in this publication involves a little data collection, as well as some of the data analysis. A number of undergraduate student volunteers also helped with data collection and external coding, and Y. Chen assisted with interpretation of the data. J. Cummine assisted with some of the statistical analyses and edited the manuscript along with E. Kim. J. Cummine and E. Kim were the supervising authors, and developed the idea for the project along with myself.

Dedication

This thesis is dedicated to my parents, who have always supported my academic pursuits.

Acknowledgements

There are many people to thank who were involved in this project and who helped me on this journey. Firstly, I would like to thank the Natural Sciences and Engineering Council of Canada for providing me with a Canada Graduate Scholarship – Master's Award, which allowed me to focus on my classes and thesis without having to worry as much about my financial situation. Additionally, I would like to thank the donors of any other scholarships I have received throughout university.

I would also like to thank a number of teachers and professors who made an impact on my life, and who I believe helped me develop the skills I needed to complete this thesis. From Holy Cross High School, I would like to thank Mr. Ken Hodson for helping me develop the writing skills that formed the foundation of my writing skills today. From the University of Saskatchewan, I would like to thank Dr. Jamie Campbell for helping me develop my research report writing abilities, and for teaching me the basics of how to complete lab reports in APA style in one of my third year lab courses.

From the University of Saskatchewan I would also especially like to thank Dr. Ron Borowsky and Layla Gould. I am so lucky to have been a part of Ron's lab, and I learned so much from working with him and Layla on how to develop, plan, conduct, analyze, and write the results of experiments. Our lab meetings were always great, and I loved being able to spend a couple summers working in the lab developing the abilities I needed to complete this thesis. I would also like to thank Ron for pushing me to pursue the thesis option in the Speech-Language Pathology program, and for all of the advice he has given me over the years. I look forward to seeing what comes out of his lab in the future!

At the University of Alberta, I would like to thank the administrative staff and professors I had the pleasure of learning from and working with. It was not always easy trying to complete a thesis and all of the coursework at the same time, but it was definitely worth it, and you were all very cognizant of the demands of the program.

A huge thank-you also goes out to all the undergraduate student volunteers at the University of Alberta who either helped me run my experiment or who helped code the data after it was videotaped. I could not have completed my thesis on time without every single one of you. I would especially like to thank Rami Chaouki for all of his help over the summer, and Yvonne Chen, without whom I would probably still be trying to hopelessly analyze my data. You do not know how much I appreciated your help with the ERP data, and I don't know what I would've done without you!

To my co-supervisors, Dr. Jacqueline Cummine and Dr. Esther Kim, thank-you for being so understanding and for allowing me to work on this thesis under your supervision. I know it was not always easy being my supervisors, but I learned so much and really enjoyed working with both of you. I truly appreciate how much work you put into being my supervisors, as I know how busy you both are. It was a pleasure!

I would also like to thank all of my classmates, friends, and extended family members for supporting me while I completed my thesis. You guys are all awesome!

And last, but certainly not least, I would like to thank my parents, Phil and Karen Anton, my older brother Travis and sister-in-law Allyssa, and my younger brother Jayme, for all of your love and support. It has been a long couple of years, and you guys have stuck with me through the blood, sweat, and tears. You all inspire me to do better and be a better person, and you guys mean the world to me. Love and hugs, forever and always!

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List of Abbreviations

CEPHA(s): Colour exception pseudohomophone associate(s)

CEWA(s): Colour exception word associate(s)

CPH(s): Colour pseudohomophone(s)

CPHA(s): Colour pseudohomophone associate(s)

CW(s): Colour word(s)

CWA(s): Colour word associate(s)

EEG: Electroencephalography

ERP(s): Event-related potential(s)

EXC(s): Exception word(s)

GPC: Grapheme-to-phoneme conversion

PH(s): Pseudohomophone(s)

RT(s): Response time(s)

Examining Activation of Lexical and Semantic Representations Without Intention:

Evidence from Event-Related Potentials

Introduction

When an individual thinks about reading, the mind often turns to books, newspapers, magazines, and poems. As Walt Disney said, “There is more treasure in books than in all the pirates’ loot on Treasure Island . . . and best of all, you can enjoy these riches every day of your life” (Peter, 1977, p. 77). Walt Disney’s words show the importance of reading and the joy that it can instill in individuals. Yet there is more to reading than being able to peruse literature, as the ability to read is often a prerequisite in Western society in order to function optimally (Green & Riddell, 2007). From street signs and price tags in grocery stores, to labels on food items and procedures in instruction manuals, reading is required in everyday tasks. Even technological advancements such as emailing, texting, and use of the internet rely extensively, if not solely, on reading abilities. Without these abilities, an individual would find it difficult to not only complete tasks in school and one’s occupation, but to operate in literate Western society. This raises the question of how reading proceeds when an individual comes across an unfamiliar letter string, and whether or not this process occurs without intention to a lexical and semantic level when the letter string sounds like an actual word but is spelled differently. The purpose of this study is to use *electroencephalography* (*EEG*), a neuroimaging technique, to explore the mechanisms and waveforms in the brain involved in reading without intention, and to determine possible implications that this may have for models of reading and disordered reading.

Models of Reading

One of the predominant types of models of reading espoused today are dual-route models of reading (Anton, Gould, & Borowsky, 2014; Borowsky et al., 2013; Cummine et al., 2013, Gould, Cummine, & Borowsky, 2012; see also Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). According to one form of this type of model, there are two pathways with which words can be read (see Figure 1). One pathway, referred to as the orthographic-lexical pathway, utilizes memory representations to read familiar *regular words* (i.e., words that have normal spelling-sound correspondences) and *exception words* (i.e., words that cannot be "sounded out" correctly using *grapheme-to-phoneme conversion* [*GPC*]; e.g., "ocean"). The other pathway, called the GPC-sublexical pathway, uses the process of GPC to read unfamiliar regular words (i.e., words that an individual is unfamiliar with and that can be "sounded out" correctly using GPC; e.g., "fabulist"), *pseudohomophones* (*PHs*, i.e., letter strings that sound like words but are spelled differently; e.g., "oshin" = "ocean"), and *nonwords* (i.e., words that have no orthographic, phonological, or semantic representations; e.g., "vup"). Whether each of these routes activates the meaning of the letter strings being read during their use has recently been the subject of debate (Anton et al., 2014; Augustinova & Ferrand, 2012a, 2012b; Augustinova, Flaudias, & Ferrand, 2010; Besner & Stolz, 1998; Klein, 1964) and is the focus of the current work.

Reading Without Intention: Evidence from the Stroop Effect

One method that has been used extensively to determine whether letter strings are read without intention is the Stroop paradigm (Stroop, 1935/1992). In the original Stroop task, Stroop presented participants with *colour words* (*CWs*, e.g., "blue"), coloured squares, and coloured symbols, and asked his participants to name the colour of ink they were presented in. Stroop found that participants had significantly longer colour naming response times (RTs) and responded less accurately when reporting the colour of incongruent CWs (e.g., "blue" in red font) than when reporting the colour of the squares and symbols. This finding, referred to as the

Stroop effect, has been taken as evidence that individuals cannot stop themselves from reading words presented in their visual field despite explicit instructions to only name the colour of the letter string, and suggests that word reading occurs without intention.

In recent years, the Stroop task has been used in a variety of ways to examine different types of cognitive processes (for a review, see MacLeod, 1991). In regards to the process of reading specifically, different types of words have been presented to participants in various ways in order to determine whether they are read without intention. For example, Klein (1964) extended the findings of Stroop (1935/1992) to a lexical-semantic level by using colour word associates (e.g., “sky”) in a Stroop paradigm in order to show that words that are associated with a particular colour (e.g., “sky” is commonly associated with the colour blue) activate their lexical and semantic representations without intention along the orthographic-lexical pathway of reading. In his experiment, Klein presented participants with nonsense syllables, rare English words, CWs not used as part of the experiment, CWs whose colours were used in the experiment, and colour word associates. Klein found that as the association between a letter string and a particular colour increased, the greater the amount of interference a participant displayed. That is, CWs whose colours were used in the experiment, CWs whose colours were not used in the experiment, and even colour word associates exhibited more interference relative to the rare English words and nonsense syllables, suggesting that words that rely on the orthographic-lexical pathway of reading are read without intention. The fact that colour word associates displayed a significant, albeit reduced Stroop effect relative to the CWs, suggests that their lexical-semantic representations were being automatically activated.

In addition to the finding by Klein (1964) that extended Stroop’s (1935/1992) findings to a lexical and semantic level through the use of colour word associates, the seminal finding by

Stroop has been extended to a sublexical level by Dennis and Newstead (1981). Dennis and Newstead presented participants with CWs, *colour PHs* (*CPHs*, e.g., “bloo” = “blue”), and neutral control words (e.g., “blir”), and asked them to name the colour of the letter string as quickly as possible. The results showed that both the CWs and CPHs exhibited larger Stroop effects than the neutral control words, as indicated by longer colour naming RTs. Importantly, the RTs of the CWs and CPHs did not differ, suggesting that letter strings read using the GPC-sublexical pathway are activated in a similar manner to letter strings read using the orthographic-lexical pathway. In terms of dual-route models of reading, this finding suggests that the CPHs likely activate an entry in the phonological lexicon in the GPC-sublexical pathway because they sound like a real word (i.e., the CPH “bloo” would activate an entry in the phonological lexicon because it sounds like the word “blue” when GPC is used). The finding that CWs and CPHs exhibit Stroop effects of similar magnitude regardless of the reading pathway being used suggests that both pathways are capable of reading letter strings without intention.

Nevertheless, despite the findings by Klein (1964) and Dennis and Newstead (1981), some researchers have argued that letter strings do not activate lexical and semantic representations without intention (Besner & Stolz, 1998; Besner, Stolz, & Boutilier, 1997; Cherney, 2004; Kuper & Heil, 2012; Manwell, Roberts, & Besner, 2004). Using the Stroop task, Besner et al. (1997) showed that when only a single letter was coloured in a word, the magnitude of the Stroop effect decreased. Similarly, Manwell et al. (2004) and Kuper and Heil (2012) showed that the Stroop effect could be eliminated in colour word associates (e.g., “sky”) if only a single letter was precued and coloured. The researchers took these findings as an indication that semantic activation does not occur without intention, a suggestion that Besner and Stolz (1998) agreed with despite their finding of a significant Stroop effect for CPHs relative to neutral control words. The results of all of these researchers, however, may be due to the attentional processing required to focus one's attention on a single letter in the letter string (Kuper & Heil, 2012), confounding the question of whether lexical and semantic representations are activated without intention.

Most recently, Anton et al. (2014) provided evidence that lexical and semantic representations are activated without intention during reading in both the orthographic-lexical pathway of reading and the GPC-sublexical pathway of reading. These researchers argued that in order to determine whether lexical and semantic representations are activated without intention in the GPC-sublexical pathway of reading, a novel type of stimuli, *colour pseudohomophone associates* (*CPHAs*, e.g., "skigh" = "sky") must be used. This is because these stimuli are associated with a particular colour (i.e., they do not directly implicate a colour in their name as regular CWs like "blue" and "red" do), and must use the GPC-sublexical pathway of reading. In two experiments using mixed and pure lists, Anton et al. demonstrated that CPHAs have Stroop effects of similar magnitude to CWAs, as indicated by faster RTs and higher accuracy rates in congruent trials (i.e., "skigh" in blue font) relative to incongruent trials (i.e., "skigh" in red font). Due to the fact that most of the CWs and CWAs used were regular words and could be read using either reading pathway (Cummine et al., 2013; Gould et al., 2012; Monsell et al., 1992), a third experiment was conducted in order to directly compare the orthographic-lexical and GPC-sublexical pathways of reading. This was accomplished through the introduction of *colour exception word associates* (*CEWAs*, letter strings that cannot be sounded out correctly and that must use the orthographic-lexical pathway of reading; e.g., "ocean") and *colour exception pseudohomophone associates* (*CEPHAs*, letter strings that must be sounded out in order to be correctly pronounced and activate their meaning and thus rely on the GPC-sublexical pathway; e.g., “oshin”). Because the CEPHA stimuli were derived from the CEWAs, the stimuli were matched on phonological characteristics, allowing Anton et al. to make a direct comparison between the two reading pathways. Results of the experiment showed Stroop effects of similar magnitude for the CEPHAs and CEWAs, suggesting that participants activated lexical and semantic representations without intention to a similar degree regardless of whether they had to rely on the lexical-orthographic reading pathway, as when reading the CEWAs, or when they had to rely on the GPC-sublexical reading pathway, as when reading the CEPHAs. This finding contrasts with the suggestion made by Paap and Noel (1991) that GPC is a controlled process that is only utilized when a reader comes across an unfamiliar word that must be sounded out. Support for this idea was recently provided by a functional magnetic resonance imaging (fMRI) study conducted by Cummine et al. (2013), who showed that readers can control their reliance on a specific reading pathway depending on the instructions given, such as when participants are asked to “name words” (increased reliance on the orthographic-lexical pathway) or to “name all” (either the orthographic-lexical or GPC-sublexical pathway could be used). Thus, whereas the results of Anton et al. suggest that lexical and semantic representations are activated without intention in a similar manner regardless of which reading pathway is being used, other research has suggested that GPC is a more controlled, serial process that is intentionally implemented by skilled readers.

Electroencephalography

In recent years, the use of neuroimaging techniques such as *electroencephalography* (*EEG*) have been used to examine the localization and time course of neurological events tied to external stimuli (Hanslmayr et al., 2008; West & Alain, 1999; Zurron, Pouso, Lindin, Galdo, & Diaz, 2009; Zurron, Ramos-Goicoa, & Diaz, 2013). EEG is a type of neuroimaging that has excellent temporal resolution and poorer spatial resolution. It measures the electrical activity generated by neurons in the brain when an external stimulus such as a letter string is presented. By summing the electrical signals generated by the brain, waveforms called *event-related potentials* (*ERPs*) can be examined in order to determine when in time the processing of the stimulus occurred, as well as the general region of the brain in which the processing occurred.

Event-related Potentials (ERPs)

As mentioned above, ERPs represent the summed electrical activity generated by neurons in the brain in response to external stimuli (Kutas & Federmeier, 2011). This activity is recorded by placing electrodes against the scalp of the individual being tested. Importantly, although the signal generated by a particular neuron may be strongest at the electrode placed directly above it on the scalp, that electrode does not only receive signals from the neurons directly below it. Instead, the electrode receives electrical activity from many neurons because the bioelectrical field generated by each individual neuron radiates outward (Michel & Murray, 2012). Furthermore, as Michel and Murray point out, the signals received by the electrodes on the scalp are somewhat attenuated, owing to the fact that they must pass through bone, skin, and hair before reaching the electrodes. Nevertheless, use of a sufficient number of electrodes allows the electrical activity generated by the neurons to be localized and time-stamped, providing information on where and when stimuli are processed by the brain. With its excellent temporal resolution, EEG presents a way to examine different ERP components and the time at which they occur through the process of signal averaging (Duncan et al., 2009). In turn, these different ERP components have been linked to specific cognitive activities (Duncan et al., 2009; Kutas & Federmeier, 2011). Numerous components have been identified, including the mismatch negativity (MMN) component, the P300/P3/P3b, the N400 and the N450, and the positive slow wave (PSW) component (Duncan et al., 2009; Hanslmayr et al., 2008; Zurron et al., 2009; Zurron et al., 2013). Importantly, the N400 has been suggested to be involved in the processing of meaning and semantic information, making it an ideal waveform to examine in order to determine whether lexical and semantic representations are activated without intention.

The N400. The N400 is an ERP component that has often been associated with the processing of semantic information (Kutas & Federmeier, 2011). This component represents a relative negativity occurring approximately 400 milliseconds (ms) post-stimulus onset, although it can occur as early as 200 ms or as late as 600 ms post-stimulus onset (Kutas & Federmeier, 2011). In a review of the literature on the N400, Kutas and Federmeier found that the N400 is typically evoked when meaning is processed, such as when an individual is presented with semantic anomalies in a sentence or during lexical priming paradigms in which target words are either associated or not associated with a following word. These researchers suggest that the N400 is not just a measure of semantic plausibility, and instead suggest that it is involved in the broader processing of meaning. As Duncan et al. (2009) suggested, the N400 may represent a measure of how individuals retrieve stored conceptual knowledge about a particular word. Overall, the N400 has been used extensively to study language processing and the processing of semantic information, with Kutas and Federmeier suggesting that the N400 may reflect semantic processing itself.

In regards to the workings of the N400, Kutas and Federmeier (2011) suggest that the size and timing of the N400 should be dependent on when a stimulus accesses its semantic representation. Thus, they caution against the idea that the N400 reflects activation of a word's meaning, and instead suggest that it reflects semantic information being accessed from long-term memory. These researchers further suggest that the N400 does not reflect a particular time point (as evidenced by the finding that it can be seen as early as 200 ms or as late as 600 ms post-stimulus onset), and that semantic access occurs across time as a process and not a discrete state. Furthermore, the N400 has been found to be largest over central and parietal brain regions, with greater amplitude being found over the right hemisphere than the left hemisphere (Luck, 2005).

As Kutas and Federmeier (2011) point out in their review of the N400 component, the N400 is typically examined using point-by-point subtraction, such as by taking a congruent ERP and subtracting it from an incongruent ERP in any experimental paradigm that contains a difference in congruency between the stimuli. This suggests that the N400 component should be examinable using the Stroop paradigm, which considers congruent and incongruent trials as measures to assess whether individuals can access lexical and semantic representations of letter strings without intention. Furthermore, in their review, Kutas and Federmeier point out that the N400 response occurs even when processing the semantics of a stimulus is of no benefit, as would be the case in the Stroop task. Based on work using sentences with semantic anomalies and lexical priming paradigms that have shown that related items have reduced N400 amplitudes compared to unassociated items, it can be hypothesized that congruent trials in the Stroop task (e.g., the letter string “blue” seen in blue font) should show smaller or reduced ERPs (i.e., more positivity) relative to the N400 response on incongruent trials (e.g., the letter string “blue” in red font).

This idea was recently explored in relation to the notion of interference in a study conducted by Hanslmayr et al. (2008). Using the Stroop task, Hanslmayr et al. examined the time course and spatial topography of the brain’s waveforms when presented with congruent, neutral, incongruent, and negatively primed CW stimuli, and found that significant Stroop effects were obtained for both RT and accuracy data. When the N400 time window was examined, it was found that the incongruent and negative priming stimuli had greater negative waveforms than the congruent and neutral stimuli in fronto-central regions, but stronger positivity for the incongruent and negative priming stimuli relative to the congruent and neutral stimuli in fronto-polar regions. This finding contrasts with what Kutas and Federmeier (2011) found in the literature regarding localization of the N400, as Kutas and Federmeier suggested that the N400 is often largest over centro-parietal regions of the brain, a suggestion that is also consistent with the finding by Duncan et al. (2009) that maximal amplitudes for the N400 typically occur over central and parietal sites. Although Hanslmayr et al. interpreted their findings as being indicative that the N400 is involved in the detection of interference rather than the detection of semantic incongruencies, it can be argued that Hanslmayr et al. were also examining detection of semantic incongruencies (e.g., "blue" in red font). This is because interference effects have often been examined in the Stroop paradigm in relation to language processing by subtracting the RTs or number of errors made on neutral trials from the RTs or number of errors made on incongruent trials (Augustinova & Ferrand, 2012a, 2012b; Augustinova et al., 2010; Besner et al., 1997; Kuper & Heil, 2012; MacLeod, 1991; Neely & Kahan, 2001). Thus, interference is also a component of language tasks involving the Stroop paradigm, and the finding by Hanslmayr et al. can be taken as evidence that the N400 may also reflect the processing of semantic information in the Stroop task.

The Stroop task. Examination of the neural activity associated with the Stroop task was completed by West and Alain (1999). These researchers had participants identify the font colour of colour words and recognize words using a manual button-press response box in three different conditions: congruent, incongruent, and neutral, plus a word identification condition. Significant Stroop effects were found in the behavioural data, and analysis of the electrophysiological data indicated that four modulations differentiated incongruent trials from congruent and neutral trials. The first modulation showed positivity in the lateral fronto-polar region and negativity in fronto-central regions 500 ms post-stimulus onset, which the authors suggested could represent neural activity pertaining to conflict detection processes. The second modulation showed a slow wave in fronto-central regions that began 500 ms post-stimulus onset and remained for the rest of the trial, with a greater effect in the right hemisphere of the brain than the left hemisphere of the brain. The authors suggested this activity probably resulted from activation of the anterior cingulate cortex with involvement of conflict resolution processes, although it is important to note that this may also reflect activation of the N400, which Kutas and Federmeier (2011) suggest can occur between 200 and 600 ms post-stimulus onset, and which Luck (2005) suggests is larger over the right hemisphere than the left hemisphere. The third modulation found greater negativity in parietal regions (i.e., P3 and P4 electrodes) for incongruent trials relative to congruent and neutral trials, with a peak that was greater in the left hemisphere than the right hemisphere at approximately 522 ms. West and Alain suggested that this indicated that on incongruent trials conceptual representations of word meaning are not activated and may even be suppressed by the competing colour and word information. Finally, the fourth modulation found greater positivity in temporo-parietal regions approximately 650 ms post-stimulus onset, with greater activation in the left hemisphere than the right, for incongruent trials. As a result, West and Alain suggest that this activation may represent the perceptual processing of the colour information of the stimulus, and that this information, together with that of the slow wave located in fronto-central regions, helps enhance perceptual level information when conceptual level information from the word competes with the colour of the stimulus.

West and Alain (1999) were not the first researchers to examine ERP data in the context of the Stroop task. Rebai, Bernard, and Lannou (1997) used the Stroop task to examine the amplitude of the N400, which they suggested occurs when an individual automatically processes semantic associations. Rebai et al. had participants either read the word presented on-screen or mentally name the colour of its font in congruent, incongruent, and neutral trials. They found that when presented in a mixed list of congruent and incongruent stimuli, reading the word presented on-screen resulted in greater positivity in the incongruent condition during the P300 time window (250 – 350 ms) in central brain regions (e.g., Cz). However, mentally naming the colour of the font when it was incongruent with the word presented resulted in greater negativity during the N400 time window (350 - 450 ms) in central-parietal locations. Importantly, these researchers suggested that the N400 represented a priming effect in which the word presented on-screen "primed" a response in the mental lexicon, impairing access to the correct colour word (i.e., the colour word that was incongruent with the word presented on-screen). While the results of this study must be taken cautiously as the study employed only eight participants and five different electrode sites, they suggest that the Stroop task and N400 can be used to examine the unintentional processing of information.

Overall, the results of Hanslmayr et al. (2008), West and Alain (1999), Rebai et al. (1997), and the reviews by Kutas and Federmeier (2011) and Duncan et al. (2009) suggest that the N400 is a useful ERP component to examine in the context of unintentional reading and the Stroop task. Furthermore, previous research involving models of both reading and disordered reading have yielded inconclusive results regarding whether lexical and semantic activation occurs without intention in both reading pathways. To our present knowledge, no one has yet examined the response of the N400 in relation to CEWAs and CEPHAs, which provide information on whether lexical and semantic activation occurs without intention in the orthographic-lexical and GPC-sublexical reading pathways, respectively.

Experiment

Research Question and Hypotheses

The purpose of the present paper is to explore the aforementioned idea through the use of EEG and the Stroop task. The experiment conducted included neurologically normal individuals in order to try to replicate the findings of Anton et al. (2014) by showing that lexical and semantic representations are activated without intention regardless of the reading pathway being used, as evidenced by a significant Stroop effect on response times for CEWAs and CEPHAs. As such, four types of stimuli were used: CWs (e.g., “blue”), CPHs (e.g., “bloo”), CEWAs (e.g., “ocean”) and CEPHAs (e.g., “oshin”). The experiment was also designed to extend the research by examining the magnitude of the N400, thereby providing additional evidence that letter strings are read automatically in both reading pathways. There were two main hypotheses for the experiment: (1) To the degree that individuals activate lexical and semantic representations without intention, a larger Stroop effect, as indicated by slower response times in incongruent conditions as compared to congruent conditions, should be found for both the CEWAs and CEPHAs; and (2) To the degree that individuals activate lexical and semantic representations without intention, an N400 component should be observed for all four types of stimuli, with incongruent stimuli exhibiting greater negativity than congruent stimuli. Results are discussed in terms of a dual-route model of reading.

Method

Participants. Participants in the experiment were 28 neurologically normal undergraduate students from the University of Alberta (Edmonton, Alberta, Canada) who were recruited from the Department of Linguistics participant pool. Three participants were left-handed and 21 were right-handed. The average age of the participants was 20.6 years (range = 18 years to 31 years). Prior to completing the experiment, participants completed a reading screening comprised of four randomly selected pure lists of 20 regular words, 20 exception words, 20 PHs, and 20 nonwords. Participants also completed Raven's Coloured Progressive Matrices (Raven, 1976) in order to ensure normal nonverbal intelligence. For a variety of reasons (e.g., equipment failure, colour blindness), data from four participants was excluded, resulting in a total of 24 participants. Participants received a $10 gift card for their participation. All participants spoke English as their primary language, and informed consent was obtained from the participants prior to taking part in the experiment. The study was granted approval by the Research Ethics Office at the University of Alberta.

Materials. Participants viewed the four types of stimuli (see Appendix) used in the third experiment of Anton et al. (2014; see for a full list of the lexical characteristics associated with the stimuli): CWs (e.g., "blue"), CPHs (e.g., "bloo"), CEWAs (e.g., "ocean") and CEPHAs (e.g., "oshin"). The longest stimulus, "cantaloupe", subtended a visual angle of .947° in height × 8.999° in width. The stimuli were presented in nine different colours: blue (E-Prime's blue), green (E-Prime's green), pink (RGB: 255, 128, 192), red (E-Prime's red), yellow (E-Prime's yellow), orange (RGB: 210, 105, 0), purple (RGB: 159, 0, 159), white (E-Prime's white), and grey (RGB: 141, 141, 141). Each stimulus was randomly presented eight times in a congruent condition (e.g., the letter string "blue" in blue font; i.e., the letter string named the colour or was associated with the font colour it was presented in), and once in every incongruent colour condition (e.g., the letter string "blue" in red font; i.e., the letter string did not name the colour or was not associated with the font colour it was presented in). This resulted in 144 trials per stimulus type (e.g., CWs, CPHs, CEWAs, CEPHAs), with half being congruent trials and half being incongruent trials. Therefore, the entire experiment contained 576 trials, and following the conventions of Anton et al., was presented using a single, mixed list. Stimuli were presented via E-Prime software (v2.0, Psychology Software Tools, Inc., http://www.pstnet.com) on a 21 × 11.75 inch BenQ LCD colour monitor.

Procedure. Participants came to the lab where they completed the informed consent form, reading screen, and Raven's Coloured Progressive Matrices (Raven, 1976). Participants were then instructed about the procedures of the experiment.

Each participant was tested individually in a quiet room, with the researcher sitting in an adjacent room where the participant's responses could still be heard and simultaneously monitored and coded via a separate computer monitor. After being fitted with a 64-electrode EEG cap (Hydrocel 64 channel Geodesic Sensor Net, EGI Geodesics, Inc.), participants were presented with on-screen instructions describing the nature of the task: "You will see a fixation cross (+) followed by a string of letters. Please name, as quickly as possible, the font colour that the letter string is presented in. Do not worry about making occasional errors as this type of research relies on you making at least some errors! Please try to avoid unnecessary movements and blinking during the experiment. Please let the researcher know when you are ready to begin." Concurrently, participants were verbally instructed to ignore what the letter string said and to simply name the font colour as quickly and accurately as possible, and the point was emphasized that the participants were not to worry about making occasional mistakes.

Following these verbal instructions, a visual screening was conducted by asking the participants to read aloud the last sentence of the on-screen instructions in order to verify that they could actually read the words presented on-screen. Participants then completed 27 practice trials, which contained nine congruent CW trials to familiarize the participants with the colours used in the experiment, nine incongruent trials consisting of a mixture of CWs, CPHs, CEWAs and CEPHAs to familiarize participants with the four stimulus types used in the experiment, and nine coloured squares to determine how long it took participants to name each colour (i.e., verbally produce a response). The practice session was started by the experimenter upon the participant's instruction. Participants were provided with feedback regarding incorrect colour responses only on the practice trials.

For both the practice and experimental trials, a fixation cross was presented in the centre of the screen, and participants pressed a button causing the fixation cross to be immediately replaced by a stimulus in the centre of the screen. The stimulus remained on the monitor until participants provided a vocal response. If no vocal response was detected, the stimulus disappeared after 3000 ms. The experimenter coded each response as correct, incorrect, or spoiled. Spoiled trials consisted of beginning to vocalize one word but then switching to another word [e.g., "bl- grey"], failure of the microphone to detect a correct vocal response, trials consisting of external noises that triggered the microphone, and computer errors and/or glitches. Participants were video recorded during the experiment and each trial was double-checked to ensure accuracy in coding. After the researcher coded the participant's response the fixation cross immediately reappeared in the centre of the screen to begin the next trial. A break was given to participants approximately every eight minutes during the experimental trials. The experiment took approximately 30 minutes to complete.

Vocal responses for the experimental trials were collected via a Cardioid audio-technica ATR1200 microphone interfaced with the voice key in the E-Prime serial response box, and RTs were measured to the nearest millisecond (ms). The data was recorded by E-Prime and was also concurrently sent to a computer running Net Station (version 4.5.6, Electrical Geodesic, Inc. [EGI], 2009), where the EEG data was then exported and transferred to another computer for analysis via MATLAB (MathWorks, Inc., 2013) and EEGLAB (Delorme & Makeig, 2004), as discussed below.

Design. A 2 × 2 × 2 (Congruency [congruent, incongruent] × Colour Type [actual, associate] × Stimulus Type [word, PH]) within-subjects design was used in the experiment.

Analysis.

Behavioural Stroop analysis. Median correct response time (RT) was measured in milliseconds. Incorrect and spoiled trials were removed prior to conducting analyses on the median RT. Correct median RT was chosen as the dependent variable because it is less influenced by outlier data than is mean RT. The mean error rate for each condition was also analyzed by subtracting the number of correct responses for each stimulus type from 72 (the total number of congruent trials), dividing the result by 72, and multiplying by 100. This analysis was done solely to ensure that there were no speed-accuracy trade-offs.

EEG analysis. Data was collected at a sampling rate of 1000 Hz with 64 channels per frame, using electrode Cz as the reference electrode. The data collected on Net Station was then exported for analysis in MATLAB using EEGLAB. Impedances for the scalp electrodes were less than 50 kΩ. For each participant, the EEG waveforms were filtered using a bandwidth from 0.1 Hz to 30 Hz. Data was also controlled for artifact detection (e.g., eye blinks) by using an automatic channel rejection procedure in which channels were rejected using a z-score threshold between three and five, with visual inspection determining whether the z-score was based on kurtosis (allows for the detection of small amounts of noise), probability (detects large amounts of noise), or kurtosis and probability combined. Individual electrodes were also rejected based on visual inspection of the topographic maps and channel data. The data was average re-referenced, and the data from each participant then underwent Independent Component Analysis (ICA) in order to remove additional noise from the data and form the best data set. Corresponding to a warning issued by Electrical Geodesics Inc. regarding a delay of the EEG data in the anti-aliasing filters of the EGI Net Amps 400, 36 ms was added to each trial's latency in order to rectify the delay. Single participant averages were calculated for each condition (e.g., CW, CPH, CEWA, CEPHA) and then amalgamated into a grand average time window from 100 ms before stimulus onset to 1000 ms post-stimulus onset (see Figure 2). A 100 ms baseline was used during analysis.

As Kutas and Federmeier (2011) suggested that the N400 can occur any time between 200 and 600 ms, three different time windows were chosen for analysis: 200 – 300 ms, 300 – 400 ms, and 500 – 600 ms. Furthermore, as the N400 is largest over central and parietal brain regions (Duncan, 2009; Kutas & Federmeier, 2011), we analyzed electrode CPz (referred to as COM in the EGI montage and electrode 30 in EEGLab) at each of these time windows. To address our hypotheses outlined above, dependent measures included mean amplitude and peak amplitude. Additionally, peak latency was measured and analyzed, although no specific hypotheses were made in regards to its outcome.

Results

Behavioural Stroop median RT omnibus analysis of variance (ANOVA). Correct median RT data was analyzed using a 2 × 2 × 2 (Congruency [congruent, incongruent] × Colour Type [actual, associate] × Stimulus Type [word, PH]) repeated-measures GLM ANOVA. Table 1 shows the means for the stimuli used in the experiment. A significant main effect of congruency was found, $F(1, 23) = 300.648$, $MSE = 935.104$, $p < .001$, and showed that the median RT to respond to congruent stimuli (*M* = 638.875 ms, *SD* = 60.760 ms) was faster than the median RT for incongruent stimuli (*M* = 715.406 ms, 67.010 ms). In contrast, there was neither a main effect of colour type, *F*(1, 23) = .077, *MSE* = 443.489, *p* = .784; nor a main effect of stimulus type, *F*(1, 23) = .245, *MSE* = 343.535, *p* = .626. As is shown in Figure 3, an interaction between congruency and colour type was found, *F*(1, 23) = 156.289, *MSE* = 702.399, *p* < .001, and showed a larger difference in median RT between the congruent and incongruent trials for the *actual* colour type stimuli (e.g., CWs, CPHs) relative to the *associate* colour type stimuli (e.g., CEWAs, CEPHAs). No interactions were found between congruency and stimulus type, *F*(1, 23) = .049, *MSE* = 235.100, *p* = .827; or between colour type and stimulus type, *F*(1, 23) = .003, *MSE* = 124.039, *p* = .954. Lastly, there was no three-way interaction between congruency, colour type, and stimulus type, *F*(1, 23) = 1.041, *MSE* = 210.269, *p* = .318.

Behavioural Stroop mean error rate omnibus ANOVA. The mean error rate in percentage was calculated for each condition in order to determine whether there were any speed-accuracy trade-offs. Speed-accuracy trade-offs would be indicated by a higher percentage of errors in the congruent conditions (corresponding to decreased median RT) and a lower percentage of errors in the incongruent conditions (corresponding to increased median RT). Table 2 displays the means and standard deviations for the stimuli. The results of a 2 × 2 × 2 (Congruency [congruent, incongruent] × Colour Type [actual, associate] × Stimulus Type [word, PH]) repeated-measures GLM ANOVA for error rate revealed a trend for a speed-accuracy trade-off pattern (see Figure 4). There were no main effects of congruency, *F*(1, 23) = .504, *MSE* = .718, *p* = .485; colour type, *F*(1, 23) = 1.816, *MSE* = .797, *p* = .191; or stimulus type, *F*(1, 23) = 1.195, *MSE* = .538, *p* = .286. Similarly, no interactions were found between congruency and colour type, *F*(1, 23) = .000, *MSE* = .482, *p* = 1.000; congruency and stimulus type, *F*(1, 23)

= .000, *MSE* = .534, $p = 1.000$; and colour type and stimulus type, *F*(1, 23) = .062, *MSE* = .648, $p = .806$. Lastly, there was no evidence of a Congruency × Colour Type × Stimulus Type interaction, *F*(1, 23) = .113, *MSE* = .355, $p = .739$. These results suggest that despite a trend toward a speed-accuracy trade-off, no significant speed-accuracy trade-offs were found.

Behavioural Stroop CEPHA-CEWA median RT comparison. The two conditions corresponding to the CEPHAs and CEWAs were of primary importance in this experiment, as they represent a direct comparison between use of the GPC-sublexical pathway of reading and the orthographic-lexical pathway of reading, respectively. An exploratory direct comparison between the CEPHAs and CEWAs was conducted in order to determine if the median RT results followed the pattern found by Anton et al. (2014). Thus, a 2 × 2 (Congruency [congruent, incongruent] × Stimulus Type [word, PH]) repeated-measures GLM ANOVA was conducted. A significant main effect of congruency was found, *F*(1, 23) = 66.364, *MSE* = 298.053, $p < .001$, indicating that congruent stimuli (*M* = 662.365 ms, *SD* = 57.456 ms) were named faster than incongruent stimuli (*M* = 691.073 ms, *SD* = 64.682 ms). In contrast, there was no main effect of stimulus type, *F*(1, 23) = .367, *MSE* = 131.091, $p = .550$, and there was no evidence of an interaction between congruency and stimulus type, *F*(1, 23) = .467, *MSE* = 139.130, $p = .501$.

Behavioural Stroop CEPHA-CEWA mean error rate comparison. A 2 × 2 (Congruency [congruent, incongruent] × Stimulus Type [word, PH]) repeated-measures GLM ANOVA was conducted on the error rate data. Similar to the results obtained for the mean error rate omnibus ANOVA, there were neither main effects for congruency, *F*(1, 23) = .381, *MSE* = .474, $p = .543$; nor stimulus type, *F*(1, 23) = .800, *MSE* = .628, $p = .380$. Furthermore, there was no evidence of an interaction between congruency and stimulus type, *F*(1, 23) = .051, *MSE* = .398, $p = .824$.

Summary of behavioural results. In summary, the behavioural results showed a significant Stroop effect, as indicated by faster RTs in the congruent conditions as compared to the incongruent conditions. The mean error rate data found no significant speed-accuracy trade-offs. Overall, these results support the hypothesis made that all four types of stimuli (i.e., CWs, CPHs, CEWAs, CEPHAs) would display significant Stroop effects. Furthermore, the results of the CEWA-CEPHA comparison found Stroop effects of similar magnitude. Thus, the results provide additional evidence to that obtained by Anton et al. (2014) that skilled readers access lexical and semantic representations without intention regardless of the reading pathway being used.

ERP time window 200 – 300 ms.

Mean amplitude ANOVA for CPz in the 200 – 300 ms time window. Correct responses in the 200 – 300 ms time window for electrode CPz were averaged together in microvolts (μV) and analyzed using a 2 × 2 × 2 (Congruency [congruent, incongruent] × Colour Type [actual, associate] × Stimulus Type [word, PH]) repeated-measures GLM ANOVA. See Table 3 for the means and standard deviations. No significant effects or interactions were found. There was no evidence of a main effect of congruency, $F(1, 23) = .547$, $MSE = .556$, $p = .467$; colour type, $F(1, 23) = .000$, $MSE = .971$, $p = .988$; or stimulus type, $F(1, 23) = 1.106$, $MSE = .611$, $p = .304$. Similarly, there was no evidence of interactions between congruency and colour type, $F(1, 23) = 1.341$, $MSE = .413$, $p = .259$; congruency and stimulus type, $F(1, 23) = 1.317$, $MSE = .638$, $p = .263$; colour type and stimulus type, $F(1, 23) = .254$, $MSE = .467$, $p = .619$; or congruency, colour type, and stimulus type, $F(1, 23) = .007$, $MSE = .335$, $p = .935$.

Peak amplitude ANOVA for CPz in the 200 – 300 ms time window. Correct responses in the 200 – 300 ms time window for electrode CPz were analyzed by searching the time window for the greatest peak amplitude in microvolts (μV) that had smaller peaks on each side. A 2 × 2 × 2 (Congruency [congruent, incongruent] × Colour Type [actual, associate] × Stimulus Type [word, PH]) repeated-measures GLM ANOVA was then run on the obtained data. Means and standard deviations are shown in Table 4. The main effect of congruency approached significance, $F(1, 23) = 3.581$, $MSE = .531$, $p = .071$, and as shown in Figure 5, revealed that congruent stimuli ($M = -1.375$ μV, $SD = 1.765$ μV) had a greater negative peak amplitude than incongruent stimuli ($M = -1.176$ μV, $SD = 1.761$ μV). No other effects or interactions approached significance or were significant. There were no main effects of colour type, $F(1, 23) = .402$, $MSE = 1.153$, $p = .532$; or stimulus type, $F(1, 23) = .893$, $MSE = .730$, $p = .355$. There was no evidence of interactions between congruency and colour type, $F(1, 23) = .828$, $MSE = .576$, $p = .372$; congruency and stimulus type, $F(1, 23) = .152$, $MSE = .689$, $p = .701$; colour type and stimulus type, $F(1, 23) = .859$, $MSE = .630$, $p = .364$; or congruency, colour type, and stimulus type, $F(1, 23) = .183$, $MSE = .467$, $p = .672$.

Peak latency ANOVA for CPz in the 200 – 300 ms time window. Correct responses in the 200 – 300 ms time window were analyzed in regard to how long it took for the peak to reach a maximum amplitude. This data was subjected to a 2 × 2 × 2 (Congruency [congruent, incongruent] × Colour Type [actual, associate] × Stimulus Type [word, PH]) repeated-measures GLM ANOVA. Refer to Table 5 for the means and standard deviations of the peak latencies. No main effects or interactions were significant. Neither the main effect of congruency, $F(1, 23) = .194$, $MSE = 454.130$, $p = .664$; colour type, $F(1, 23) = .323$, $MSE = 500.246$, $p = .576$; nor stimulus type, $F(1, 23) = .165$, $MSE = 367.902$, $p = .688$, reached significance. Similarly, there was no evidence for the Congruency × Colour Type interaction, $F(1, 23) = .015$, $MSE = 716.956$, $p = .902$; Congruency × Stimulus Type interaction, $F(1, 23) = .039$, $MSE = 732.912$, $p = .845$;

Colour Type × Stimulus Type interaction, *F*(1, 23) = .207, *MSE* = 338.844, *p* = .654; or Congruency × Colour Type × Stimulus Type interaction, *F*(1, 23) = 1.716, *MSE* = 338.630, *p* = .203.

ERP Time Window 300 – 400 ms.

Mean amplitude ANOVA for CPz in the 300 – 400 ms time window. Correct responses in the 300 – 400 ms time window for electrode CPz were averaged together in microvolts (μV) and analyzed using a 2 × 2 × 2 (Congruency [congruent, incongruent] × Colour Type [actual, associate] × Stimulus Type [word, PH]) repeated-measures GLM ANOVA. See Table 6 for the means and standard deviations. No main effects or interactions were significant. Neither the main effect of congruency, *F*(1, 23) = .047, *MSE* = 1.084, *p* = .830; colour type, *F*(1, 23) = .460, *MSE* = 1.684, *p* = .505; nor stimulus type, *F*(1, 23) = .594, *MSE* = .829, *p* = .449, were significant. Similarly, there was no evidence of interactions between congruency and colour type, *F*(1, 23) = 1.177, *MSE* = .720, *p* = .289; congruency and stimulus type, *F*(1, 23) = .611, *MSE* = .802, *p* = .442; colour type and stimulus type, *F*(1, 23) = .000, *MSE* = .666, *p* = .986; or congruency, colour type, and stimulus type, *F*(1, 23) = 1.009, *MSE* = .630, *p* = .326.

Peak amplitude ANOVA for CPz in the 300 – 400 ms time window. Correct responses in the 300 – 400 ms time window for electrode CPz were analyzed by searching the time window for the greatest peak amplitude in microvolts (μV) that had smaller peaks on each side. A 2 × 2 × 2 (Congruency [congruent, incongruent] × Colour Type [actual, associate] × Stimulus Type [word, PH]) repeated-measures GLM ANOVA was then run on the data. Means and standard deviations are shown in Table 7. The main effect of congruency was not significant, *F*(1, 23) = .994, *MSE* = .722, *p* = .329; nor were the main effects of colour type, *F*(1, 23) = .400, *MSE* = 1.270, *p* = .534; and stimulus type, *F*(1, 23) = .000, *MSE* = .958, *p* = .995. An interaction between congruency and colour type was found, *F*(1, 23) = 4.717, *MSE* = .887, *p* = .040, and showed that there was a greater difference between congruent CEWAs and CEPHAs (e.g., “ocean” and “oshin”; *M* = -.374 µV, *SD* = 1.286 µV) and incongruent CEWAs and CEPHAs (*M* = .044 µV, *SD* = 1.058 µV) than between congruent CWs and CPHs (e.g., “blue” and “bloo”; *M* = -.181 µV, *SD* = .906 µV) and incongruent CWs and CPHs (*M* = -.354 µV, *SD* = 1.162 µV), as is shown in Figure 6 and Figure 7. There was no evidence of an interaction between congruency and stimulus type, *F*(1, 23) = .050, *MSE* = .875, *p* = .825. However, as shown in Figure 8 and Figure 9, there was an interaction between colour type and stimulus type, *F*(1, 23) = 5.146, *MSE* = .865, *p* = .033, that indicated a greater difference between associate words (e.g., CEWAs like “ocean”; *M* = -.013 µV, *SD* = 1.104 µV) and actual words (e.g., CWs like “blue”; *M* = -.420 µV, *SD* = 1.158 µV) than between associate PHs (e.g., CEPHAs like “oshin”; *M* = -.317 µV, *SD* = 1.240 µV) and actual PHs (e.g., CPHs like “bloo”; *M* = -.115 µV, *SD* = .909 µV). There was no evidence of a three-way interaction between congruency, colour type and stimulus type, *F*(1, 23) = 1.280, *MSE* = .839, *p* = .270.

Peak amplitude simple effects Congruency × Colour Type ANOVAs (300 – 400 ms). In order to further explore the interaction between congruency and colour type that was observed in the omnibus ANOVA conducted for the peak amplitude in the 300 to 400 ms time window, a 2 × 2 (Congruency [congruent, incongruent] × Colour Type [actual, associate]) repeated-measures GLM ANOVA was conducted for both the PH and word data. For the *PH* simple effects ANOVA, there was no evidence of a main effect of congruency, *F*(1, 23) = .509, *MSE* = 1.097, *p* = .483; or colour type, *F*(1, 23) = .904, *MSE* = 1.079, *p* = .352. The Congruency × Colour Type interaction approached significance, *F*(1, 23) = 3.855, *MSE* = 1.232, *p* = .062. For the *word* simple effects ANOVA, there was no evidence of a main effect of congruency, *F*(1, 23) = .406, *MSE* = .501, *p* = .530. The main effect of colour type approached significance, *F*(1, 23) = 3.773, *MSE* = 3.980 , *p* = .064. The Congruency × Colour Type interaction was not significant, *F*(1, 23) = 1.030, *MSE* = .509, *p* = .321.

Peak amplitude simple effects Colour Type × Stimulus Type ANOVAs (300 – 400 ms). To further explore the interaction between colour type and stimulus type that was observed in the omnibus ANOVA conducted for the peak amplitude in the 300 to 400 ms time window, a 2 × 2 (Colour Type [actual, associate] × Stimulus Type [word, PH]) repeated-measures GLM ANOVA was conducted for both the congruent and incongruent data. For the *congruent* simple effects ANOVA, neither the main effect of colour type, *F*(1, 23) = .940, *MSE* = .945, *p* = .342; nor the main effect of stimulus type, *F*(1, 23) = .016, *MSE* = 1.308, *p* = .901, were significant. The interaction between colour type and stimulus type approached significance, *F*(1, 23) = 3.877, *MSE* = 1.276, *p* = .061, and showed a larger effect of colour type (i.e., *actual* vs. *associate*) on PHs than on words. In regards to the incongruent stimuli, the main effect of colour type approached significance, *F*(1, 23) = 3.138, *MSE* = 1.212, *p* = .090, and showed that *associate* stimuli had more positive peak amplitudes (*M* = .044 μV, *SD* = 1.058 μV) than *actual* stimuli (*M* = -.354 μV, *SD* = 1.162 μV). The main effect of stimulus type did not reach significance, *F*(1, 23) = .044, *MSE* = .526, *p* = .835. There was no evidence of an interaction between colour type and stimulus type, *F*(1, 23) = 1.345, *MSE* = .428, *p* = .258.

Peak latency ANOVA for CPz in the 300 – 400 ms time window. Correct responses in the 300 – 400 ms time window were analyzed in regard to how long it took for the peak to reach a maximum amplitude. This data was subjected to a 2 × 2 × 2 (Congruency [congruent, incongruent] × Colour Type [actual, associate] × Stimulus Type [word, PH]) repeated-measures GLM ANOVA. Refer to Table 8 for the means and standard deviations of the peak latencies. Neither the main effect of congruency, *F*(1, 23) = 1.280, *MSE* = 501.313, *p* = .270; nor the main effect of colour type, *F*(1, 23) = .027, *MSE* = 924.156, *p* = .871; nor the main effect of stimulus type, *F*(1, 23) = 1.833, *MSE* =562.608, *p* = .189, reached significance. There was evidence of a congruency and colour type interaction, *F*(1, 23) = 10.308, *MSE* = 447.413, *p* = .004, that showed a larger difference between the congruent *associate* stimuli (e.g., CEWAs and CEPHAs; *M* = 329.146 ms, *SD* = 36.714 ms) and incongruent *associate* stimuli (*M* = 342.604 ms, *SD* = 38.501 ms) than between the congruent *actual* stimuli (e.g., CWs and CPHs; *M* = 339.667 ms, *SD* = 41.435 ms) and incongruent *actual* stimuli (*M* = 333.521 ms, *SD* = 38.393 ms), as is shown in Figure 6 and Figure 10. In contrast, there was no evidence of interactions between congruency and stimulus type, *F*(1, 23) = 2.735, *MSE* = 536.993*, p* = .112; colour type and stimulus type, *F*(1, 23) = 2.168, *MSE* = 560.558, *p* = .155; and congruency, colour type, and stimulus type, *F*(1, 23) = 1.770, *MSE* = 379.244*, p* = .196.

Peak latency simple effects Congruency × Colour Type ANOVAs (300 – 400 ms). In order to further explore the interaction between congruency and colour type that was observed in the omnibus ANOVA conducted for the peak latency in the 300 to 400 ms time window, a 2 × 2 (Congruency [congruent, incongruent] × Colour Type [actual, associate]) repeated-measures GLM ANOVA was conducted for both the PH and word data. For the *PH* simple effects ANOVA, there was no evidence of a main effect of congruency, *F*(1, 23) = .153, *MSE* = 549.897, *p* = .699; or colour type, *F*(1, 23) = 1.044, *MSE* = 760.370, *p* = .318. There was evidence of a Congruency × Colour Type interaction, *F*(1, 23) = 9.560, *MSE* = 460.346*, p* = .005, and it showed a larger difference in latency between congruent CPHs (e.g., “bloo”; *M* = 344.500 ms, *SD* = 43.295 ms) and incongruent CPHs (*M* = 329.083 ms, *SD* = 37.325 ms) than the difference in latency between congruent CEPHAs (e.g., “oshin”; *M* = 325.208 ms, *SD* = 35.173 ms) and incongruent CEPHAs (*M* = 336.875 ms, *SD* = 40.338 ms). In regards to the *word* simple effects ANOVA, the main effect of congruency approached significance, *F*(1, 23) = 4.148, *MSE* = 488.409, *p* = .053; whereas the main effect of colour type did not reach significance, *F*(1, 23) = .616, *MSE* = 724.344, *p* = .440. The interaction between congruency and colour type was not significant, *F*(1, 23) = 2.408, *MSE* = 366.311, *p* = .134.

ERP Time Window 500 – 600 ms.

Mean amplitude ANOVA for CPz in the 500 – 600 ms time window. Correct responses in the 500 – 600 ms time window for electrode CPz were averaged together in microvolts (µV) and analyzed using a 2 × 2 × 2 (Congruency [congruent, incongruent] × Colour Type [actual, associate] × Stimulus Type [word, PH]) repeated-measures GLM ANOVA. See Table 9 for the means and standard deviations. The main effect of congruency approached significance as seen in Figure 5, *F*(1, 23) = 3.481, *MSE* = 2.561, *p* = .075, and showed that congruent stimuli exhibited greater negativity in amplitude (*M* = -1.520 µV, *SD* = 3.221 µV) than the incongruent stimuli (*M* = -1.090 µV, *SD* = 2.318 µV). Similarly, Figure 11 shows that the main effect of stimulus type approached significance, *F*(1, 23) = 3.304, *MSE* = .878, *p* = .082, and suggested that the *word* stimuli (i.e., CWs and CEWAS; *M* = -1.428 µV, *SD* = 2.736 µV) exhibited greater negativity in their amplitudes than the *PH* stimuli (i.e., CPHs and CEPHAs; *M* = -1.182 µV, *SD* = 2.804 µV). The main effect of colour type was not significant, *F*(1, 23) = .029, *MSE* = 4.336, *p* = .867. Similarly, neither the interaction between congruency and colour type, *F*(1, 23) = .083, *MSE* = 2.624, *p* = .775; nor the interaction between congruency and stimulus type, *F*(1, 23) = .664, *MSE* = .850, *p* = .424, reached significance. As Figure 8 and Figure 12 show, the Colour Type × Stimulus Type interaction approached significance, *F*(1, 23) = 3.702, *MSE* = .668, *p* = .067, and showed a greater effect of colour type (i.e., *actual* vs. *associate* stimuli) on the *PH* stimuli relative to the *word* stimuli. The three-way interaction between congruency, colour type, and stimulus type, *F*(1, 23) = .020, *MSE* = 1.087, *p* = .889, was not significant.

Mean amplitude simple effects Colour Type × Stimulus Type ANOVAs (500 – 600 ms). To further explore the interaction between colour type and stimulus type observed in the omnibus ANOVA conducted for peak amplitude in the 500 to 600 ms time window, a 2 × 2 (Colour Type [actual, associate] × Stimulus Type [word, PH]) repeated-measures GLM ANOVA was conducted for both the congruent and incongruent data. For the *congruent* simple effects ANOVA, there was no evidence of any significant main effects or interactions. Neither the main effect of colour type, *F*(1, 23) = .054, *MSE* = 6.247, *p* = .818; nor the main effect of stimulus type, *F*(1, 23) = 2.504, *MSE* = 1.203, *p* = .127; nor the Colour Type × Stimulus Type interaction, *F*(1, 23) = .840, *MSE* = 1.207, *p* = .369, were significant. For the *incongruent* simple effects ANOVA, there was no evidence of significant main effects or interactions. The main effects of colour type, *F*(1, 23) = .009, *MSE* = .713, *p* = .925; and stimulus type, *F*(1, 23) = .863, *MSE* = .525, *p* = .362, were not significant. Similarly, there was no evidence of an interaction between colour type and stimulus type, *F*(1, 23) = 2.701, *MSE* = .548, *p* = .114.

Peak amplitude ANOVA for CPz in the 500 – 600 ms time window. Correct responses in the 500 – 600 ms time window for electrode CPz were analyzed by searching the time window for the greatest peak amplitude in microvolts (µV) that had smaller peaks on each side. A 2 × 2 × 2 (Congruency [congruent, incongruent] × Colour Type [actual, associate] × Stimulus Type [word, PH]) repeated-measures GLM ANOVA was then run on the data. Means and standard deviations are shown in Table 10. As seen in Figure 5, the main effect of congruency approached significance, *F*(1, 23) = 3.881, *MSE* = 8.680, *p* = .061, and showed that congruent stimuli (*M* = -1.610 µV, *SD* = 3.200 µV) had greater negativity in peak amplitude than incongruent stimuli (*M* = -.772 μV, *SD* = 1.697 μV). Similarly, Figure 11 shows that the main effect of stimulus type approached significance, *F*(1, 23) = 3.998, *MSE* = 3.584, *p* = .058, and exhibited greater negativity for *word* stimuli (i.e., CWs and CEWAs; *M* = -1.464 μV, *SD* = 2.678 μV) compared to *PH* stimuli (i.e., CPHs and CEPHAs; *M* = -.918 μV, *SD* = 2.220 μV). The main effect of colour type was not significant, *F*(1, 23) = .021, *MSE* = 7.687, *p* = .886. There was no evidence of interactions between congruency and colour type, *F*(1, 23) = .005, *MSE* = 2.327, *p* = .942; congruency and stimulus type, *F*(1, 23) = .002, *MSE* = 1.472, *p* = .969; colour type and stimulus type, *F*(1, 23) = .000, *MSE* = 3.815, *p* = .992; and congruency, colour type, and stimulus type, *F*(1, 23) = .370, *MSE* = .862, *p* = .549.

Peak latency ANOVA for CPz in the 500 – 600 ms time window. Correct responses in the 500 – 600 ms time window were analyzed in regard to how long it took for the peak to reach a maximum amplitude. This data was subjected to a 2 × 2 × 2 (Congruency [congruent, incongruent] × Colour Type [actual, associate] × Stimulus Type [word, PH]) repeated-measures GLM ANOVA. Refer to Table 11 for the means and standard deviations of the peak latencies. The main effect of congruency approached significance, *F*(1, 23) = 3.779, *MSE* = 210.712, *p* = .064, and Figure 5 shows that the congruent stimuli had an earlier peak latency (*M* = 573.208 ms, *SD* = 30.870 ms) relative to the incongruent stimuli (*M* = 577.281 ms, *SD* = 31.435 ms). In contrast, neither the main effect of colour type, *F*(1, 23) = 1.715, *MSE* = 464.407, *p* = .203; nor the main effect of stimulus type, *F*(1, 23) = 2.755, *MSE* = 225.031, *p* = .111, were significant. Similarly, there was no evidence of interactions between congruency and colour type, *F*(1, 23) = .631, *MSE* = 463.612, *p* = .435; congruency and stimulus type, *F*(1, 23) = 1.500, *MSE* = 558.310, *p* = .233; colour type and stimulus type, *F*(1, 23) = 1.653, *MSE* = 558.413, *p* = .211; or congruency, colour type, and stimulus type, *F*(1, 23) = .018, *MSE* = 697.570, *p* = .895.

Summary of ERP results. A summary of the significant ERP results can be seen in Table 12. The ERP results show an N400 with various effects in different time windows. In the 200 – 300 ms time window, no significant effects or interactions were found although a main effect of congruency approached significance in the peak amplitude. In the 300 – 400 ms time window, significant interactions between congruency and colour type and colour type and stimulus type were found in the peak amplitude, and a significant interaction between congruency and colour type was found in the peak latency. In the 500 – 600 ms time window, no significant effects or interactions were observed although some approached significance. Specifically, main effects of congruency and stimulus type, and an interaction between colour type and stimulus type approached significance in the mean amplitude; the main effects of congruency and stimulus type approached significance in the peak amplitude; and the main effect of congruency approached significance in the peak latency. Together, these effects and interactions support the hypothesis that skilled readers access lexical and semantic representations without intention, as discussed further below.

Discussion

The purpose of the present experiment was to examine whether skilled readers access lexical and semantic representations without intention regardless of whether they are using the orthographic-lexical reading pathway or the GPC-sublexical reading pathway. This was explored both in behavioural and in electrophysiological data through the use of the Stroop task with four different types of stimuli: CWs, CPHs, CEWAs, and CEPHAs. It was hypothesized that behaviourally, all four types of stimuli would show significant Stroop effects, which has been suggested to reflect unintentional processing of orthographic stimuli (Anton et al., 2014; Dennis & Newstead, 1981; Klein, 1964). It was also hypothesized that an N400, which has been said to be indicative of semantic processing (Kutas & Federmeier, 2011), would be seen in the ERP data. It was hypothesized that the N400 would show greater negativity in amplitude on incongruent trials as compared to congruent trials, due to previous findings that have shown greater negativity for unexpected stimuli (Hanslmayr et al., 2008). The findings of the present experiment are discussed below.

Reading Without Intention: Behavioural Data

The findings of the behavioural data in the current experiment support the conclusions of Anton et al. (2014). Specifically, we provide additional evidence to support the hypothesis that skilled readers access lexical and semantic representations regardless of the reading pathway that is used. This is shown through the significant Stroop effects exhibited by all four types of stimuli, with the incongruent conditions having slower response times and the congruent conditions having faster response times. The data also revealed that the *associate* stimuli (e.g., CEWAs, CEPHAs) exhibited attenuated effects relative to the *actual* stimuli (e.g., CWs, CPHs), a finding also made by Anton et al. Additionally, both *associate* colour type stimuli exhibited Stroop RT effects of similar magnitude, as did the *actual* colour type stimuli. In terms of a dual-route model of reading (refer to Figure 1), this suggests that when a letter string is presented visually, readers phonologically decode PHs (e.g., “oshin”) using GPC and access a representation in the phonological lexical system in a similar time frame and manner as is required for them to access a representation of an exception word (e.g., “ocean”) in the orthographic lexical system. Both types of letter strings then access information in the semantic system before being overtly articulated. As Anton et al. suggested, this contrasts with earlier models of reading in that it was previously proposed that GPC is a controlled process only implemented by skilled readers when they come across an unfamiliar word, PH, or nonword

(Paap & Noel, 1991). However, the current experiment provides further support to Anton et al.'s claim that reading occurs without intention regardless of the reading pathway that is used, and that GPC may not be as strictly controlled as others have suggested.

Reading Without Intention: ERP Data

The ERP data of the present experiment showed an N400 (see Figure 2), with a negative-going peak occurring between 200 and 300 ms, followed by a negative slow wave starting at approximately 400 ms post-stimulus onset across all conditions. Despite the presence of an N400, statistical analyses on the mean amplitude, peak amplitude, and peak latency across three time windows (i.e., 200 – 300 ms, 300 – 400 ms, and 500 – 600 ms) failed to find the hypothesized effects and interactions. In the 200 to 300 ms time window, only a main effect of congruency that approached significance was observed in the peak amplitude data. Similarly, in the 500 to 600 ms time window, effects and interactions only approached significance. The results found in the 300 to 400 ms time window correspond most closely to our hypothesis that an N400 should be observed for all four types of stimuli (with incongruent stimuli exhibiting greater negativity than congruent stimuli) if individuals access lexical and semantic representations without intention. In this time window, the hypothesized interaction between congruency and colour type occurred both in the peak amplitude and peak latency data, but the direction of the hypothesized interaction differed from what was expected, as is discussed below.

The N400.

One goal of the current work was to expand our knowledge of reading without intention using an EEG experimental protocol. Although the results were not in line with our initial hypotheses, we provide novel evidence with respect to elucidating the role that semantic information plays in reading. More specifically, as was aforementioned, the findings in the peak amplitude (300 – 400 ms) and peak latency data (300 – 400 ms) that show larger effects of congruency on the *associate* stimuli relative to the *actual* stimuli contrast with what was hypothesized. In previous behavioural literature (Anton et al., 2014) and the behavioural data from the present experiment, response times have shown a Congruency × Colour Type interaction in which larger differences occur between congruent and incongruent *actual* colour type stimuli relative to *associate* colour type stimuli. In the study conducted by Anton et al. it was suggested that the *associate* colour type stimuli exhibited attenuated effects due to the fact that they are only associated with a particular colour and do not name that colour in the letter string. The ERP results of the present experiment show the opposite trend, with the *associate* colour type stimuli exhibiting a larger effect than the *actual* colour type stimuli. One possible explanation for the difference between the behavioural data and ERP data is that the greater effect of congruency on the *associate* colour type stimuli in the ERP data may reflect greater cognitive processing requirements. For instance, there might be a greater difference between the congruent and incongruent trials in the *associate* colour type ERP data because the stimuli are only associated with a particular colour. Thus, as a greater number of cognitive resources may need to be devoted to the task of processing the *associate* colour type stimuli and linking them with a certain colour, this could be reflected in the ERP data both as greater peak amplitude and longer peak latency. This could also help explain the behavioural results because a greater cognitive load may be reflected in slower response times, as is seen in the *associate* colour type stimuli behavioural data.

Also of note is the fact that in the peak latency data (300 – 400 ms time window), the congruent *actual* colour type stimuli had a longer latency than the incongruent *actual* colour type stimuli. This contrasts with typical findings in behavioural Stroop experiments, in which congruent stimuli are responded to more quickly than incongruent stimuli due to the match between the letter strings and font colours (e.g., Anton et al., 2014; Dennis & Newstead, 1981; Klein, 1964; Stroop, 1935/1992; West & Alain, 1999). One possible explanation for this is that response time in behavioural data and peak latency in ERP data represent different cognitive processes. For example, response time in the current experiment represents the time after stimulus presentation to overtly name the orthographic stimuli, whereas peak latency represents the time for the sum of the electrical activity generated by neurons in the brain to reach their maximum amplitude. Thus, the two measures represent different types of responses. As Luck (2005) suggests, it is extremely difficult to compare behavioural RTs and ERP latencies due to the fact that behavioural RTs commonly represent the average across trials (i.e., the mean) whereas ERP latencies commonly represent the peak amplitude (i.e., the mode). Kutas and Federmeier (2011) provide additional support to this reasoning, as they suggest dissociations are often found between RT and measures of the N400. Nevertheless, irrespective of whether the *congruent* stimuli or *incongruent* stimuli exhibit longer latencies, the results suggest that individuals are accessing lexical and semantic representations without intention regardless of the reading pathway used because of the similar amplitudes observed between the two *associate* colour type stimuli and between the two *actual* colour type stimuli.

Another difference between the hypothesis regarding the ERP data and the actual findings relates to the negativity of the ERP components. Based on previous findings and suggestions (Kutas & Federmeier, 2011; Rebai et al., 1997; West & Alain, 1999) it was hypothesized that the incongruent stimuli would exhibit greater negativity relative to the congruent stimuli regardless of colour type (i.e., *actual* vs. *associate*) and stimulus type (i.e., *PHs* vs. *words*). As reviewed by Kutas and Federmeier (2011), incongruent and unexpected stimuli have been shown to elicit greater negativity in ERP components when compared to congruent and/or expected stimuli. This was not observed in the present experiment, as congruent stimuli showed a trend towards greater negativity than incongruent stimuli. This trend was seen in the peak amplitude ERP data for the 200 – 300 ms and 500 – 600 ms time windows, as well as in the mean amplitude ERP data for the 500 – 600 ms time window. It is possible that this may have resulted from the large number of trials in the experiment. Despite seeing an equal number of congruent and incongruent stimuli, participants may have adopted a mental strategy whereby they came to anticipate incongruent stimuli (i.e., the more difficult congruency condition) and diverted their attention away from congruent stimuli (i.e., the easier congruency condition). If participants came to preferentially anticipate incongruent stimuli, then the congruent stimuli might be considered unexpected when they appeared, leading to a greater number of errors in the behavioural data and larger negative amplitudes in the ERP data. This would explain the trend for the speed-accuracy trade-off observed in the behavioural data.

Nevertheless, despite many studies showing evidence of greater negativity for incongruent conditions relative to congruent conditions in the Stroop task (e.g., Kutas & Federmeier, 2011; Rebai et al., 1997; West & Alain, 1999), incongruent trials in the Stroop task have also been shown to exert greater positivity relative to congruent trials and neutral trials (Markela-Lerenc et al., 2004). Markela-Lerenc et al. found a trend that approached significance in which greater negativity was found in fronto-central regions for congruent and neutral trials relative to incongruent trials between 450 and 550 ms. This negativity was also found for congruent and neutral trials between 600 and 1000 ms, and was significantly greater than that observed for incongruent trials in parietal regions. Using dipole source analysis, Markela-Lerenc et al. was able to isolate the neural activity in the 450 to 550 ms time window as originating in the anterior cingulate cortex, a finding similar to West and Alain (1999), albeit with reversed polarity. These results also concur with the findings of the present experiment, in which the main effects of congruency for mean amplitude, peak amplitude, and peak latency approached significance in the 500 to 600 ms time window, with greater negativity observed in the congruent conditions relative to the incongruent conditions. As Markela-Lerenc et al. suggest, this may be indicative of activation of executive control functions. Interestingly, West and Alain also proposed something similar, positing that their modulation observed 500 ms post-stimulus onset represents conflict detection and resolution processes. Together, the results of Markela-Lerenc et al., West and Alain, and the present study suggest that brain regions known to be associated with response inhibition and conflict detection are being activated during the Stroop task. In relation to the hypotheses of this thesis, these findings imply that individuals are accessing lexical and semantic representations of letter strings presented on-screen regardless of the reading pathway they rely on, as the participants had difficulty stopping themselves from reading the word and naming the font colour, as indicated by the Stroop effect in the behavioural data.

Our findings can also be compared to those of Rebai et al. (1997), who explored the amplitude of the N400 when participants were asked to read the word or mentally name the colour of the word presented on-screen. They found greater negativity when mentally naming the font colour on incongruent trials in a time window from 350 to 450 ms in central-parietal regions. These results can be compared to what was observed in the 300 to 400 ms time window in the present study, in which Congruency × Colour Type interactions were found in both the peak amplitude and peak latency data. However, in these interactions it was found that the congruent conditions exhibited greater negativity than the incongruent conditions, which differs from the results of Rebai et al. Possible explanations accounting for this were discussed above. Nevertheless, as Rebai et al. interpreted their findings as being indicative that the Stroop task and

N400 can be used to explore the unintentional processing of semantic information, the results of the present study (which demonstrated significant interactions regardless of their direction) provide additional evidence for the suggestions made by Rebai et al. and further imply that the skilled readers in the present study were accessing lexical and semantic information without intention despite whether they had to rely on the orthographic-lexical or the GPC-sublexical pathway of reading.

Despite differences between our findings and those of previous experiments (e.g., Rebai et al, 1997; West & Alain, 1999), the current study showed that each stimulus type displayed an N400 effect, primarily through a peak of negativity occurring between 200 and 300 ms, followed by a negative slow wave occurring approximately 400 ms post-stimulus onset. The fact that this occurred for each stimulus type (i.e., CWs, CPHs, CEWAs, CEPHAs) suggests that each was accessing its semantic and lexical representation regardless of the reading pathway being used. As Kutas and Federmeier (2011) suggest, the size and timing of the N400 is dependent on when a stimulus accesses its semantic representation. Overall, this suggests that the findings regarding the N400 reported in this thesis may represent activation of the letter string's semantic information in long-term memory.

The negative slow wave. The finding of a negative slow wave in the 500 to 600 ms time window supports the findings of West and Alain (1999), who examined ERP data in the Stroop task. As discussed above, these researchers had participants identify the font colour of colour words and recognize words using a manual button-press response box in three different conditions: congruent, incongruent, and neutral. From their experiment, they identified four modulations that differentiated incongruent trials from congruent and neutral trials, with many of these modulations involving greater negativity in the data at least 500 ms post-stimulus onset.

Our data suggest there is a negative slow wave during this time window (see Figure 2). However, whereas the results of West and Alain reached statistical significance and indicated incongruent trials exhibited greater negativity during this time window, the results of the present experiment did not reach statistical significance, and when they approached significance in the 500 to 600 ms time window, they showed an opposite trend in which congruent stimuli exhibited greater negativity than the incongruent stimuli. As mentioned above, the exact reason behind this reversal is unclear. It should be noted, however, that while West and Alain focused their analyses on fronto-central, parietal, and temporo-parietal regions, the current study only examined a central-parietal electrode, CPz. Thus, the differences found between the two experiments could be partly attributed to the different electrodes examined in each study.

Despite similarities to some of West and Alain's (1999) findings, our findings contrast with what other researchers have found in the late time window, as Liotti, Woldorff, Perez III, and Mayberg (2000) observed a late positive complex (500 – 800 ms post-stimulus onset) that they suggested represents activation of semantic information on incongruent trials. Nevertheless, the slow negative wave ERP component can be offered as an alternative explanation that can account for the findings of the present study in the late time window. Although the slow negative wave is most often examined as the contingent negative variation ERP component, the readiness potential ERP component, or the stimulus-preceding negativity ERP component (Brunia, van Boxtel, & Böcker, 2012), Khader (n.d.) and Rösler, Heil, and Glowalla (1993) suggest that it can occur after the presentation of a stimulus and may reflect more than just preparation of a motor response. Rösler, Heil, and Röder (1997) provided evidence for this in a series of studies involving episodic long-term memory and mental rotation tasks. They found evidence that the locus of the negative slow wave depends on the task performed and brain areas involved in the task, as well as the difficulty of the task. However, whereas Rösler et al. (1997) found greater negativity in the wave as task difficulty increased, we found greater negativity for congruent stimuli (stimuli that were less difficult to process due to the match between the letter string and font colour) relative to incongruent stimuli. Nevertheless, as Rösler et al. (1993) suggest, the negative slow wave ERP component can be used to examine the amount of neural activity generated by different cognitive processes such as concept formation. Examination of our data in the 500 to 600 ms time window shows that the Colour Type × Stimulus Type interaction approached significance, with the *actual* colour type exhibiting a larger difference in negativity between the *word* stimulus type and the *PH* stimulus type. As the *actual word* stimuli (i.e., CWs) are directly related to a particular colour (i.e., their letter strings directly name a colour; e.g., “blue”) and have representations in the orthographic and phonological lexicons, these stimuli may have increased cognitive demands in the context of the Stroop task because there is more information to inhibit relative to the *actual PH* stimuli which only have a phonological representation after undergoing GPC. Furthermore, the *associate words* (e.g., CEWAs) and *associate PHs* (e.g., CEPHAs) may not have exhibited as large of a difference in negativity as the *actual* colour type stimuli (e.g., CWs, CPHs) because their mental representations (e.g., “ocean”, “oshin”) implicate colour less strongly when read and mentally rehearsed. Thus, they may not exhibit as much negativity as CWs because they do not directly imply a colour in the orthographic and phonological lexicons, but they may show greater negativity relative to the CPHs because of the mental effort required to associate the letter strings with a particular colour and then use that association to facilitate or inhibit an answer. Whereas the main effect of stimulus type that approached significance in the 500 to 600 ms time window argues against our hypothesis that letter strings that rely on the orthographic-lexical (e.g., words) and GPC-sublexical (e.g., PHs) reading pathways access lexical and semantic representations in a similar manner, examination of the aforementioned Colour Type × Stimulus Type interaction suggests otherwise. This is shown through the similar negativity in amplitude exhibited by the *associate words* (e.g., CEWAs) and *associate PHs* (e.g., CEPHAs), which were designed to force reliance on the orthographic-lexical reading pathway or GPC-sublexical reading pathway, respectively.

The N2. A recent ERP study conducted by Xiao, Qui, and Zhang (2009) has also explored the concept of colour type (although it was not referred to in this way) by examining the levels of processing involved in the Stroop task. They presented participants with a word associated with either the colour red or colour green in both congruent and incongruent conditions (e.g., “blood” in green and “blood” in red, and “grass” in green and “grass” in red), and asked them to press a computer key corresponding to whether the target stimulus was red in life or green in life (i.e., they were instructed to ignore the font colour). Xiao et al. found greater negativity in the incongruent condition compared to the congruent condition in two different time windows: 270 – 400 ms and 400 – 600 ms. Using principal components analysis, the researchers were able to isolate the neural generator for the brain activity in the 270 – 400 ms time window as occurring in the posterior cingulate cortex, which they suggested indicated its role in inhibition of the interference created by the incongruent font colour of the target stimulus. Importantly, however, Xiao et al. suggested that the N520 response they observed between 400 and 600 ms in the temporo-parietal region might be related to activation of the target word’s meaning and subsequent response inhibition in the incongruent conditions. Similarly, we found effects of congruency that approached significance in our 500 to 600 ms time window. However, our results showed the opposite trend in which congruent stimuli exhibited greater negativity than incongruent stimuli. In addition to the possible reasons for this discussed above, this could be caused by several differences between the two studies. Firstly, Xiao et al. presented participants with words written in Chinese, a logographic language in which each symbol represents a word. Thus, words written in Chinese cannot be sounded out, per se, since the symbols do not correspond to individual sounds. Secondly, Xiao et al. had their participants identify the colour of the word as it is in actual life, as opposed to the current study in which participants were told to ignore the word (and by implication its meaning) and name the font colour presented on-screen. As a result, there are several factors in the two studies that could have contributed to the differences observed.

The results of Xiao et al. (2009) in the 270 – 400 ms time window, as well as the activity observed in the early time window of the present study, may reflect the N2 ERP component in addition to the N400. The N2 represents multiple negative ERPs that occur between 250 – 300 ms post-stimulus onset, and the anterior components of this ERP have been suggested to be involved in cognitive control (i.e., response inhibition and response conflict) and the detection of novel stimuli (for a review see Folstein & Van Petten, 2008). This component has often been observed using oddball paradigms such as the *go-no go* task, in which participants are asked to respond to one type of stimulus but not another. It has also been suggested that the N2 component related to the detection of novel stimuli occurs only with very unfamiliar stimuli that have no long-term memory representations (Folstein & Van Petten, 2008). Thus, analysis of this component could seemingly be extended to the classic Stroop task, in which participants must inhibit reading the word presented on-screen and instead name the colour of the font the word is printed in, as well as the current study in which unfamiliar letter strings with no long-term orthographic memory representations (i.e., CPHs and CEPHAs) were presented to participants.

Although our results did not reach significance in this time window, the peak of negativity observed in Figure 2 between 200 and 300 ms could represent the N2. However, as our data showed an effect of congruency that approached significance for the peak amplitude data in the 200 to 300 ms time window, with the congruent stimuli having greater negative peak amplitudes than the incongruent stimuli, there are some differences that suggest further exploration of the N2 component using the Stroop task is needed.

Limitations

Despite the findings of the present study, there are several limitations of the current experiment that must be taken into account. Firstly, despite our best efforts, some amount of noise, not readily removed through ICA, may have been introduced into the EEG signal as the EGI system on which the data was collected was not situated in an electrically shielded room.

Secondly, Luck (2005) suggests that peak latency measures must be interpreted cautiously as they are subject to a number of limitations also associated with peak amplitude, such as nonlinearity, problems with the measurement time window, sensitivity to high-frequency noise, and sensitivity to increases in noise in general. Furthermore, Luck cautions that if any differences are found between conditions in the peak latency data, the peak amplitude data will also differ between conditions. To guard against the possibility of spurious results due to the limitations associated with these measures, we also analyzed the mean amplitude, which is not subject to the limitations of peak amplitude and peak latency measures. Nevertheless, an interaction in the peak latency time window from 300 – 400 ms in the current experiment suggests that this interaction (and the corresponding peak amplitude interactions) must be viewed with caution.

Thirdly, the findings of this experiment can, currently, only be generalized to alphabets, and within the writing systems classified as alphabets, those languages with deeper orthographies in which words may have multiple spelling-to-sound correspondences (e.g., in English, the grapheme <c> can be pronounced with either the phoneme /k/ [e.g., "*c*art"] or the phoneme /s/ [e.g., "*c*istern"]). As Anton et al. (2014) suggested, languages with shallower orthographies in which graphemes have regular spelling-to-sound correspondences may exhibit larger effects for CPHs and CEPHAs, as GPC is used to a greater extent in those languages (Mumtaz & Humphreys, 2001). Thus, it remains to be seen whether the present results can be generalized to alphabets that have shallow orthographies and rely more predominately on the GPC-sublexical pathway of reading.

Similarly, the results of the current experiment are not readily extended to types of writing systems other than alphabets (i.e., syllabaries and logographies). As discussed above, logographies are languages in which each written symbol represents a word, as opposed to alphabets in which each written symbol (sometimes more than one symbol in the case of digraphs; e.g., <th>) corresponds to an individual phoneme. Therefore, logographies do not have an equivalent type of processing to GPC, as graphemes are not mapped onto phonemes like they are in alphabets. Similarly, syllabaries are languages in which each symbol corresponds to a syllable, so they also would not utilize the process of GPC to the same extent as alphabets. This limits the results of the current study to alphabetic languages in which GPC is possible.

Lastly, the results of the present experiment can only be generalized to the sample population (skilled readers who primarily speak English). The results of the current study cannot be extended to children still learning to read, nor to individuals with dyslexia or alexia.

However, these populations may be fruitful to study in regards to this paradigm in future research, as discussed below.

Future Direction

One way to further explore the current findings would be to involve a clinical population composed of individuals with different types of reading impairments (i.e., surface alexia vs. phonological alexia).

Models of disordered reading

Although most research on the automaticity of word reading has been conducted on neurologically normal individuals, individuals who experience difficulty reading due to acquired brain injuries, referred to as alexia, can also inform us about how general reading processes occur. Many different types of alexia have been proposed depending on the site of lesion and symptoms displayed by the individual (for a review see Cherney, 2004). Two of the main types of alexia are surface alexia and phonological alexia.

Surface alexia. Surface alexia is characterized by damage to the orthographic lexical system in the orthographic-lexical pathway of reading in dual route models of reading (Cherney, 2004), as shown in Figure 13. This damage to the orthographic lexicon results in an inability to read exception words. The GPC-sublexical pathway of reading is still preserved though, allowing an individual with surface alexia to read familiar regular words, unfamiliar regular words, PHs, and nonwords using the process of GPC (Cherney, 2004).

Phonological alexia. In contrast to surface alexia, phonological alexia results from damage to the GPC-sublexical reading pathway, as can be seen in Figure 14. This results in an inability to read unfamiliar regular words, PHs, and nonwords, which must be sounded out using GPC in order to be correctly pronounced or read. The orthographic-lexical reading pathway is still intact in phonological alexia, allowing individuals to read familiar regular words and exception words (Cherney, 2004).

Alexia and the Stroop effect. Despite the implications that disordered models of reading have for understanding how lexical and semantic representations are activated in normal dual-route models of reading, few research studies have included patients with alexia as participants. Furthermore, those studies that have used patients with alexia have predominately used individuals with *pure alexia*, a form of alexia associated with damage to the occipital lobe that results in damage to the connections between visual processing and the orthographic lexicon. These individuals demonstrate the phenomenon of *letter-by-letter reading,* in which reading occurs by serial identification of component letters (McKeeff & Behrmann, 2004). For example, individuals with pure alexia would read the word "ocean" by identifying the letter "o", then the letter "c", and so on until all of the letters in the word had been identified, which leads them to read the word as a whole. Studies involving this type of alexia have often been used to examine the *Saffran effect*, the finding that some people with pure alexia can access lexical-semantic representations of letter strings (i.e., the meaning of a word) despite the inability to identify the word explicitly (Lambon Ralph, Hesketh, & Sage, 2004). McKeeff and Behrmann (2004) and Revonsuo (1995) have both provided evidence using CW Stroop tasks that individuals who use letter-by-letter reading or who have aphasia and an inability to read, respectively, are able to access representations of words without intention, as indicated by significant Stroop effects. These findings suggest that at least in some individuals with acquired reading impairments there are residual abilities that allow them to activate representations of CWs without intention, although it is unclear whether these findings extend to lexical-semantic and sublexical levels.

Examining individuals with different types of alexia would thus provide a unique perspective regarding the question of whether or not individuals activate lexical and semantic representations without intention, as individuals with surface alexia should rely primarily on the GPC-sublexical pathway of reading and individuals with phonological alexia should rely primarily on the orthographic-lexical pathway of reading. Thus, it might be expected that individuals with reading impairments would display differential results depending on the nature of their deficit. For example, to the degree that individuals activate lexical and semantic representations without intention, individuals with lexical reading impairments (e.g., surface alexia) might show significant N400 and Stroop effects for CEPHAs and CPHs and possibly CWs that are regular (due the fact that regular words can be read using either reading pathway) but not CEWAs; whereas individuals with sublexical reading impairments (e.g., phonological alexia) might show significant N400 and Stroop effects for CEWAs and CWs, but not CEPHAs and CPHs.

Alexia and its effects in society. As previously mentioned, the inability to read has a direct impact on one's ability to function in modern Western society (Green & Riddell, 2007). According to Ruben (2000), the 21^{st} century will experience a shift in how it defines 'survival of the fittest', as there is now a shift being made towards an individual's communication skills as the primary determinant of his or her 'fitness' in society. According to Ruben, "Communication disorders will be a major public health concern for the 21^{st} century because, untreated, they adversely affect the economic well-being of a communication-age society". Thus, it is important to study clinical populations, such as those with alexia, in the hopes that individuals who rely on the GPC-sublexical pathway of reading may be found to be able to read as effectively as individuals who primarily rely on the orthographic-lexical pathway of reading.

Conclusion

Overall, the present experiment provides additional evidence that individuals access lexical and semantic representations of letters strings without intention regardless of whether they are relying on the orthographic-lexical pathway of reading or the GPC-sublexical pathway of reading. This was demonstrated both in the behavioural and electrophysiological data. In the behavioural data, a significant Stroop effect was found that indicated that CEWAs and CEPHAs, which force reliance on the orthographic-lexical and GPC-sublexical pathways, respectively, are read in a similar manner and time frame. The ERP data also provide evidence of this, as an N400 effect was found that differentiated between congruent and incongruent stimuli. Overall, the findings were interpreted as representing access to lexical and semantic representations. Thus, this study provides the first electrophysiological evidence that individuals access lexical and semantic representations without intention regardless of whether they are relying on the orthographic-lexical pathway of reading or the GPC-sublexical pathway of reading.

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Table 1

Behavioural Average Correct Median Response Time in Milliseconds

	Congruent			Incongruent		
Stimulus	*n*	*M*	*SD*	*n*	*M*	*SD*
CPHs	24	616.083	62.682	24	737.813	67.568
CEPHAs	24	660.833	58.511	24	691.188	62.787
CWs	24	614.688	65.449	24	741.667	71.110
CEWAs	24	663.896	56.400	24	690.958	66.576

Note. CPHs = colour pseudohomophones (e.g., “bloo”); CEPHAs = colour exception pseudohomophone associates (e.g., “oshin”); CWs = colour words (e.g., “blue”); CEWAs = colour exception word associates (e.g., “ocean”).

Table 2

Behavioural Mean Error Rate in Percentage

	Congruent			Incongruent		
Stimulus	*n*	*M*	*SD*	*n*	*M*	*SD*
CPHs	24	.463	.885	24	.405	.867
CEPHAs	24	.289	.707	24	.174	.469
CWs	24	.579	1.077	24	.463	.784
CEWAs	24	.405	.764	24	.347	1.024

Note. CPHs = colour pseudohomophones (e.g., "bloo"); CEPHAs = colour exception pseudohomophone associates (e.g., "oshin"); CWs = colour words (e.g., "blue"); CEWAs = colour exception word associates (e.g., "ocean").

Table 3

Mean Amplitude in Microvolts for the 200 – 300 ms Time Window

	Congruent			Incongruent		
Stimulus	*n*	*M*	*SD*	*n*	*M*	*SD*
CPHs	24	-.581	1.617	24	-.734	1.563
CEPHAs	24	-.629	1.521	24	-.582	1.695
CWs	24	-.538	1.604	24	-.440	1.593
CEWAs	24	-.700	1.486	24	-.373	1.550

Note. CPHs = colour pseudohomophones (e.g., “bloo”); CEPHAs = colour exception pseudohomophone associates (e.g., “oshin”); CWs = colour words (e.g., “blue”); CEWAs = colour exception word associates (e.g., “ocean”).

Table 4

Peak Amplitude in Microvolts for the 200 – 300 ms Time Window

	Congruent			Incongruent		
Stimulus	*n*	*M*	*SD*	*n*	*M*	*SD*
CPHs	24	-1.377	1.857	24	-1.283	1.791
CEPHAs	24	-1.443	1.741	24	-1.233	1.799
CWs	24	-1.372	1.680	24	-1.268	1.703
CEWAs	24	-1.309	1.781	24	-.921	1.751

Note. CPHs = colour pseudohomophones (e.g., “bloo”); CEPHAs = colour exception pseudohomophone associates (e.g., “oshin”); CWs = colour words (e.g., “blue”); CEWAs = colour exception word associates (e.g., “ocean”).

Table 5

Peak Latency in Milliseconds for the 200 – 300 ms Time Window

	Congruent			Incongruent		
Stimulus	*n*	*M*	*SD*	*n*	*M*	*SD*
CPHs	24	247.290	29.529	24	243.920	34.722
CEPHAs	24	240.290	33.703	24	244.830	35.034
CWs	24	242.960	32.193	24	248.080	33.628
CEWAs	24	245.330	32.544	24	244.460	30.484

Note. CPHs = colour pseudohomophones (e.g., "bloo"); CEPHAs = colour exception pseudohomophone associates (e.g., "oshin"); CWs = colour words (e.g., "blue"); CEWAs = colour exception word associates (e.g., "ocean").

Table 6

Mean Amplitude in Microvolts for the 300 – 400 ms Time Window

	Congruent			Incongruent		
Stimulus	*n*	*M*	*SD*	*n*	*M*	*SD*
CPHs	24	.158	1.446	24	.072	1.497
CEPHAs	24	.015	1.311	24	-.035	1.486
CWs	24	.275	1.612	24	.161	1.847
CEWAs	24	-.102	1.885	24	.279	1.624

Note. CPHs = colour pseudohomophones (e.g., “bloo”); CEPHAs = colour exception pseudohomophone associates (e.g., “oshin”); CWs = colour words (e.g., “blue”); CEWAs = colour exception word associates (e.g., “ocean”).

Table 7

Peak Amplitude in Microvolts for the 300 – 400 ms Time Window

	Congruent			Incongruent		
Stimulus	*n*	*M*	*SD*	*n*	*M*	*SD*
CPHs	24	.031	.692	24	-.261	1.126
CEPHAs	24	-.615	1.706	24	-.018	.773
CWs	24	-.394	1.119	24	-.447	1.197
CEWAs	24	-.132	.866	24	.106	1.342

Note. CPHs = colour pseudohomophones (e.g., “bloo”); CEPHAs = colour exception pseudohomophone associates (e.g., “oshin”); CWs = colour words (e.g., “blue”); CEWAs = colour exception word associates (e.g., “ocean”).

Table 8

Peak Latency in Milliseconds for the 300 – 400 ms Time Window

	Congruent			Incongruent		
Stimulus	*n*	*M*	*SD*	*n*	*M*	*SD*
CPHs	24	344.500	43.295	24	329.080	37.325
CEPHAs	24	325.210	35.173	24	336.880	40.338
CWs	24	334.830	39.575	24	337.960	39.461
CEWAs	24	333.080	38.254	24	348.330	36.663

Note. CPHs = colour pseudohomophones (e.g., “bloo”); CEPHAs = colour exception pseudohomophone associates (e.g., “oshin”); CWs = colour words (e.g., “blue”); CEWAs = colour exception word associates (e.g., “ocean”).

Table 9

Mean Amplitude in Microvolts for the 500 – 600 ms Time Window

	Congruent			Incongruent		
Stimulus	*n*	*M*	*SD*	*n*	*M*	*SD*
CPHs	24	-1.181	3.464	24	-.905	2.126
CEPHAs	24	-1.505	2.988	24	-1.137	2.638
CWs	24	-1.741	3.012	24	-1.291	2.287
CEWAs	24	-1.654	3.421	24	-1.026	2.221

Note. CPHs = colour pseudohomophones (e.g., “bloo”); CEPHAs = colour exception pseudohomophone associates (e.g., “oshin”); CWs = colour words (e.g., “blue”); CEWAs = colour exception word associates (e.g., “ocean”).

Table 10

Peak Amplitude in Microvolts for the 500 – 600 ms Time Window

	Congruent			Incongruent		
Stimulus	*n*	*M*	*SD*	*n*	*M*	*SD*
CPHs	24	-1.331	2.975	24	-.565	1.459
CEPHAs	24	-1.335	3.106	24	-.439	1.340
CWs	24	-1.963	3.204	24	-1.021	1.858
CEWAs	24	-1.810	3.516	24	-1.063	2.132

Note. CPHs = colour pseudohomophones (e.g., “bloo”); CEPHAs = colour exception pseudohomophone associates (e.g., “oshin”); CWs = colour words (e.g., “blue”); CEWAs = colour exception word associates (e.g., “ocean”).

Table 11

Peak Latency in Milliseconds for the 500 – 600 ms Time Window

	Congruent			Incongruent		
Stimulus	*n*	*M*	*SD*	*n*	*M*	*SD*
CPHs	24	572.170	32.791	24	575.040	35.444
CEPHAs	24	574.830	30.843	24	571.750	33.309
CWs	24	567.710	33.990	24	577.920	32.806
CEWAs	24	578.130	25.855	24	584.420	24.182

Note. CPHs = colour pseudohomophones (e.g., “bloo”); CEPHAs = colour exception pseudohomophone associates (e.g., “oshin”); CWs = colour words (e.g., “blue”); CEWAs = colour exception word associates (e.g., “ocean”).

Table 12

Summary Table of ERP Results

	Mean Amplitude		*Peak Amplitude*		*Peak Latency*	
Time Window	*Effect*	*p*	*Effect*	*p*	*Effect*	*p*
200 – 300 ms	No effects	.	M.E. Cong	.071	No effects	.
300 – 400 ms	No effects	.	Cong × C.T. C.T. × Stim Type	.040 .033	Cong × C.T.	.004
500 – 600 ms	M.E. Cong M.E. Stim Type C.T. × Stim Type	.075 .082 .067	M.E. Cong M.E. Stim Type	.061 .058	M.E. Cong	.064

Note. M.E. = main effect; Cong = Congruency; Stim Type = Stimulus Type; C.T. = Colour Type. Results reported include those that achieved statistical significance (p < .05) and those that only approached significance.

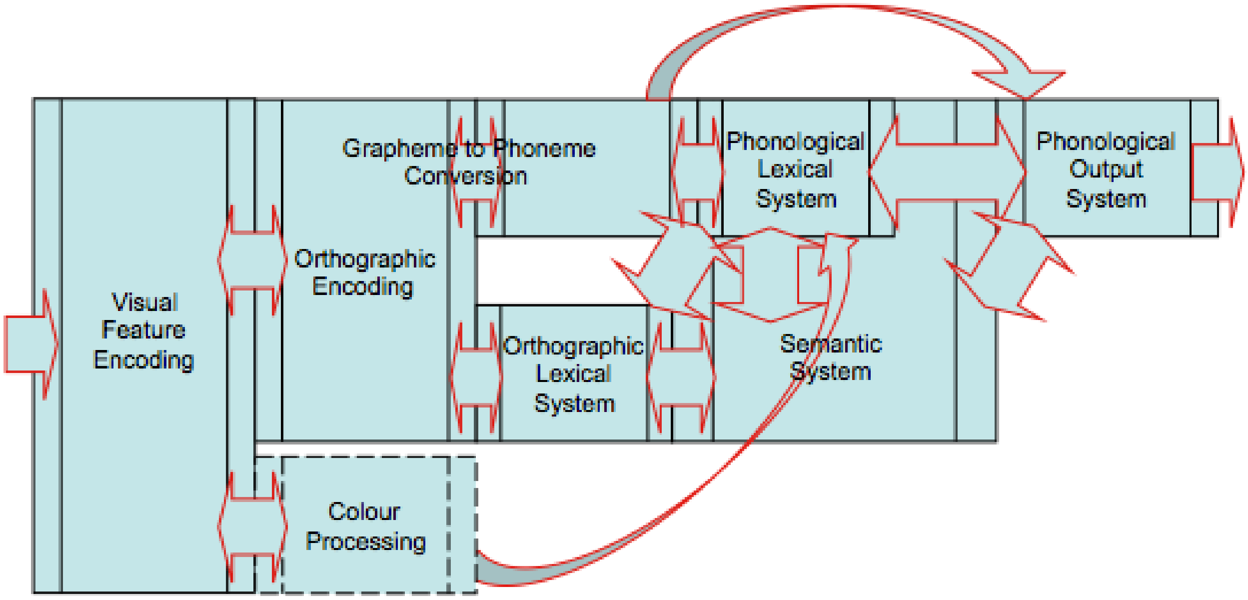

Figure 1. An example of one type of dual-route model of reading (Anton, Gould, & Borowsky, 2014; Borowsky et al., 2013; Cummine et al., 2013; Gould, Cummine, & Borowsky, 2012; see also Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). The orthographic-lexical pathway is believed to operate without intention and relies on sight vocabulary and memory representations to read familiar regular words and exception words (e.g., “ocean”). The grapheme-to-phoneme-conversion (GPC)-sublexical pathway is believed to proceed in a sequential fashion and relies on phonetic decoding to read unfamiliar regular words (e.g., “fabulist”), pseudohomophones (e.g., “oshin” = “ocean”), and nonwords (e.g., “vup”). © 2014 by the American Psychological Association. Reproduced with permission from Anton, K. F., Gould, L., & Borowsky, R. (2014). Activation of lexical and semantic representations without intention along GPC-sublexical and orthographic-lexical reading pathways in a Stroop paradigm. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *40*(3), 623-644. American Psychological Association.

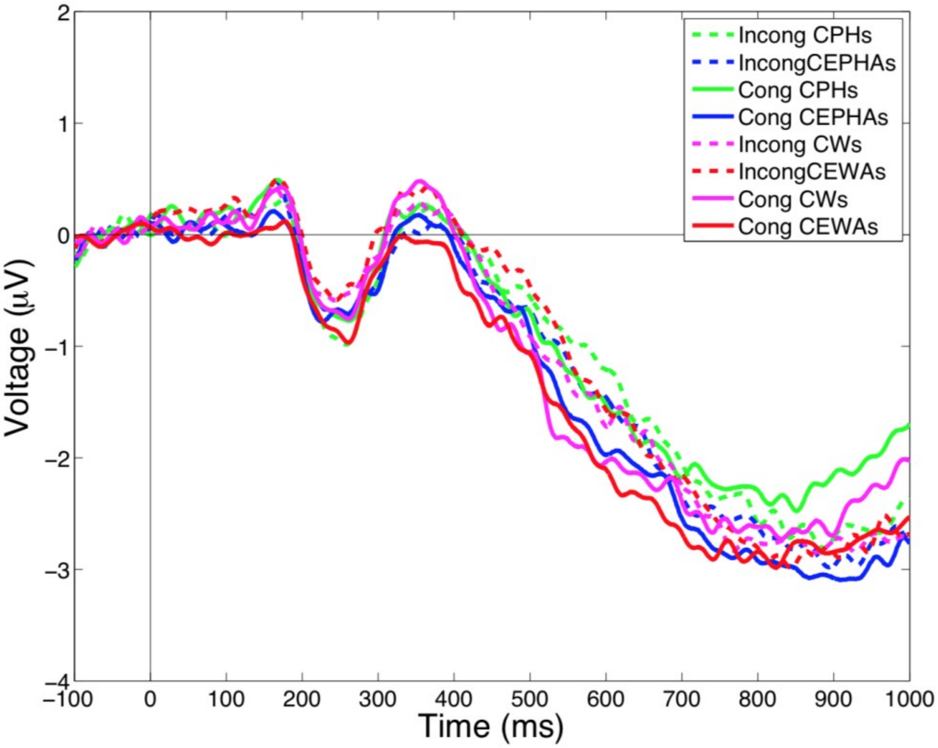

Figure 2. Group average ERPs for electrode CPz for each of the conditions (Congruency, Colour Type, and Stimulus Type). The figure shows an N400 effect occurring between 200 and 300 ms, with a negative slow wave also occurring approximately 400 ms post-stimulus onset. Negative is plotted downward.

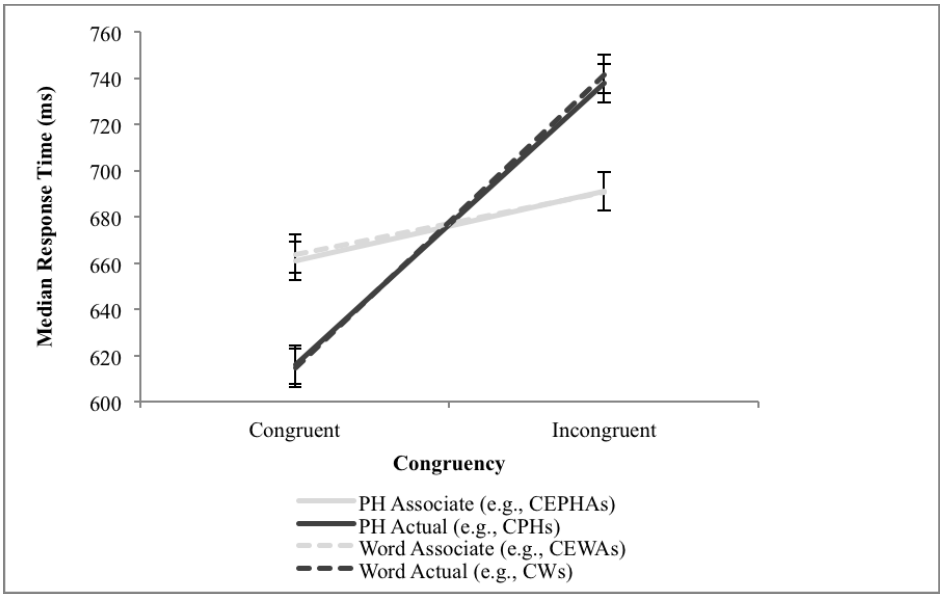

Figure 3. Behavioural median response time (RT) representing the time taken to correctly name the font colour of pseudohomophones (Associate = CEPHAs, e.g., “oshin”; Actual = CPHs, e.g., “bloo”) and words (Associate = CEWAs, e.g., “ocean”; Actual = CWs, e.g., “blue”), as a function of congruency and colour type. Error bars represent the 95% confidence interval calculated using Loftus and Masson’s (1994) method.

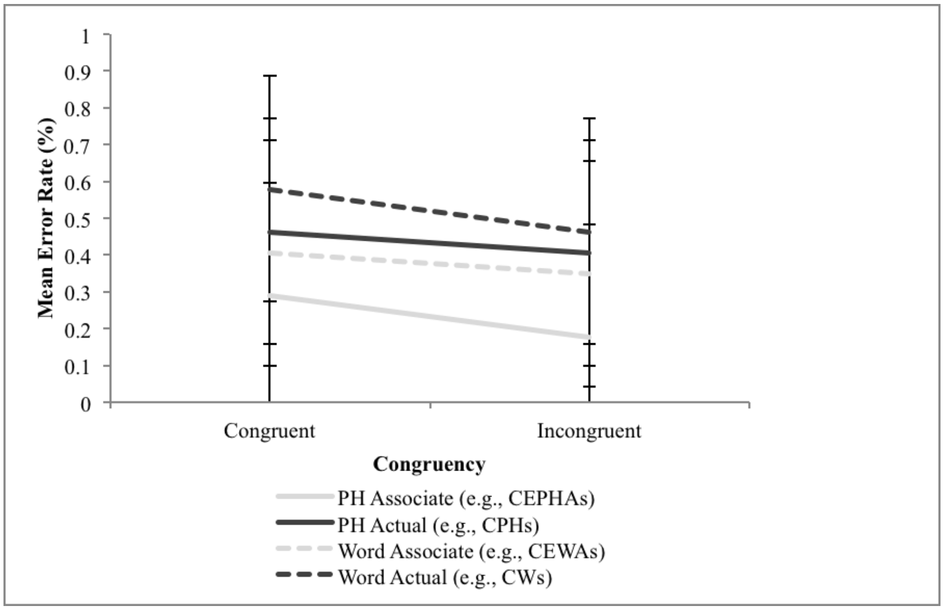

Figure 4. Behavioural mean error rate (%) representing the percentage of errors made when naming the font colour of pseudohomophones (Associate = CEPHAs, e.g., "oshin"; Actual = CPHs, e.g., "bloo") and words (Associate = CEWAs, e.g., "ocean"; Actual = CWs, e.g., "blue"), as a function of congruency and colour type. Error bars represent the 95% confidence interval calculated using Loftus and Masson's (1994) method.

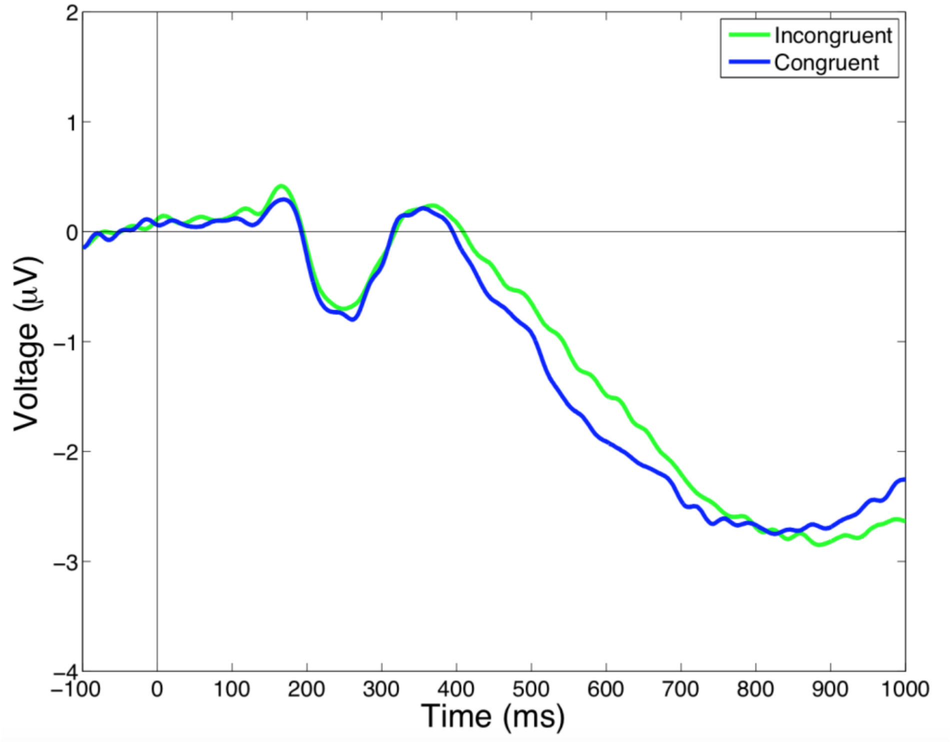

Figure 5. Group *congruent* and *incongruent* ERPs for electrode CPz averaged across *colour type and stimulus type* conditions. Negative is plotted downward.

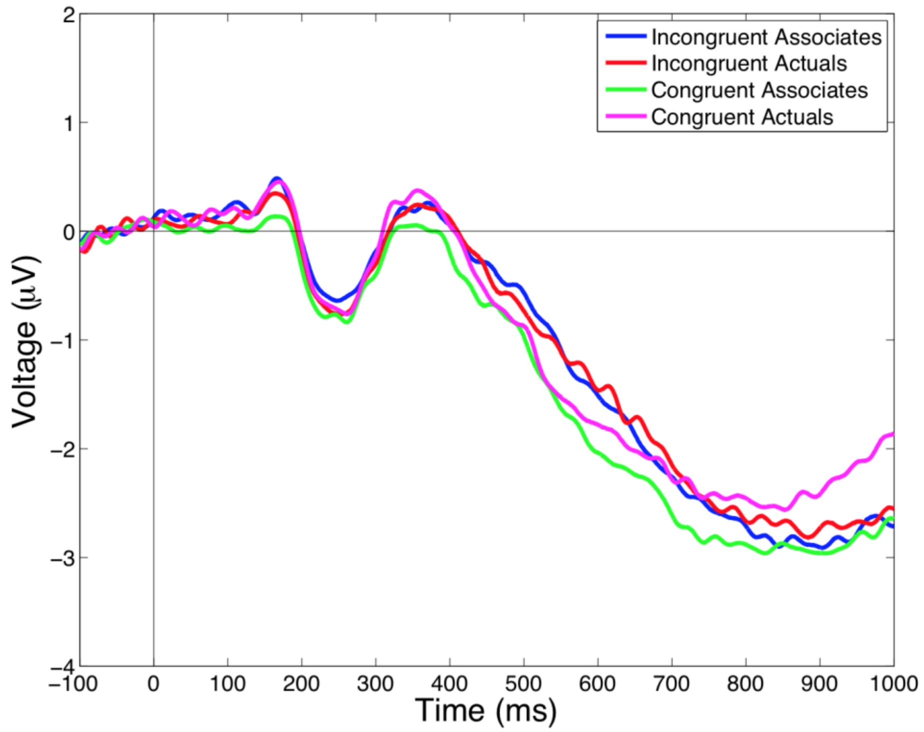

Figure 6. Group *congruency* by *colour type* ERPs for electrode CPz averaged across *stimulus type* conditions. Associates = CEPHAs (e.g., "oshin") and CEWAs (e.g., "ocean"); Actuals = CPHs (e.g. "bloo") and CWs (e.g., "blue"). Negative is plotted downward.

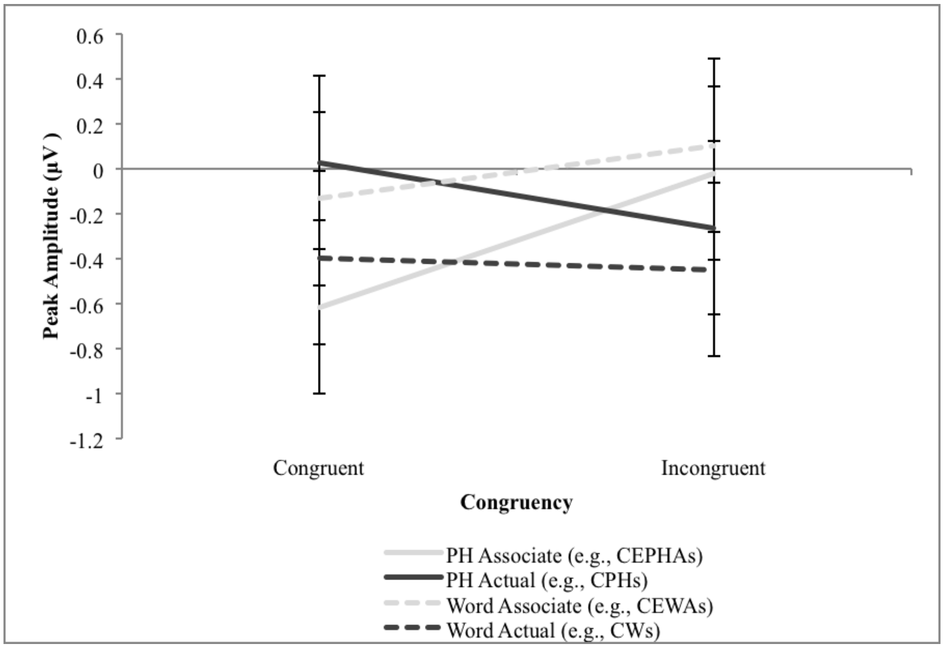

Figure 7. Peak amplitude (µV) representing the electrophysiological amplitude when correctly naming the font colour of pseudohomophones (Associate = CEPHAs, e.g., "oshin"; Actual = CPHs, e.g., "bloo") and words (Associate = CEWAs, e.g., "ocean"; Actual = CWs, e.g., "blue"), as a function of congruency and colour type in the 300 – 400 ms time window. There is a greater difference in the peak amplitude between congruent and incongruent *associate* stimuli (e.g., CEWAs and CEPHAs) than between congruent and incongruent *actual* stimuli (e.g., CWs and CPHs). Error bars represent the 95% confidence interval calculated using Loftus and Masson's (1994) method.

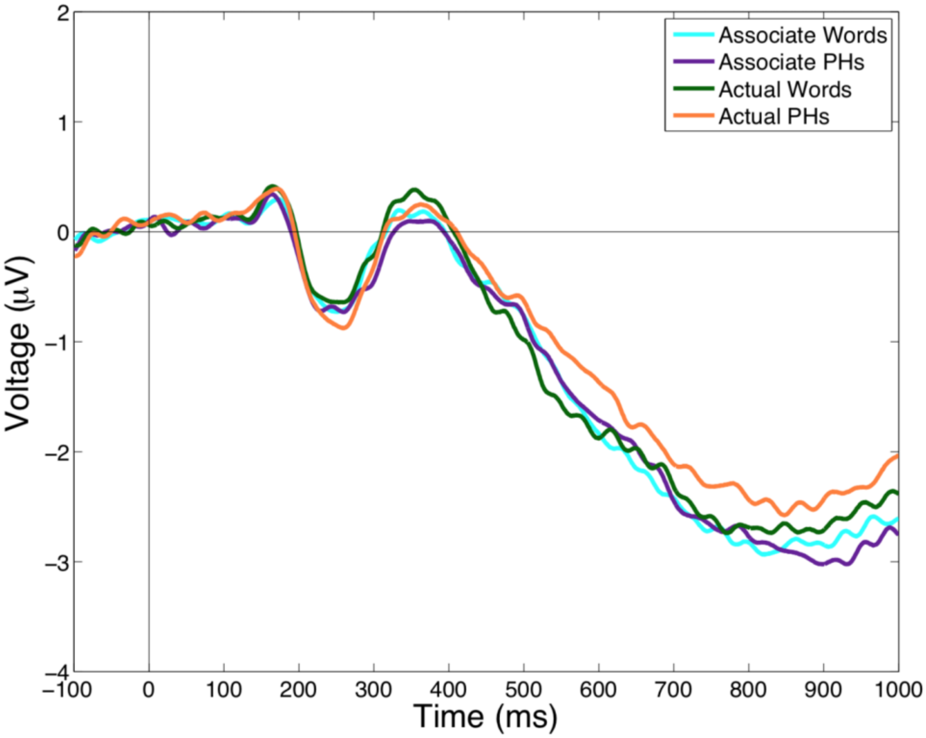

Figure 8. Group *colour type* by *stimulus type* ERPs for electrode CPz averaged across *congruency* conditions. Associate Words = CEWAs (e.g., “ocean”); Associate PHs = CEPHAs (e.g., “oshin”); Actual Words = CWs (e.g., “blue”); Actual PHs = CPHs (e.g., “bloo”). Negative is plotted downward.

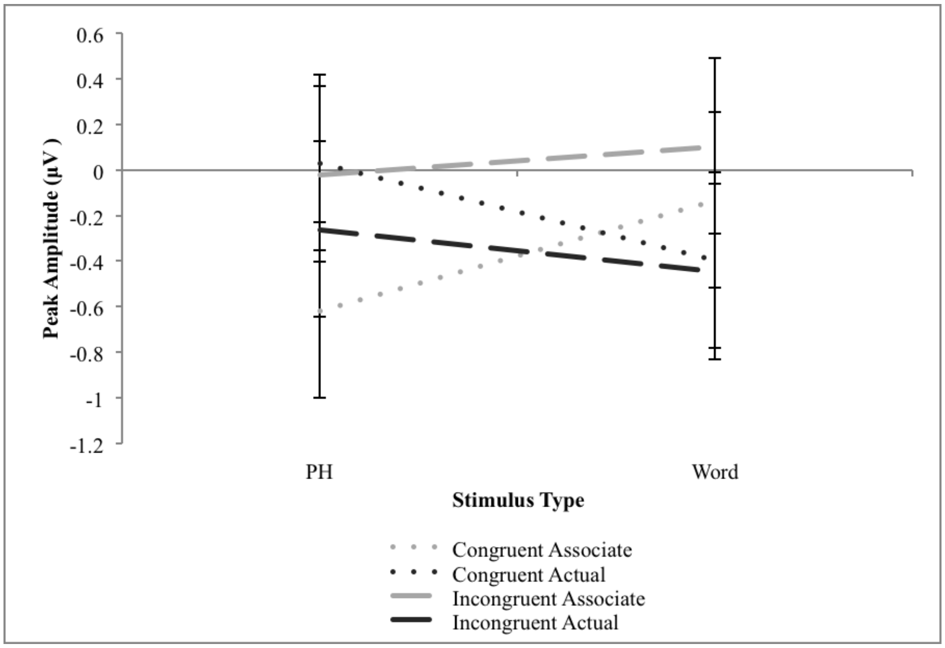

Figure 9. Peak amplitude (µV) representing the electrophysiological amplitude when correctly naming the font colour of congruent stimuli (Associate = CEPHAs and CEWAs; Actual = CPHs and CWs) and incongruent stimuli (Associate = CEPHAs and CEWAs; Actual = CPHs and CWs) as a function of colour type and stimulus type in the 300 – 400 ms time window. There is a greater effect of stimulus type (i.e., word vs. PH) on *associate* colour type stimuli than on *actual* colour type stimuli. Error bars represent the 95% confidence interval calculated using Loftus and Masson's (1994) method.

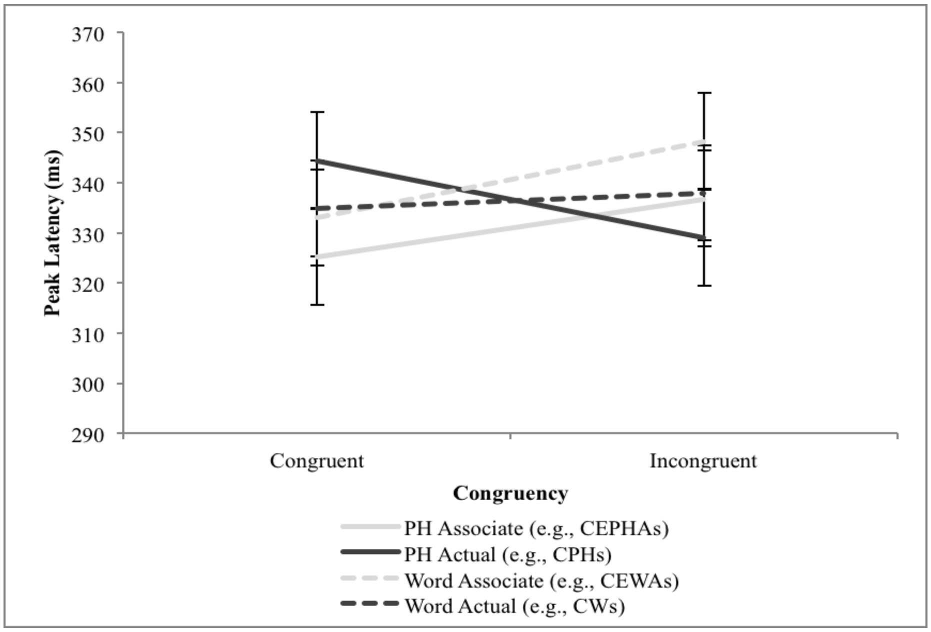

Figure 10. Peak latency (ms) representing the time to reach the peak amplitude when correctly naming the font colour of pseudohomophones (Associate = CEPHAs, e.g., “oshin”; Actual = CPHs, e.g., “bloo”) and words (Associate = CEWAs, e.g., “ocean”; Actual = CWs, e.g., “blue”), as a function of congruency and colour type in the 300 – 400 ms time window. There is a greater difference in the peak latency between congruent and incongruent *associate* stimuli (e.g., CEWAs and CEPHAs) than between congruent and incongruent *actual* stimuli (e.g., CWs and CPHs). Error bars represent the 95% confidence interval calculated using Loftus and Masson’s (1994) method.

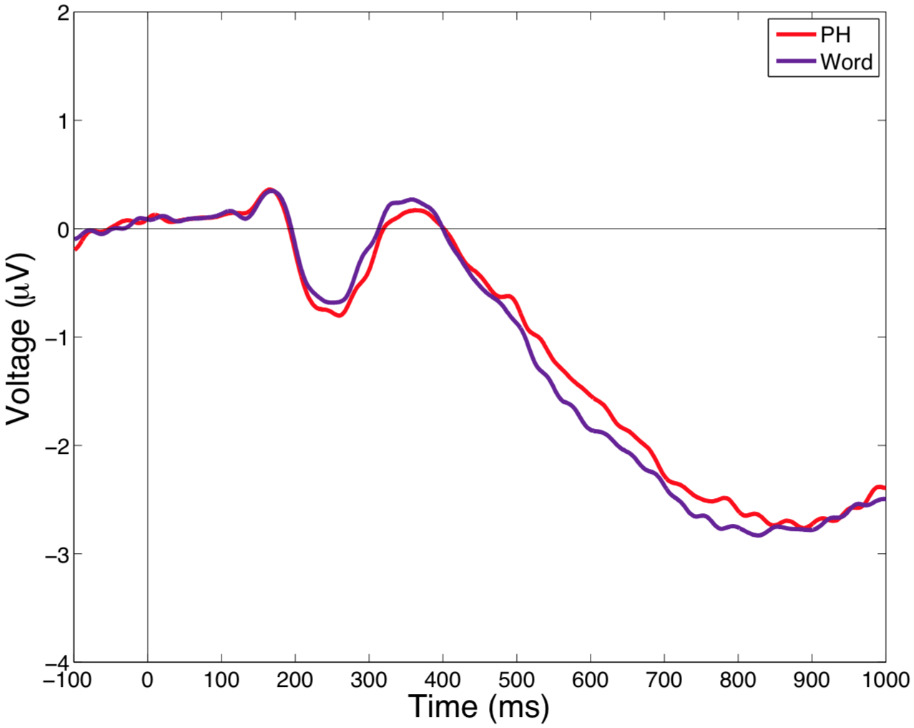

Figure 11. Group *stimulus type* ERPs for electrode CPz averaged across *congruency* and *colour type* conditions. Negative is plotted downward.

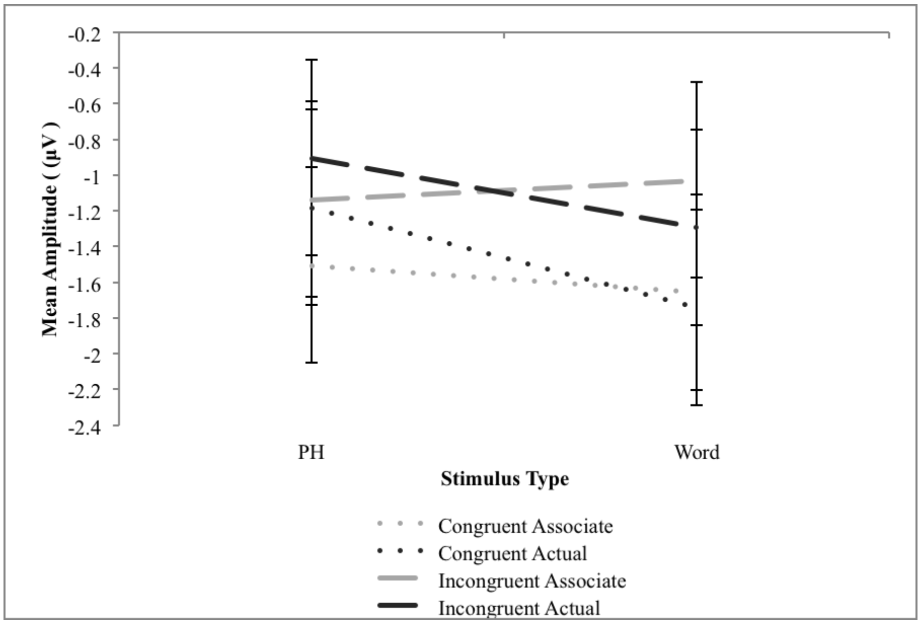

Figure 12. Mean amplitude (µV) representing the electrophysiological amplitude when correctly naming the font colour of congruent stimuli (Associate = CEPHAs and CEWAs; Actual = CPHs and CWs) and incongruent stimuli (Associate = CEPHAs and CEWAs; Actual = CPHs and CWs) as a function of colour type and stimulus type in the 500 – 600 ms time window. There is a greater effect of colour type (i.e., *actual* vs. *associate* stimuli) on the *PH* stimuli relative to the *word* stimuli. Error bars represent the 95% confidence interval calculated using Loftus and Masson's (1994) method.

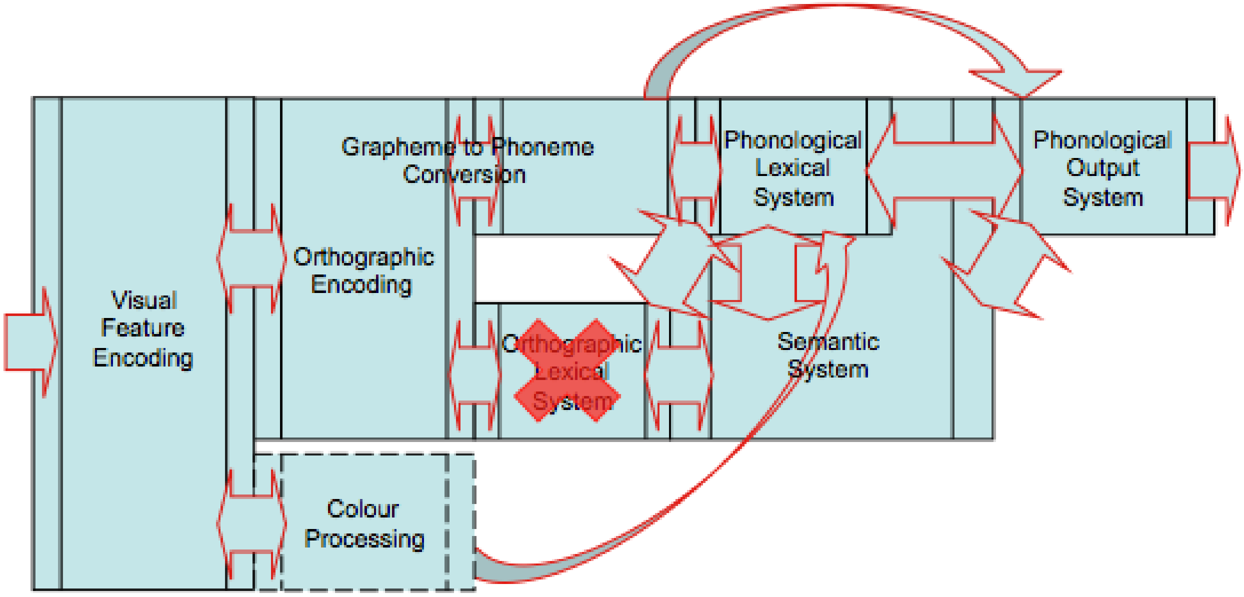

Figure 13. A model of surface alexia in a dual-route model of reading framework. Damage to the orthographic lexical system in the orthographic-lexical pathway leads to an impairment in reading exception words (e.g., "ocean"). Residual abilities in the GPC-sublexical pathway still allow an individual with surface alexia to read familiar regular words, unfamiliar regular words, PHs, and nonwords. This type of alexia is characterized by phonologically-plausible reading errors, in which the individual pronounces exception words as they would be sounded out using GPC (e.g., "ocean" = "oh-keen"). © 2014 by the American Psychological Association. Adapted with permission from Anton, K. F., Gould, L., & Borowsky, R. (2014). Activation of lexical and semantic representations without intention along GPC-sublexical and orthographic-lexical reading pathways in a Stroop paradigm. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *40*(3), 623-644. American Psychological Association.

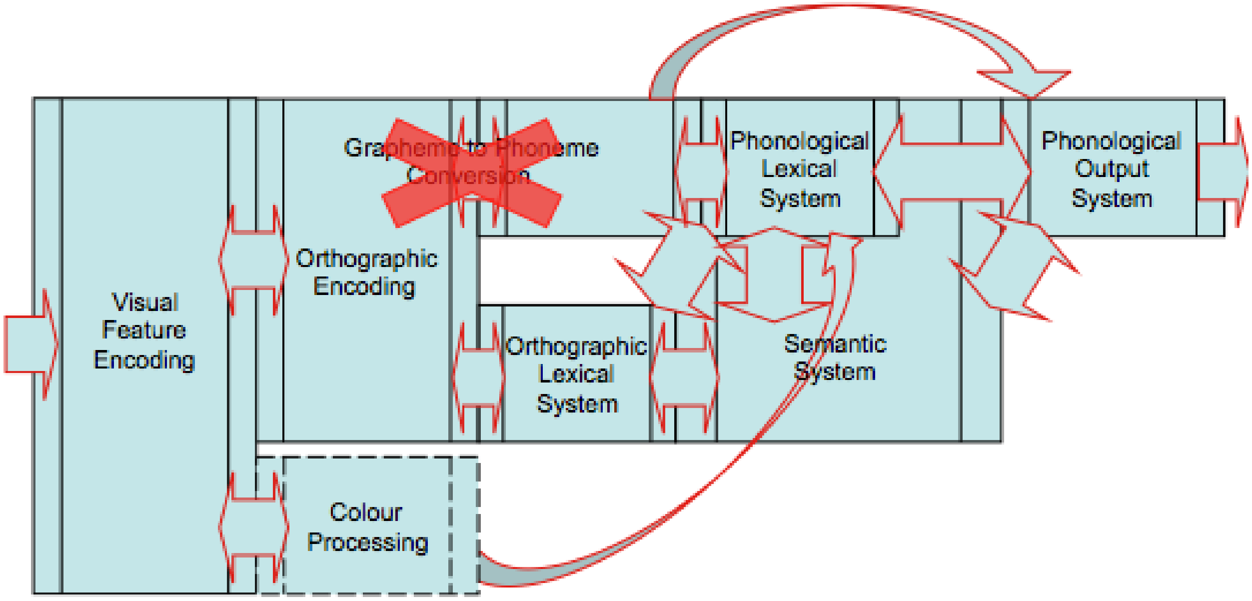

Figure 14. A model of phonological alexia in a dual-route model of reading framework. Damage to the GPC process in the GPC-sublexical pathway leads to an impairment in reading unfamiliar regular words (e.g., “fabulist”), PHs (e.g., “oshin”), and nonwords (e.g., “vup”). Residual abilities in the orthographic-lexical pathway still allow an individual with phonological alexia to read familiar regular words and exception words due to intact memory representations of these words. This type of alexia is characterized by lexical reading errors, in which the individual pronounces unfamiliar regular words, PHs, or nonwords as actual words (e.g., “oshin” = “open”). © 2014 by the American Psychological Association. Adapted with permission from Anton, K. F., Gould, L., & Borowsky, R. (2014). Activation of lexical and semantic representations without intention along GPC-sublexical and orthographic-lexical reading pathways in a Stroop paradigm. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *40*(3), 623-644. American Psychological Association.

APPENDIX

Stimuli used in the experiment

Colour Words (CWs)	Colour Exception Word Associates (CEWAs)	Colour Pseudohomophones (CPHs)	Colour Exception Pseudohomophone Associates (CEPHAs)
blue	ocean	bloo	oshin
green	bush	ghrean	boosh
pink	tongue	pynk	tuhng
red	blood	rhed	blud
yellow	yolk	yelo	yoak
orange	cantaloupe	ohrenge	kantalope
purple	lilac	perpull	lylack
white	chalk	wyte	chawk
grey	asphalt	greh	ashfault