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Syntactic processing in individuals with dyslexia: Using ERP to address the debate

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Syntactic Processing in Individuals with Dyslexia: Using ERP to Address the Debate

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Abstract

Behavioural and ERP data were collected from university and college students with and without dyslexia to determine if a deficit in syntactic processing in post-secondary students with dyslexia can be explained by the degree of phonological processing deficits. Participants read and listened to sentences of differing syntactic complexity and working memory load, particularly object relative and subject relative sentences. Slow cortical waves showed greater negativity for the object relative sentences as the sentence progressed for the control participants regardless of presentation format. The same result was seen for the participants with dyslexia when presented with sentences in an auditory format. Analyses revealed that control participants had greater left anterior negativity between 300 and 500 ms for the main verb of the object relative sentences, regardless of presentation format. Participants with dyslexia showed difficulty in processing the written versions of the syntactically complex sentences but they were able to differentiate these syntactic structures when they were presented in an auditory format. An N400 effect was seen by participants with dyslexia for the second article in the object relative sentence, presumably as a result of the unexpected occurrence of the object relative structure. The bottleneck for control participants appears to exist at the level of working memory while participants with dyslexia were limited by their phonological processing skills in general and specifically their reading skills for the written syntactic processing tasks. The results support the phonological processing deficit hypothesis in explaining the processing weaknesses of participants with dyslexia.

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Syntactic Processing in Individuals with Dyslexia: Using ERP to Address the Debate

Introduction

Developmental dyslexia is defined as a disorder in which there is a difficulty in learning to read, despite evidence of adequate intelligence, learning opportunities, and sociocultural opportunities (Lovett, Borden, DeLuca, Lacerenza, Benson, & Bracksone, 1994). Individuals with dyslexia often exhibit problems with decoding unfamiliar words, word recognition, spelling, and reading comprehension (Clark & Uhry, 1995). Previous research (Bowey, 1986, 1994; Gottardo, Siegel, & Stanovich, 1997; Gottardo, Stanovich, & Siegel, 1996) has shown that individuals with dyslexia have deficits in phonological processing, which involves understanding spelling-to-sound rules (O'Grady & Dobrovolsky, 1996). Recognizing the sound segments and how they occur in speech usually develops in the elementary school years (Siegel & Ryan, 1988).

Research on syntactic processing skills in people with reading disabilities examines the processing of words in sentences. Words are assigned to a syntactic category in order to attribute their grammatical function and subsequently their meaning. The thematic role of a sentence is the semantic relationship between a predicate (verb) and an argument (noun phrase). Knowing the thematic roles of words in a sentence allows readers to determine who is doing what to whom. The agent of a sentence is someone who deliberately performs an action, while the patient is the receiver of that action (Rochon, Laird, Bose, & Scofield, 2005). Syntactic processing performance is usually tested using sentence correction and sentence judgment tasks (Leiken, 2002). Understanding and identifying the grammatical roles (e.g., subject, object) of words is a key factor in sentence processing. Syntactic processing deficits have been reported in individuals with dyslexia (Siegel & Ryan, 1988). However, researchers continue to debate whether dyslexia is a result of specific deficits in phonological processing skills and phonological sensitivity (Gottardo et al., 1996, 1997; Shankweiler, Crain, Brady, & Macaruso, 1992; Stanovich & Siegel, 1994) or general language deficits that include phonological sensitivity as well as semantic, syntactic, and general metalinguistic deficits (Dickinson, McCabe, Anastasopoulos, Peisner-Feinberg, & Poe, 2003; Tunmer & Hoover, 1992). Dickinson et al. (2003) defined the two views addressing the relationship between oral language and literacy skills as the Phonological Sensitivity Approach (PSA) and the Comprehensive Language Approach (CLA). This debate is important for understanding underlying causes of dyslexia and possibly determining early linguistic precursors to reading difficulties.

In order to further address this debate, the present study examined syntactic processing in adults with dyslexia using Event Related Brain Potentials (ERP) techniques. As a result of the debate regarding whether the underlying causes of developmental dyslexia are phonological sensitivity deficits or general language deficits, we were interested in determining if a deficit in syntactic processing could be explained by the degree of phonological processing deficits. ERP measures were taken while the participants with dyslexia performed tasks that required syntactic processing and the results were compared to normally achieving controls. ERPs are useful in demonstrating the differences in difficulty of processing between average readers in the control group and individuals with dyslexia. In particular the Left-Lateralized Anterior Negativity (LAN), slow cortical waves, and the N400 are the components of interest in the ERP recording. Performance on different syntactic structures with differing processing demands was examined to determine group differences in terms of patterns of syntactic processing. Participants were also tested on a variety of behavioural measures such as vocabulary, working memory, and phonological processing. This approach offers further insight into the syntactic processing abilities of individuals with dyslexia. The study was designed to determine whether task performance on a syntactic processing task presented in written form differs as compared to the same task presented in an auditory format. Overall weaker performance on the written version points to phonological processing deficits while similar levels of performance across the auditory and written versions by the participants with dyslexia in comparison to the control participants suggests a more extensive linguistic deficit.

Phonological Sensitivity Approach (PSA)

The Phonological Processing Deficit Hypothesis similar to the PSA, proposes that phonological sensitivity is the key language skill that is related to reading acquisition and achievement. This approach suggests that the underlying deficits in dyslexia are phonological in nature. Deficits in phonological awareness can lead to a chain of negative side effects. If readers have difficulty with decoding unknown words, they may then be exposed to less text and reading opportunities than their peers (Stanovich, 1986). Stanovich and Siegel (1994) found that the critical deficit impairing word recognition is phonological in nature. Consistent with the PSA, Gottardo et al. (1997) administered phonological, linguistic, memory, and cognitive tasks to adults who were average readers and adults who were poor readers. Phonological processing was a consistent predictor of reading ability even when syntactic processing was statistically controlled. Similar results were found for children in elementary school (Gottardo et al., 1996). The strength of the relation between phonological processing and reading ability across ages demonstrates that phonological sensitivity is most strongly related to reading ability even when other measures were controlled.

When examining the persistence of phonological deficits in adults with dyslexia, Bruck (1992) used a Reading Level Match design. This design compares individuals with dyslexia with control readers with the same word-recognition skills. By using this design researchers are able to determine if individuals with dyslexia show a deficit in phonological awareness, in that they perform more poorly than control readers who are younger but have similar word reading skills. However, if individuals with dyslexia are performing similarly to control readers who are at the same word-recognition level, then this pattern would reflect a developmental delay for the individuals with dyslexia. Bruck (1992) found that adults with dyslexia did not acquire the appropriate levels of phonemic awareness, regardless of age and reading levels. High functioning adults with dyslexia performed more poorly at phonological awareness tasks than grade three children who were poorer at spelling and reading than the adults with dyslexia. Weaknesses in phonological awareness tasks were found in adults with dyslexia, despite having learned to compensate for their reading difficulties.

Shankweiler et al. (1992) believed that poor readers have a deficit in phonological processing capabilities. Their belief was that deficits in phonological processing create a bottleneck at lower levels of linguistic processing that have an impact on transferring information to other processes important in reading. Gottardo et al. (1996) examined how phonological sensitivity, syntactic processing, and verbal working memory contribute to reading performance. It was believed that phonological sensitivity would account for variance in reading ability after syntactic processing and working memory were partialled out. The results supported their hypothesis in that the variance explained by phonological sensitivity after syntactic processing was partialled out was much greater than the variance explained by syntactic processing after phonological sensitivity was partialled out. In fact, syntactic processing did not explain unique variance in word reading when phonological sensitivity was statistically controlled. In addition, phonological processing and syntactic processing shared statistical variance suggesting that phonological processing deficits underlie syntactic processing difficulties in poor readers (Gottardo et al., 1996).

Similarly, Bowey (2005) examined grammatical sensitivity in early childhood. Children performed tasks measuring vocabulary, phonological sensitivity, cognitive ability, grammatical sensitivity, grammatical understanding, and early word reading in a three-phase longitudinal study, beginning when children were four years of age. Measures of phonological processing ability were strong predictors of word reading skills, adding support to the view that deficits in phonological processing are reflected in word reading abilities. It was found that grammatical sensitivity was more closely tied to general language ability than cognitive ability. Grammatical sensitivity did not make a substantial contribution to word reading skills in beginning readers. Phonological sensitivity predicted word reading when nonword repetition and syntactic ability effects were controlled. Overall, grammatical sensitivity and phonological sensitivity were both predicted by earlier language ability. When cognitive ability and general language ability were controlled, phonological processing predicted substantial variance in later reading.

Bowey (1986) investigated the relationship between syntactic awareness and reading proficiency. It was hypothesized that less skilled readers would be inferior to more skilled readers in terms of syntactic awareness, and that syntactic awareness would be associated with reading comprehension. Elementary school children, in grades 4 and 5 completed tasks designed to measure syntactic awareness and oral reading. The syntactic awareness tasks required children to either imitate a grammatically incorrect sentence, or to correct a grammatically incorrect sentence. In the oral reading task, children were asked to read a passage and to then retell the story and answer questions about the story. The results showed that skilled readers performed at a higher level than less skilled readers for the error imitation and error correction tasks. A correlation was found between syntactic control and decoding skills, even when the effects of general verbal ability were statistically controlled. It was suggested that this correlation between syntactic awareness and decoding skill could not be explained only in terms of the mediation of comprehension ability. Rather, it was hypothesized that decoding skill and syntactic awareness are correlated with a general metalinguistic ability factor such as phonological awareness. This approach would predict that adults with dyslexia would find all syntactic processing tasks equally difficult if the tasks are presented in written form due to the "bottleneck" created by the phonological processing required to read the stimuli. Performance on orally presented syntactic processing tasks would be similar to that of the normally achieving controls due to decreased phonological processing demands.

Comprehensive Language Approach (CLA)

The CLA proposes that there are a variety of oral language skills that are necessary for developing literacy and that they all play a role in later reading achievement. Consistent with the CLA, Dickinson et al. (2003) found that for children with low phonological sensitivity, vocabulary had less impact on literacy growth than for children with normally developing phonological sensitivity, and that for children with low vocabulary, phonological sensitivity had less predictive power for early literacy than among children with normally developing vocabulary. The results of this study supported the CLA view in that language (i.e. vocabulary, syntactic processing) and phonological sensitivity were equally related to measures of literacy. Similarly, Tunmer and Hoover (1992) believe that phonological processing and syntactic processing are different aspects of general metalinguistic capability. They found that syntactic awareness is able to predict decoding ability even after phonological awareness ability is partialled out.

Contributions of Phonological Processing and Oral Language Abilities

Other researchers have found that both phonological awareness and language abilities are important for word reading achievement. Siegel and Ryan (1988) found that children with reading disabilities lagged behind peers in terms of phonological processing as well as grammatical sensitivity. Children with other learning disabilities (i.e., Attention Deficit Disorder or difficulty with math and written work) did not show these deficits. Grammatical sensitivity problems were not due to weaknesses in working memory because there were no differences in the sentence repetition task among groups, except at the younger ages.

Catts, Fey, Zhang, and Tomblin (1999) examined how phonological processing and oral language abilities contribute to reading and reading disabilities in children in grade two. The children were divided into good and poor readers and compared in terms of phonological processing and other language abilities. Those children who had a history of language deficits had difficulties in both phonological processing and oral language abilities. Poor readers performed significantly less well than good readers on tests of vocabulary, grammar, and narration. Regression analyses indicated that both oral language abilities and phonological processing abilities provided unique variance when predicting reading achievement. These results indicate the both phonological processing and oral language abilities are important factors for successful reading achievement in young children.

In their review of the language basis of reading disabilities Catts and Hogan (2003) found that difficulties in phonological awareness can be seen in children at the pre-reading level, and that these deficits could lead to difficulties learning to read. They also found that poor readers have difficulties with other aspects of language, such as vocabulary. Having a limited vocabulary can reduce one's ability to identify a low frequency word, as a result of having lower contextual knowledge. The CLA and other general linguistic approaches would predict lower performance by people with dyslexia on all syntactic processing tasks (including auditory tasks) as compared to normally achieving controls with task difficulty being explained by syntactic complexity. The use of working memory as a control variable would not mediate task performance.

As a result of the debate regarding whether the underlying causes of developmental dyslexia are phonological sensitivity deficits or general language deficits, we are interested in determining if a deficit in syntactic processing can be explained by the degree of phonological processing deficits. To further explore this debate our study examined syntactic processing in individuals with dyslexia using Event Related Brain Potentials (ERP) measures. The performance of participants with dyslexia was compared to normally achieving controls on tasks that required syntactic processing of oral (auditory) or written (visual) sentences with complex syntactic structures.

Event Related Brain Potentials

Event Related Brain Potentials (ERPs) are recordings of the brain's electrical activity that are linked to the occurrence of a specific event (i.e., reading words) (Banich, 1997). ERP is especially useful for examining questions that deal with the speed and difficulty of cognitive operations during different stages of information processing (Breznitz & Meyler, 2003; King & Kutas, 1995). It allows for very precise measurements on a millisecond scale, as well as providing neurocognitive information on cognitive functions. Presenting sentences on the screen one word at a time at a fixed rate allows participants to simply read for comprehension versus having to press buttons to advance text. ERP provides an index of processing individual words, as well as processing at a sentence or clause level and allows for examination of these recordings in order to determine where in the sentence processing differs (Müller, King, & Kutas, 1997). ERP recordings produce a waveform, which can be divided into components. These components are linked to certain cognitive processes (Banich, 1997). There are a number of components that are thought to be most relevant in terms of reading. These include the N100-P200, N200, P300, N400, and the P600. The N100-P200 is related to perception. For example, the N100-P200 is increased when a stimulus appears in an attended location when compared to appearing in an unattended location (Banich, 1997). The N200 is related to focused attention, stimulus classification, and discrimination. The amplitude of the N200 reflects the detection of some type of mismatch between stimulus features or between stimulus and a preformed template. Larger amplitudes are seen for rare stimuli (Fabiani, Gratton, & Coles, 2000). The P300 occurs 300 ms after sensory discrimination occurs and is associated with stimulus classification and updating in short-term memory. The amplitude of the P300 is related to processing resources demanded by a particular task. The latency of the P300 may reflect stimulus evaluation or categorization time. Larger P300s occur when the stimulus is more improbable (Fabiani et al., 2000). Finally, the P600 is believed to be related to syntactic processing (Leiken, 2002; Breznitz, & Meyler, 2003).

In the current research we are primarily interested in the amplitudes of left anterior negativity (LAN), slow cortical waves, and N400. The LAN and the slow cortical waves are more novel components for investigating reading. Problems with syntactic processing elicit a LAN 100 to 500 ms after a stimulus onset, which tends to have a left-lateralized frontal distribution on the scalp (Van den Brink & Hagoort, 2004). The LAN component is assumed to measure effortful processing and is related to how difficult the task is for the participants. It has been linked to detecting syntactic deviations as well as working memory aspects of language (Matzke, Mai, Nager, Rüsseler, & Münte, 2002). Slow cortical waves are useful in showing the overall difficulty of processing an entire sentence. The slow waves reflect additional processing required by difficult operations. Difficulty in integrating sentences is associated with increased anterior negativity in slow waves, which has been linked to working memory constraints.

Munte, Schiltz, and Kutas (1998) also found that sentences that are more demanding of working memory are associated with higher negativities in the frontal regions. These differences were found to be more salient for good comprehenders than for poor comprehenders. The difficulty of processing more complex sentences, such as object relative sentences, is reflected in the slow cortical waves (King & Kutas, 1995). Finally, the N400 occurs 400 ms after the word onset. It is related to lexical-semantic integration. It is sensitive to violations in semantic expectancies (Fabiani et al., 2000). Also, most importantly for this study the N400 is used to indirectly test the effects of working memory on syntactic aspects of sentence parsing such as thematic role assignment (King & Kutas, 1995). High negativities reflect violations in semantic relationships.

The ERP components give information regarding timing (latencies) and intensity (amplitude) of the stimulus evaluation, response selection, and lexical integration. Shorter latencies indicate faster information processing. Higher amplitudes indicate higher intensity of stimulus evaluation (Leiken, 2002). The incorporation of ERP components provides a novel methodology for addressing the debate as to the underlying deficits associated with dyslexia.

Previous ERP Studies on Dyslexia

Previous studies have shown that there are specific ERP components that seem to be most relevant for reading tasks and that the speed of processing measured by these components differs between readers with and without dyslexia. Breznitz and Meyler (2003) found that speed of processing (SOP) was slower for individuals with dyslexia than for control readers when processing low-probability targets in an oddball paradigm. In this task, participants were presented with low-probability and high-probability target stimuli, in an auditory and visual format. In the auditory format, the low-probability item was a stop consonant /t/, while the high probability item was /b/. In the visual task, two Hebrew letters were presented on the screen. The low probability item was the letter 'bet' and the high probability item was the letter 'chaf'. Participants were required to press a joystick button as quickly as possible when the low-probability stimuli were identified. This slower speed of processing by individuals with dyslexia was evident when the latencies of the P200 and the P300 components were examined. The P200 latencies occurred later among individuals with dyslexia during a visual linguistic task. The P300 latencies occurred later among individuals with dyslexia in both the visual and auditory linguistic tasks, and the auditory non-linguistic task. Because the readers with dyslexia only showed slower SOP on the low probability items, the data suggests that the readers with dyslexia may be impaired in their ability to transition between automatic and controlled processing. Responses to high probability stimuli may be more automatic, while low probability items may require greater processing resources. Slower processing was particularly apparent at the processing stages that were associated with working memory. This delay in processing for the individuals with dyslexia may affect how they integrate information.

Robichon, Besson, and Habib (2002) examined the integration of the meaning of words into a sentence context in individuals with dyslexia and control readers. Participants were presented with sentences that had either a congruous or an incongruous ending. The congruous ending was always the sentence's best completions, whereas the incongruous endings were best completions of other sentences but re-paired so that they were no longer appropriate with the sentence context. The results showed that participants with dyslexia elicited larger N400s than controls for both congruous and incongruous words. These results supported the hypothesis that individuals with dyslexia would have difficulty integrating the meaning of a word within the sentence context. The ERPs for congruous words also differed for individuals with dyslexia and control participants at around 600 ms, with individuals with dyslexia showing increased positivity. This P600 component often develops in response to syntactic violations or parsing problems. This increase in positivity for the participants with dyslexia may reflect difficulties in the parsing process.

Breznitz (2005) used ERP to examine speed of processing on Rapid Automatized Naming (RAN) tasks. It was hypothesized that individuals with dyslexia would show slower SOP on RAN tasks than control participants, and that this slower RAN processing would result from slower SOP at the perceptual and discrimination stages of processing. Two RAN subtests were used, one containing letters and one containing objects. The participants with dyslexia were slower when compared to the controls on each of the RAN tasks. Longer P200 and N200 latencies were seen on the RAN object task and longer N100-P200-N200 latencies were seen on the RAN letter task for the early identification and classification stage. There were longer P300 latencies on both RAN tasks for the immediate memory stage. The P300 was elicited at the same time for both the control participants and the participants with dyslexia; however, the P300 was significantly longer for the participants with dyslexia. It appears that for good readers, early activation in the input stage is crucial to be effective at a RAN task. For the participants with dyslexia, it appears that there is a deficit in this early activation and they therefore must rely on memory processes to find the right answer.

Leiken (2002) believed that individuals with dyslexia may have a weakness in syntactic processing and that this weakness could be measured using ERP. Participants were presented with 15 groups of sentences. Each group contained three sentences. Each sentence contained a subject, predicate, and direct object. For each group of sentences, the same word (noun) appeared in three different grammatical roles (subject, predicate, and direct object). The ERP components of interest were the N100/P200, P300, and P600. Across all grammatical roles of interest, the ERP latencies were significantly longer for the participants with dyslexia than for the controls. The participants with dyslexia also displayed higher P200 and P300 amplitudes for the predicate compared to the control participants. Higher amplitudes in ERP represent more effort in processing, while longer latencies reflect slower speed of processing. Therefore, the results seem to show that processing words by their grammatical function required more effort for the participants with dyslexia than for the control participants.

Subject and Object Relative Clauses

The complexity of a sentence is one factor that influences the demands of working memory in sentence processing (Matzke et al., 2002). In order to examine syntactic processing in the present study, two sentence types were examined. Sentences that make larger demands on working memory are those in which the syntactic structure has a center-embedded relative clause known as an object relative clause. An example of this sentence type would be *The senator who the reporter attacked admitted the serious error*. This type of clause is referred to as an object relative clause because the head noun acts as an object in the relative clause. Processing an object relative clause has been found to produce a greater working memory load beginning at the second article and at the main verb (i.e., admitted). Most English sentences are in the format of subject-verb-object, where the subject is usually the agent and the object is usually the patient. Therefore, when the initial noun is the object of the verb, people have difficulty processing the sentence and this becomes apparent at the second article where people are expecting a verb. At the main verb, the difficulty occurs because this is where people assign the initial noun to a different thematic role than at the initial relative clause verb. This difficulty is due to the fact that after encountering the first verb of the sentence, readers must determine which noun phrase is the subject of the sentence (King & Kutas, 1995). Participants who hear these types of sentences may make errors when matching verbs with their proper agents. These object relative sentences are difficult to interpret due to the difficulty in assigning different roles to a single syntactic constituent, the embedded clause interrupting the main clause, and determining the assignment of proper thematic roles to the two noun phrases. For object relative and subject relative sentences the initial noun is also the subject of the main verb of the sentence. Assigning the nouns to those two different roles is difficult.

The second type of sentence is known as a subject relative sentence, such as *The reporter who attacked the senator admitted the serious error.* This type of sentence is less difficult for participants to interpret. In subject relative sentences, the initial clauses follow the more frequent subject-verb-object structure. In this type of sentence the main clause is interrupted, but assigning roles to the words can be done one word at a time, and the constituents have parallel roles in the two clauses (King & Just, 1991). The head noun of the relative clause only needs to be remembered over a short distance, since the agent role can be assigned as soon as the verb is processed. The final reason why the subject relative sentences are easier to process is that the agent of the relative clause is the same as the agent of the main clause, and therefore there is no assignment of conflicting roles at the main verb (i.e., admitted).

King and Just (1991) found that differences in the effectiveness of working memory caused differences in processing of complex syntactic structures, such as subject relative clauses and object relative clauses. Participants were classified based on their reading span abilities into low memory capacity (low span) readers of high memory capacity (high span) readers. For the easier subject relative sentences, there was a 60 ms difference in reading times between the two reading span groups. Both groups showed similar increases in reading time at the end of the relative clause and at the main verb. The reading times for the object relative sentences also increased at the demanding areas (end of relative clause, and main verb), and this increase was much larger than that of the subject relative sentences. It was found that the low span participants had poorer comprehension even though they spent more time processing the difficult portions of object relative sentences. The increased memory load of the object relative sentences reduced comprehension for readers with high working memory capacity. This effect was not seen for the low span readers because even the less difficult subject relative sentences exceed their memory capacity, therefore differences between the two sentence types were not seen. These results suggest that readers with increased processing difficulties exhibit difficulties with complex sentences presented in written form due to their weak decoding skills and lower working memory capacity.

Previous ERP Studies and Complex Sentences

In a study examining good and poor comprehenders, King and Kutas (1995) examined slow cortical waves, LAN, and N400 while participants read subject relative and object relative sentences. The slow cortical wave results showed sustained frontal negativity occurring for the object relative clause in comparison to the subject relative clause. This positive wave for the subject relative sentences seems to reflect easier integration of this sentence type. This positivity was also more prominent for good comprehenders than for poor comprehenders. The greater negativity found for the object relative sentences is associated with the addition of a greater working memory load.

King and Kutas (1995) also examined the sentences in terms of single word analyses. When comparing the second article in the two sentence types, the second article in the object relative sentences elicited a greater N400 than the same article in the subject relative sentences. This N400 differed between good and poor comprehenders, with the poor comprehenders showing much more posterior negativity to the article when it occurred in the object relative sentences. This effect was absent in good comprehenders, suggesting the poor comprehenders were not expecting the object relative sentence structure to occur. Examination of the main verb showed a substantial LAN in the object relative sentences compared to the subject relative sentences, again suggesting that the working memory load was greater for the object relative sentences than for the subject relative sentences.

Müller, King, and Kutas (1997) examined the slow cortical waves in good comprehenders and poor comprehenders who were presented with subject relative and object relative sentences in an auditory format. Object relative clauses elicited greater negativity when compared to the subject relative clauses. This difference began in the relative clause region and become increasingly larger as the sentence progressed. The negativity seen in the subject relative clauses was shorter while the negativity for the object relative clauses was more prolonged. Also following the end of the relative clause, the subject relative clause showed a large positivity, whereas the ERP for the object relative clause remained negative. When comparing the two comprehension groups, the good comprehenders showed sustained negativity to object relative sentences at the end of the main clause, while poor comprehenders showed much less frontal negativity for the object relative sentences. These results were consistent with previous research using visual presentation of sentences (King & Kutas, 1995) that showed greater negativity for the object relative sentences for good versus poor readers.

Purpose

The purpose of the current study was to determine if syntactic processing in post-secondary students with dyslexia can be explained by the degree of phonological processing deficits. Understanding and processing sentences involves assigning words by their syntactic category, in order to determine their grammatical function (Leiken, 2002). When examining differences in syntactic processing, King and Just (1991) believed that readers try to interpret words as soon as they are encountered, known as the Immediacy of Interpretation Hypothesis. This strategy of processing entails all levels that are necessary for comprehension, such as encoding a word, accessing its meaning, associating with its referent, and determining semantic meaning and syntactic structure. In some cases, a word is presented that cannot be immediately interpreted; however an attempt at interpreting is still made. Processes such as recognizing words are most likely to become automatic in reading, and these processes often become automatic in the early stages of reading. Once processes are highly practiced, they may be executed in parallel. For example, once a word has been encoded, a reader may be simultaneously trying to determine its syntactic role, computing its referent, and referring its relation to other concepts in the sentence (Just & Carpenter, 1987). This lower-level process may be impaired in persons with dyslexia due to deficits in encoding or word reading. Lower-level processing deficits are expected to have an impact on higher levels required for integration of meaning and comprehension.

Studies involving ERP components and syntactic processing have been conducted comparing Hebrew speaking university students with dyslexia with age-matched good readers (Leiken, 2002). However, the comparisons have not been made with English speaking students. Hebrew and English differ greatly in terms of the order of words in a sentence. In English, the syntactic order of a sentence is usually fixed, and therefore provides crucial cues for processing a sentence. In Hebrew however, the syntactic order is not necessarily fixed, so word order is less important. What is important for syntactic information in Hebrew is the form of the word that is denoted by morphological markers (i.e. inflections on words that determine if they are noun, verb, etc.). In Hebrew most words can be broken down into two components: root and pattern. The root is the semantic core of the word. Verbs and other content words have different patterns. Verbs follow seven patterns, while nouns and adjectives can follow a dozen. Verb patterns indicate predicate-argument relations and noun patterns indicate lexical classes. The verb provides important information for sentence understanding. As a result, Hebrew is a highly inflected language, resulting in longer, morphologically dense lexical items. In contrast, English inflectional morphology is simple with few words being inflected, and words containing a maximum of one inflectional morpheme. By observing syntactic processing in English, we are able to examine a language in which word order determines syntax, and lexical items are less dense.

A large number of studies examining dyslexia and reading difficulties have been conducted with child participants (Bowey, 1986; Georgiewa et al., 2002; Wolf & Obregon, 1992; Lovett et al., 1994). Ongoing problems with reading and reading related activities into adulthood have an impact on daily life by causing embarrassment and anxiety when faced with tasks such as writing letters and filling out forms (Maughan, 1995). By studying university and college aged students with dyslexia we can examine the strategies used and the difficulties faced by students who are in post-secondary education. By increasing our knowledge of how individuals with dyslexia process information, we can provide services to those individuals to help them succeed in reading and writing tasks.

To measure syntactic processing in the present study, participants were presented with sentences that differ in their level of difficulty (i.e., subject relative sentences are less difficult than object relative sentences). ERP components were measured while the participants read these sentences and answered questions based on these sentences. The ERP components of interest are the left-lateralized anterior negativity component, slow cortical waves, and the N400. Similar to previous research examining good and poor readers (King & Kutas, 1995), it was hypothesized that when participants were presented with visual stimuli individuals with dyslexia would show no differences in negativity of the ERP for both the subject relative sentences and the object relative sentences, because their poor word reading skills would create a bottleneck and impair syntactic processing. Both sentences would be too complex for their weak phonological processing skills and differences based on the complexity of the syntactic structures would not be found.

It was expected that control participants would have a more sustained frontal negative slow waves for the visually presented object relative sentences compared to the subject relative sentences. When presented with auditory stimuli, it was hypothesized that individuals with dyslexia and control participants would show similar processing, with the object relative sentences being more difficult than the subject relative sentences. Therefore, it was expected that both control participants and individuals with dyslexia will exhibit greater slow cortical potentials to the object sentences, compared to the subject sentences. Overall, it was expected that LAN effects would be present at the main verb, slow wave differences would be seen across the sentences, and N400 effects would be present at the second article.

King and Kutas (1995) found that the point at which the relative clause subject is added to working memory is when the good comprehenders showed reliable ERP differences between the two sentence types: subject relative and object relative. This pattern may not be evident in the readers with dyslexia. A significant interaction was expected with the participants with dyslexia having relatively more difficulty with the visual condition. It is expected that the participants with dyslexia will not show differences in processing between the two sentence types when presented with the sentences in the visual condition because the working memory load will be too great, even for the less complex subject relative sentences.

In previous research examining syntactic processing using the object relative and subject relative sentence structures (King & Kutas, 1995; Muller, King, & Kutas 1997), the good and poor comprehenders were created using a median split of the participant's scores on the responses to questions about the target sentences. All of the participants were university students and no history of reading disabilities were reported. In contrast, our study examined students diagnosed with dyslexia in comparison with average readers matched on age, gender, and education level.

To measure phonological processing abilities participants were also presented with groups of pseudowords and had to decide which word sounds like a real English word. Participants were also given a pseudoword phoneme deletion task, in which they repeated a pseudoword, and then repeated the word omitting a predesignated part. It was expected that a relationship exists between phonological processing abilities and syntactic processing abilities, such that individuals who show poor phonological processing also show syntactic processing difficulties.

Verbal working memory was also assessed using a variation of a task by Daneman and Carpenter (Gottardo et al., 1996). Participants were asked to listen to a series of tape-recorded statements and to then answer true or false questions. After answering each question in a set, the participant was asked to recall the last word in each of the sentences in that set. It was expected that control participants would perform better on this task than the participants with dyslexia.

A series of correlational analyses were performed in order to examine the relationship between the behavioural measures, in particular verbal working memory and phonological processing, and the ERP measures.

We hypothesized that:

1) Participants with dyslexia will show an N400 at the second article for the object relative sentences. This is expected because it is believed that the participants with dyslexia will not expect the occurrence of the object relative sentence structure.

2) Slow cortical waves will show increased anterior negativity for the object relative sentences for control participants, regardless of presentation format. The same effect will be seen for participants with dyslexia when presented with sentences in an auditory format.

3) Normally achieving controls show greater LAN for sentences with objective relative clauses than subject relative clauses at the main verb regardless of presentation format.

4) Participants with dyslexia show patterns similar to controls on auditorily presented sentences, such that they show greater LAN for sentences with objective relative clauses at the main verb.

5) Control participants show significant correlations between electrode locations and the verbal working memory task for both the visual and auditory conditions. Participants with dyslexia show significant correlations between the electrode locations and reading accuracy and fluency measures for the visual condition, and significant correlations between electrode sites and the verbal working memory task for the auditory condition.

Method

Participants

Participants were university and college students, both male and female, recruited from Wilfrid Laurier University, Conestoga College, and The Learning Disabilities

Association of Kitchener-Waterloo (LDAKW). All participants were native English speakers between the ages of 17 and 38 (mean: 22.7). There were 17 males and 12 females. There were 15 participants with dyslexia and 14 normally reading participants. Four of the participants were left-handed. The university participants with dyslexia were informed of the experiment via recruitment posters placed around the university, which provided information about where they could contact the principal investigator if they were interested in participating. The college participants with dyslexia were informed of the experiment through the Disability Services Office at Conestoga College and were also given information about where they could contact the principal investigator if they were interested in participating. The participants from the LDAKW were recruited through flyers sent with the LDAKW monthly newsletter. The control participants were recruited through posters placed around Wilfrid Laurier University and Conestoga College. Normally achieving participants were recruited to resemble the participants with dyslexia on age, gender, education (college or university) and handedness. Matching occurred on a case-by-case basis. All participants were paid $40 for their participation.

Materials

A battery of standardized and experimental measures were administered in a behavioural and ERP format. In Session 1 of the study a series of behavioural baseline measures were administered to assess reading skill, vocabulary knowledge, working memory, and phonological sensitivity. These measures were used as control measures, as predictors of performance in the ERP task, and to confirm placement of the individuals in the dyslexic or the control groups. In session 2 of the study, ERPs were recorded while participants read and listened to sentences designed to assess syntactic processing ability.

Reading Related Measures.

Reading Accuracy. To measure reading accuracy, the Word Attack and Word Identification subtests of the Woodcock Reading Master Test Revised (Woodcock, 1991) were used. Word Attack involves reading non-words and Word Identification involves reading real words. For the Word Attack subtest, reported reliabilities from the norms for adults age 18 were 0.92 and for adults ages 30-39 reported reliabilities from the norms were 0.87. For the Word Identification subtest, reported reliabilities from the norms for adults age 18 were 0.89 and for adults ages 30-39 the reported reliabilities from the norms were 0.90. Although both word and pseudoword reading skills are weak in adults with dyslexia, a pseudoword reading deficit is a defining feature of phonological dyslexia (Olson, Wise, Conners, Rack, & Fulker, 1989).

Reading Fluency. To assess reading fluency the Sight Word Efficiency and Phonetic Decoding Efficiency subtests of the Test of Word Reading Efficiency (Torgesen, Wagner, & Rashotte, 1999) were used. These tasks required participants to read through a list of words as quickly as they can in 45 seconds. The Sight Word subtest uses real words and reported reliabilities from the norms for adults ages 18-24 were 0.89. The Phonetic Decoding subtest uses nonwords and reported reliabilities from the norms for adults ages 18-24 were 0.94.

Reading Comprehension. To measure reading comprehension the Nelson-Denny Reading Test (Brown, Nelson, & Denny, 1973) was used. Participants were required to read different passages and then answer multiple-choice questions regarding the passages. The reported reliabilities from the norms for grade 12 students were 0.74. To determine the reading rate of each participant the Nelson-Denny Reading Test was also used. Participants were instructed to begin reading the first passage of the test at their normal pace. After one minute, participants were instructed to circle the last word that they had read. Reading rate was then calculated as the number of words read per minute, based on the first minute of reading. The reported reliabilities from the norms for grade 12 students were 0.66.

Print Exposure. To measure the general amount of reading participants engage in, the Author Recognition Test and the Magazine Recognition Test were used (Stanovich & West, 1989). For the Author Recognition Test (ART) participants were given a checklist with the names of 40 popular authors/writers and 40 names of people who are not popular authors/writers. The participant was then asked to check off any authors who were known to them. Participants were discouraged from guessing by being told that not all the names on the list were real authors and incorrect answers would result in the loss of points on the task. Similarly, the Magazine Recognition Test (MRT) requires participants to check off the names of magazines that were known to them from a list of real titles and foils. Print exposure explains variance in reading skill in normally achieving children and adults as well as poor readers. Stanovich and Cunningham (1993) found that print exposure accounted for significant variance in general knowledge, even after variance associated with general cognitive ability was partialled out.

Phonological Awareness/Sensitivity. Two separate tasks were used to measure phonological sensitivity. The first task was a pseudoword phoneme deletion task. For example, a participant was asked to repeat a pseudoword such as ‘neep’. They were then asked to repeat the word without saying part of the word, such as say ‘neep’ but don’t say the ‘n’ part. The participant would then answer ‘eep’ (Olson et al., 1989). The second phonological awareness/sensitivity measure was a lexical decision task (Olson, Forsberg, Wise, & Rack, 1994). In this task the participant was visually presented with three nonsense words. None of the words were real words, however one sounded like a real English word. The participant had to choose which word sounds like a real English word. For example if the words were 'nite', 'kile', and 'hote', the correct response for the participant to choose would be 'nite', because it sounds like the real English word *night*. Participants were asked to respond as quickly and as accurately as possible.

Standardised Measures.

Vocabulary. To assess vocabulary the Peabody Picture Vocabulary Test III (Dunn & Dunn, 1997) was used. In this test participants were presented with four pictures and had to choose which picture corresponded to a given word. For example, if the word given was 'island', they were required to point to the picture of an 'island'. Reported reliabilities from the norms for adults are high (ages 17-18, $\alpha = 0.96$; ages 19-24, $\alpha = 0.94$; ages 25-30, $\alpha = 0.97$; and ages 31-40, $\alpha = 0.97$). Stanovich (1986) described the Matthew effect as a phenomenon that over time, better readers get even better and poorer readers become relatively poorer. Vocabulary adds to this effect because, while vocabulary does not predict the reading of single words out of context, it is important for reading text. Readers with a wider vocabulary are able to deduce meaning of new words encountered in text. Factors that may contribute to Matthew effects include differences in exposure to reading, differences in the ability to derive meaning, which is facilitated by knowledge base, and differences in the efficiency at which readers are able to learn new words from context.

Nonverbal Reasoning. To measure nonverbal reasoning, the Serial Reasoning and Spatial Visualization subtests of the Matrix Analogies Test (Naglieri, 1985) were used. For this task participants were shown a geometric picture or pattern and had to choose, from a selection of five or six pictures, which one best completed the picture or pattern. Reported reliabilities from the norms for adults age 17 were 0.94. This measure was used as a control variable to ensure that participants were broadly within the average range.

Working Memory. To measure working memory the Digits Backwards subtest of the Weschler Adult Intelligence Scale III (Weschler, 1997) was used. This task is an auditory task that requires participants to repeat a series of digits in reverse order to what they heard. Verbal working memory was also assessed using a variation of a task by Daneman and Carpenter (Gottardo et al., 1996). Participants were asked to listen to a series of tape-recorded statements and to then answer true or false questions. After answering each question in a set, the participant was asked to recall the last word in each of the sentences in that set. The number of sentences in a set increased with each set ranging from 2 to 5 items. The participants listened to a total of 42 statements and had to recall up to 42 words.

Syntactic Processing

In session 2 participants were presented with sentences with subject relative clauses and object relative clauses. For this task, ERPs were recorded while the participant was presented with the two types of sentences. Two lists were created for both visual and auditory conditions. In one list the same words were used in the subject relative sentences and in the other list the words were used in the object relative sentences. The first type of sentence was an object relative sentence, such as *The* *assistant who the senator disliked admitted the costly error.* The second type of sentence is known as a subject relative sentence, such as *The senator who disliked the assistant admitted the costly error.* Sentence regions are shown in Table 1. The participants then answered simple questions based on these sentences to ensure that they were attempting to process the sentences. Participants were presented with these tasks in a visual format, and then in an auditory format. The order of presentation (visual or auditory) was counterbalanced among participants.

Procedure

In Session 1 participants were administered the tasks that did not require the ERP measurements. These tasks measured vocabulary, reading accuracy, non-verbal reasoning, reading fluency, working memory, reading comprehension, phonological processing, and print exposure. Tasks were administered in a previously determined fixed order, alternating reading tasks with other tasks requiring auditory or nonverbal processing. Breaks were provided during this session to prevent feelings of fatigue and frustration in participants. Session 1 took approximately one and a half hours to complete.

On average Session 2 occurred one week after session 1. In session 2 participants completed the syntactic processing task. For this task, participants were fitted with a 64-channel ERP cap. The capping process took approximately one hour. Once participants were capped they were asked to sit in front of a computer monitor located in an electrically shielded chamber. Participants were asked to refrain from moving as much as possible and to remain quiet throughout the testing session. Participants were also instructed to avoid blinking or excessive eye movements as much as possible during the presentation of items on the computer screen. ERPs were recorded onto a computer from the electrodes positioned on the participant's scalp. Each set of stimuli (visual and auditory) contained 60 experimental sentences dispersed among 60 filler sentences. The filler sentences did not contain any object relative or subject relative sentences. Sentences were arranged so that there were no more than three consecutive experimental sentences or filler sentences. The experimental sentences contained equal numbers of subject relative sentences and object relative sentences. Session 2 took approximately two hours to complete.

For the visual syntactic processing task, sentences were presented to the participant on the screen one word at a time. Each word was presented on the screen for a duration of 300 ms with a stimulus onset asynchrocy of 500 ms. The final word of the sentence was then followed by a blank screen for 2000 ms. Following the presentation of each sentence, a comprehension question appeared on the screen. To answer these questions participants used a keypad and pressed the key that corresponded to their yes or no answer. While the question was on the screen participants were allowed to blink and move in order to make themselves more comfortable. The next sentence did not appear until the participant had answered the question.

For the auditory syntactic processing task, sentences were presented to participants through headphones. All 120 sentences were syntactically and semantically similar English sentences and were spoken by a female speaker with natural intonation and at a normal rate. The mean duration of the experimental stimuli averaged 4673 ms (range: 3680-5677 ms) for the SS sentences and 4794 ms (range: 3447-5997) for the SO sentences. Similar to the visual task, questions were then presented on the computer screen following each sentence, and participants were required to answer the question using the keypad. The order of the visual and auditory syntactic processing task was counter-balanced.

Results

Behavioural Baseline Measures

Means were calculated for each group (individuals with dyslexia and control readers) separately. Comparisons between the individuals with dyslexia and the control group were made on the behavioural measures tasks using One Way ANOVAs for each measure. Correlations and regressions were calculated to determine variables related to the reading measures. Hierarchical regression analyses were conducted to determine the variables that accounted for unique variance on the reading measures.

Means, standard deviations, F values and significance levels for the behavioural measures are displayed in Table 2. The control participants performed significantly better on all reading measures, print exposure, phonological awareness, vocabulary, and working memory. The participants with dyslexia had mean scores on the word reading measures that were greater than one standard deviation below the mean standard score for the test. The control participants had mean reading scores at or above the mean. Differences between participants with dyslexia and control participants were significant on all behavioural measures except for measures of nonverbal reasoning. These results show that our participants are representative of the groups for which they were selected.

The correlations among the behavioural measures for the two groups are displayed in Table 3. For the participants with dyslexia the standardized measures of reading ability were correlated with phonological awareness. For the control participants the standard scores for the standardized measures of reading ability (reading fluency, accuracy, and comprehension) were correlated with each other. The print exposure measures were correlated with the measures of reading ability. Vocabulary was correlated with the reading comprehension measures.

All of the regression analyses were conducted for the whole sample collapsed across groups due to the limited number of participants. In order to reduce the number of variables in the regression analyses, composite scores were calculated for two of the three constructs that were most likely related to reading performance based on the results of the correlational analyses and previous research. Within each construct the measures had the same number of items, and similar levels of difficulty, therefore composites were created by summing the scores across these measures. A composite score for phonological awareness was created by taking the sum of the raw scores from the pseudoword phoneme deletion task and the lexical decision task. A composite score for print exposure was created by taking the sum of the raw scores from the author recognition task and the magazine recognition task. A series of multiple regression analyses were then conducted using vocabulary, phonological awareness and print exposure as statistical predictors of reading accuracy, reading fluency, and reading comprehension.

For predicting reading accuracy, as measured by the Woodcock Word Attack subtest (Woodcock, 1991) the predictor variables vocabulary, phonological awareness, and print exposure accounted for 79% of the variance for the Word Attack standard score. Inspection of the β weights indicated that the phonological awareness measure seemed to make a major contribution to this model, as shown in Table 4. For predicting reading accuracy as measured by the Woodcock Word Identification subtest (Woodcock, 1991), the predictor variables accounted for 86% of the variance for the Word Identification standard score. Inspection of the β weights indicated that phonological awareness seemed to make a major contribution to this model, while print exposure made a moderate contribution to this model, as shown in Table 4.

For predicting reading fluency, as measured by the TOWRE Sight Word Efficiency subtest (Torgesen, Wagner, & Rashotte, 1999), the predictor variables accounted for 54% of the variance for the Sight Word Efficiency standard score. Inspection of the β weights indicated that phonological awareness seemed to make a major contribution to this model, as shown in Table 5. For predicting reading fluency, as measured by the TOWRE Phonetic Decoding subtest, the predictor variables accounted for 64% of the variance for the Phonetic Decoding standard score. Inspection of the β weights indicated that phonological awareness seemed to make a major contribution to this model, as shown in Table 5.

For predicting reading comprehension, as measured by the Nelson Denny Passage Comprehension subtest (Brown, Nelson, & Denny, 1973), the predictor variables accounted for 65% of the variance for the Passage Comprehension standard score. Inspection of the β weights indicated that vocabulary and print exposure both seemed to make a major contribution to this model, as shown in Table 6.

For predicting reading rate, as measured by the Nelson Denny Passage Comprehension reading time, the predictor variables accounted for 63% of the variance of the Passage Comprehension reading rate. Inspection of the β weights indicated that print exposure seemed to make a major contribution to this model, as shown in Table 6.

A series of hierarchical regression analyses were then conducted using the vocabulary score, the phonological awareness composite score, and the print exposure composite score to determine the unique variance that the variables accounted for when entered into the model. Given that the lexical decision task measured pseudoword decoding among other things, the hierarchical regression analyses were also conducted using the pseudoword phoneme deletion task as the phonological awareness measure. The results were similar to those regression analyses conducted with the phonological awareness composite score. Therefore, only those regression analyses using the phonological awareness composite score were reported. Based on the multiple regression analyses, phonological awareness and print exposure were each entered last for predicting reading accuracy, and reading fluency, while vocabulary was always entered first.

Vocabulary failed to account for significant unique variance in the reading accuracy and reading fluency measures once phonological awareness and print exposure were entered into the regression equation, therefore this variable is not reported as the last step. When predicting reading accuracy as measured by the Woodcock Word Attack subtest, print exposure failed to account for significant unique variance when entered last into the model. Phonological awareness accounted for 47% of unique variance when entered into the regression equation as the last step after the vocabulary measure and print exposure measure were entered into the regression equation (Table 7). When predicting reading accuracy as measured by the Woodcock Word Identification subtest, phonological awareness accounted for 41% of unique variance when entered last into the regression equation after the vocabulary measure and print exposure measure were entered into the regression equation (Table 7). Print exposure accounted for less unique variance, but still accounted for a statistically significant proportion of unique variance when entered last into the regression equation (6%) after the vocabulary measures and phonological awareness measure were entered into the regression equation (Table 7).

When predicting reading fluency, as measured by the TOWRE Sight Word Efficiency subtest, phonological awareness accounted for 14% of unique variance when entered last into the regression equation after the vocabulary measure and print exposure measure were entered into the regression equation (Table 8). When predicting reading fluency, as measured by the TOWRE Phonetic Decoding subtest, phonological awareness accounted for 21% of unique variance when entered last into the regression equation after the vocabulary measure and print exposure measure were entered into the regression equation (Table 8). Print exposure failed to account for significant unique variance for both reading fluency measures.

Based on the multiple regression analyses, vocabulary and print exposure were each entered last for predicting reading comprehension, while phonological awareness was always entered first. Although phonological awareness was statistically significant as the first step, it failed to account for significant unique variance in the reading comprehension measure and reading rate of connected text measure once vocabulary and print exposure were entered into the regression equation. When predicting reading comprehension, as measured by the Nelson Denny Passage Comprehension subtest, print exposure accounted for 12% of unique variance when entered last into the regression equation after phonological awareness and vocabulary had been entered into the regression equation (Table 9). Vocabulary accounted for 13% of unique variance when entered last into the regression equation after phonological awareness and print exposure had been entered into the regression equation (Table 9).

When predicting reading rate, as measured by the Nelson Denny Passage Comprehension reading time, print exposure accounted for 17% of unique variance when entered last into the regression equation after phonological awareness and vocabulary had been entered into the regression equation (Table 9). Vocabulary accounted for 6 % of unique variance when entered last into the regression equation after phonological awareness and print exposure had been entered into the regression equation, but failed to reach traditional levels of significance ($p = 0.051$).

ERP Measure

ERP Comprehension Questions

Scores on the comprehension questions were calculated and converted into percentages. Comparisons between the individuals with dyslexia and the control group and stimulus presentation format (visual or auditory) were made on the ERP comprehension questions using a Two-Way ANOVA. A significant main effect of reading condition was found, $F(1,44) = 10.01$, $p = .003$. The control participants (M = 94.0, SD = 4.39) had higher comprehension scores than the participants with dyslexia (M = 89.37, SD = 5.33). Although the participants with dyslexia did not perform as well as the control participants, with the exception of one outlier none of the participants scored below 80%. Therefore, it was not possible to divide the participants into good and poor comprehenders using a median value. There was no main effect of stimulus presentation format and there was no interaction of reading condition and stimulus presentation format. The questions were designed to ensure that participants were paying attention when reading or listening. It is likely that the questions were not difficult enough to be a true measure of comprehension and it is possible that the participants with dyslexia used a word matching strategy when answering the questions.

ERP Recording and Analysis.

The ERP waves were recorded from 64 electrodes distributed evenly over the scalp. Two electrodes were placed on the mastoids bilaterally. Electrodes were placed on the outer canthi and above and below the left eye in order to monitor eye blinks and movements. Electrode impedances were kept below 5 KΩ and were processed using a Neuroscan Synamps2 amplifier set at a bandpass of 0.05 – 100 Hz, and were digitized at 250 Hz.

Visual Slow Wave Analysis

The data were re-referenced offline to the average of the left and right mastoids. A low pass filter set at 30 Hz was used to remove high frequency noise. ERPs were computed in epochs that extended from 200 ms before the first word of the sentence to 500 ms after the final word's onset (i.e. –200 to 5000 ms). Trials that were contaminated by blinks, eye movements, and excessive muscle activity were rejected offline before averaging. For the visual syntactic processing task, 24% of trials were lost due to artifacts. Three participants with dyslexia and two control participants were not included in the ERP analysis due to too many artifacts in their ERP recordings.

The multiword ERPs were divided into non-overlapping single word regions, with a duration of 500 ms. The mean amplitudes of the ERP were measured for each of these regions. ANOVAs for each reading condition (individuals with dyslexia or controls) were then run with the within-participants variables of sentence type (SS or SO) and electrode site and the between-participants variable of stimuli list (one or two), resulting in a 2 x 2 x 2 ANOVA. The results for each region of interest are shown in Table 10 for the control readers and Table 11 for the individuals with dyslexia. All p values in this and subsequent analyses are reported after Epsilon correction (Huynh-Felt) for repeated measures with greater than one degree of freedom.

Control Participants. As illustrated in Table 10 there were no significant main effects of sentence type and no interactions between sentence type and electrode site on any of the word regions for the control participants. Although there were no significant differences, Figures 1 and 2 show that for the frontal electrodes there was a trend for the object relative sentences to show greater negativity than the subject relative sentences.

Participants With Dyslexia. As illustrated in Table 11 there were no significant main effects of sentence type and no interactions between sentence type and electrode site on any of the word regions for the participants with dyslexia. These results are also displayed in Figures 3 and 4.

Visual Single Word Analysis

The ERPs of the single words that formed the sentences were examined in order to observe any differences in processing on a shorter time scale. ERPs were computed in epochs that extended from 100 ms before each word to 1000 ms following the onset of the word. Separate ANOVAs were run on the mean amplitudes between 300 and 500 ms post-onset for the items being investigated. This region was chosen to examine differences in the LAN and the N400. The items of interest for the single word analysis were the second article in the relative clause, and the verb from the main verb phrase. For the single word analysis 18% of trials were lost due to artifacts. The results of this analysis are shown in Table 12 for the control participants and Table 14 for the participants with dyslexia.

Control Participants. As shown in Table 12 there was no significant main effect of sentence type or significant interaction between sentence type and electrode site for the second article of the relative clause for control participants. There was no significant main effect of sentence type for the main verb, although Figure 5 shows that there was pattern of greater LAN for the object relative sentences. There was a significant interaction of sentence type and electrode site for the main verb for the control participants. In order to examine the interaction between sentence type and electrode site, a 5-way ANOVA on the sentence region in which the interaction was significant was conducted. In addition to the sentence type and list factors previously used in the analysis, hemisphere (left vs. right), laterality (lateral vs. medial), and anteriority (prefrontal vs. frontal vs. parietal vs. occipital) were added. The results of this analysis are presented in Table 13. Only the results of interactions involving sentence type will be discussed, as they are the interactions that are of theoretical interest.

As shown in Table 13 there was a significant interaction of sentence type and hemisphere, $F(1,10) = 6.14$, $p = .033$. A comparison of the means indicated that there was greater negativity in the left hemisphere (i.e., LAN) for the object relative sentences than subject relative sentences, $F(1,10) = 17.011$, $p = .002$. There was a significant interaction of sentence type and anteriority, $F(3,10) = 9.47$, $p = .004$. A comparison of the means showed the LAN region was more negative for object relative sentences than subject relative sentences at the frontal sites, $F(1,10) = 14.84$, $p < .001$ and prefrontal sites, $F = 12.88$, $p = .001$.

Participants With Dyslexia. As shown in Table 14 there was a marginally significant main effect of sentence type for the second article of the relative clause for the participants with dyslexia, (p= .08). There was greater negativity (i.e., N400) for the object relative sentences than for the subject relative sentences. There was no significant interaction of sentence type and electrode site for the article of the relative clause. There were no significant main effects of sentence type or interactions between sentence type and electrode site for the verb of the main verb phrase for the participants with dyslexia, as shown in Figure 6.

Auditory Slow Wave Analysis

The data were re-referenced offline to the average of the left and right mastoids. A low pass filter set at 30 Hz was used to remove high frequency noise. ERPs were computed in epochs that extended from 200 ms before the first word of the sentence to approximately 300 ms after the final word's onset (i.e., –200 to 5000 ms). Trials that were contaminated by blinks, eye movements, and excessive muscle activity were rejected offline before averaging. For the auditory syntactic processing task 33% of trials were lost due to artifacts.

Similar to the visual slow wave analysis, the multiword ERPs were divided into single word regions. The borders for these regions were chosen to fall at what were the average boundaries for the regions being examined. ANOVAs were then run with the within-participants variables of sentence type (SS or SO) and electrode site and the between-participants variables of stimuli list (one or two) and reading condition (dyslexia or control). The results for each region of interest are shown in Table 15 for the control readers and Table 16 for the individuals with dyslexia.

Control Participants. As illustrated in Table 15 there were no significant main effects of sentence type and no interactions between sentence type and electrode site on any of the word regions for the control participants. While no significant main effects for sentence type were found, Figure 7 shows that towards the middle and end of the sentence, there is greater negativity for the for the object relative sentences.

Participants With Dyslexia. As illustrated in Table 16 there was a significant main effect of sentence type for the word 8 region (article of main verb phrase) for the participants with dyslexia. Greater negativity was found for the object relative sentence than for the subject relative sentence, as shown in Figure 8. There was a significant interaction between sentence type and electrode site for the word 4 region (SO second article vs. SS verb 1) for the participants with dyslexia.

Slow Wave Distribution Analysis

In order to examine the interaction between sentence type and electrode site for the participants with dyslexia, the same 5-way ANOVA as reported above was performed on the sentence region in which the interaction was significant (1500-2000 ms). The results of this analysis are shown in Table 17.

As shown in Table 17 the sentence type by anteriority interaction was significant. A comparison of the means shows that the object relative sentences were more negative than the subject relative sentences at the frontal $F(1,10) = 21.29, p < .001$ and prefrontal sites, $F(1,10) = 11.98, p = .002$. The subject relative sentences showed greater negativity than the object relative sentences at the parietal sites $F(1,10) = 5.74, p = .02$.

Auditory Single Word Analysis

The ERPs of the single words that formed the sentences were examined in order to determine any differences in processing on a shorter time scale. Separate ANOVAs were run on the mean amplitudes between 300 and 500 ms post-onset for the items being investigated. The items of interest for the single word analysis were the article in the relative clause, as well as the verb from the main verb phrase. For the single word analysis 37% of trials were lost due to artifacts. The results of this analysis are shown in Table 18 for the control participants and Table 20 for the participants with dyslexia.

Control Participants. As shown in Table 18 there was no significant main effect of sentence type or interaction of sentence type and electrode site for the article in the relative clause for the control participants. There was, however, a significant main effect of sentence type when the main verb region was examined. There was greater negativity (i.e., LAN) for the object relative sentence than for the subject relative sentence, as shown in Figure 9. There was also a marginal interaction of sentence type and electrode site for the main verb ($p = .07$). In order to examine this marginal interaction a 5-way distribution ANOVA reported above was performed on the mean amplitudes. Only the results of interactions involving sentence type will be discussed, as they are the interactions that are of theoretical interest.

As shown in Table 19 there was a significant interaction of sentence type and hemisphere, $F(1,10) = 7.94$, $p = .02$. A comparison of the means indicated that there was greater negativity in the right hemisphere for the object relative sentences than the subject relative sentences $F(1,10) = 40.00$, $p < .001$. There was also a significant interaction of sentence type and laterality. A comparison of the means indicated that there was greater negativity for object relative sentences than for subject relative sentences in both the lateral $F(1,10) = 6.10, p = .03$ and medial regions $F(1,10) = 32.62, p < .001$.

Participants With Dyslexia. As shown in Table 20 there was no significant main effect of sentence type or interaction of sentence type and electrode site for the article in the relative clause for the participants with dyslexia. While the differences were not significant, Figure 10 shows that there was greater N400 for the object relative sentences than the subject relative sentences. There was a significant main effect of sentence type for the main verb, with greater negativity (i.e. LAN) being seen for the object relative sentences, as shown in Figure 11. No significant interaction between sentence type and electrode site was found for the main verb.

Slow Wave Comparison Analysis

The multiword ERPs were divided into non-overlapping single word regions. The mean amplitudes of the ERP were measured for each of these regions. ANOVAs for each reading condition (dyslexia or control) were then run with the within-participants variables of sentence type (SS or SO) and electrode site and the between-participants variable of stimuli list (one or two) and stimulus condition (visual or auditory). The results for each region of interest are shown in Table 21 for the control readers and Table 22 for the individuals with dyslexia.

Control Participants. As shown in Table 21 there were significant main effects of stimuli condition for the regions measuring words one (article), three (article), four (object relative article vs. subject relative verb), and five (object relative noun vs. subject relative article). There were marginal main effects of stimuli condition for the regions measuring word two (noun) ($p = 0.065$) and word six (main verb) ($p = 0.052$). In each case greater negativity was seen for the auditory stimuli than for the visual stimuli. There were no significant interactions of stimulus condition and sentence type.

Participants With Dyslexia. As shown in Table 22 there were significant main effects of stimulus condition for the regions measuring words one, two, three, four, and five. There was a marginal main effect of stimuli condition for word six (p = .07). There were no significant interactions of stimuli condition and sentence type. In each case greater negativity was seen for the auditory stimuli than for the visual stimuli.

Single Word Comparison Analysis

The ERPs of the single words that formed the whole clauses were examined in order to observe any differences in processing on a shorter time scale. Separate ANOVAs were run on the mean amplitudes between 300 and 500 ms post-onset for the items being investigated. This region was chosen to examine differences in the LAN and the N400. The items of interest for the single word comparison analysis were the second article in the relative clause, and the verb from the main verb phrase. The results of this analysis are shown in Table 23 for the control participants and Table 24 for the participants with dyslexia.

Control Participants. As shown in Table 23 there was no significant main effect of stimulus condition nor was there a significant interaction of stimulus condition and sentence type for the article of the relative clause. There was no significant main effect of stimulus condition for the verb of the main verb phrase. There was no significant interaction of stimulus condition and sentence type. There was a significant three-way interaction of sentence type by electrode site by stimuli condition for the verb of the main verb phrase. In order to examine this interaction a 5-way distribution ANOVA reported above was performed on the mean amplitudes. Only the results of interactions involving sentence type will be discussed, as they are the interactions that are of theoretical interest.

As shown in Table 24 there was a significant interaction of sentence type x hemisphere x condition. Examination of the means indicated greater negativity for object relative sentences than for subject relative sentences. The auditory condition showed greater negativity for object relative sentences than for the visual condition. The left hemisphere showed greater negativity for object relative sentences than the right hemisphere.

Participants With Dyslexia. As shown in Table 25 there was no significant main effect of stimulus condition nor was there a significant interaction of stimulus condition and sentence type for the article of the relative clause. There was no significant main effect of stimulus condition for the verb of the main verb phrase. There was a marginal interaction of stimulus condition and sentence type ($p = .059$) for the verb of the main verb phrase. There was greater negativity for object relative sentences than for subject relative sentences for both the auditory and visual stimuli conditions. When examining the means of each sentence across the two stimuli conditions, there was greater negativity for the auditory object relative sentences than for the visual object relative sentences. There was greater negativity for the visual subject relative sentences than for the auditory subject relative sentences.

Correlational Analysis

Finally, a series of correlational analyses were performed in order to examine the relationship between the behavioural measures and the ERP measures. The ERP area of interest was the main verb from the slow wave analysis for both the control participants and the participants with dyslexia. This second article was not examined because there were not significant correlations among locations of electrodes and the behavioural measures for this region. Due to the large number of correlations conducted and the high chance of a Type I error occurring, correlations where a single electrode was related to behavioural measures were not included, as these significant correlations were likely due to chance. Therefore, only those correlations that occurred between behavioural measures and several electrodes in a particular location will be reported. Table 26 shows a summary of the correlation results.

Control Participants – Visual Stimuli. As shown in Table 27 for the main verb of the SS sentences slow wave analysis, there were significant correlations among the vocabulary measures and the frontal electrodes. There were also significant correlations among the verbal working memory measure and the frontal and central electrodes.

As shown in Table 28 for the main verb of the SO sentences slow wave analysis there were significant correlations among the vocabulary measure and the frontal and central electrodes. There were also significant correlations among the reading accuracy word identification measure and the central and parietal electrodes. There were significant correlations among the verbal working memory measure and frontal and central electrodes. Finally, there were significant correlations among the print exposure Magazine Recognition Test measure and the frontal electrodes.

Participants With Dyslexia – Visual Stimuli. As shown in Table 29 for the main verb of the SS sentences slow wave analysis there were significant correlations among the reading fluency Sight Word Efficiency and Phonetic Decoding measures and the frontal electrodes. In contrast to the controls, working memory measures were not significantly correlated with amplitudes.

As shown in Table 30 for the main verb of the SO sentences slow wave analysis there were significant correlations among the reading fluency Sight Word Efficiency and Phonetic Decoding measures and the central and parietal electrodes. None of the other behavioural variables were significantly related to processing the visual stimuli.

Control Participants – Auditory Stimuli. As shown in Table 31 for the main verb of the subject relative sentences slow wave analysis there were significant correlations among the vocabulary measure and the frontal and central electrodes. There were also significant correlations among the nonverbal reasoning Spatial Visualization measure and the frontal, central, and parietal electrodes.

As shown in Table 32 for the main verb of the object relative sentences slow wave analysis there were significant correlations among the vocabulary measure and the frontal electrodes. There were significant correlations among the verbal working measure and the frontal and central electrodes.

Participants With Dyslexia – Auditory Stimuli. As shown in Table 33 for the main verb of the subject relative sentences slow wave analysis there were significant correlations among the reading accuracy Word Attack measure and the central and parietal electrodes.

As shown in Table 34 for the main verb of the object relative sentences slow wave analysis there were significant correlations among the reading accuracy Word Attack measure and the frontal electrodes, as well as among the reading fluency Sight Word Efficiency and Phonetic Decoding measures and the frontal electrodes.

Summary of Main ERP Findings

As expected greater negativities were seen across the slow cortical waves for object relative sentences compared to subject relative sentences for the control participants. This was seen in both the visual and auditory presentation formats. The participants with dyslexia did not show any differences between sentence types when sentences were presented in a visual format, but differences similar to that of the control participants were seen when the sentences were presented in auditory format.

A LAN effect was seen for the main verb of the object relative sentences for control participants in both the visual and auditory formats. Participants with dyslexia also showed a LAN effect for object relative sentences when sentences were presented in an auditory format.

An N400 effect was seen for the second article of the object relative sentences for the participants with dyslexia, when sentences were presented in a visual format. The effect was not seen for control participants or during the auditory presentation for participants with dyslexia.

Correlations between the behavioural measures and the ERP measures at the main verb showed vocabulary and verbal working memory produced strong correlations with electrodes at the frontal and central regions of the head, for both subject relative and object relative sentences for the control participants. For the participants with dyslexia however, strong correlations were shown among the reading fluency measures.

Discussion

The purpose of the current study is to determine if a deficit in syntactic processing in post-secondary students with dyslexia can be explained by the specific deficits in phonological processing (Gottardo et al., 1996; Shankweiler et al., 1992) or general oral language processing deficits (Dickinson et al., 2003). Participants were administered a series of behavioural tests designed to measure reading variables such as reading accuracy, reading fluency, phonological awareness, print exposure, and reading comprehension. Participants were also tested on vocabulary, nonverbal reasoning, and working memory. ERPs were measured for auditory and visual syntactic processing tasks.

Individuals with dyslexia and control participants who were average readers differed significantly on all behavioural baseline measures including reading, vocabulary, and phonological processing. No differences were found for non-verbal reasoning. These results demonstrate that the participants were representative of the groups for which they were selected. It was expected that the adult participants with dyslexia would have normal intelligence levels. The findings are consistent with previous research that shows that reading deficits, but not reasoning deficits, differentiate persons with dyslexia from average readers. Bruck (1990) found that the IQ scores of children with dyslexia remained in the average range into adulthood, and that IQ did not decline as a result of deficits in literacy skills. Bruck (1990) also found that even for adults with dyslexia, who did not enter college programs and whose literacy levels were lower than college educated individuals with dyslexia, their scores on nonverbal and verbal intelligence tests were average or better. Lefly and Pennington (1991) found no differences in IQ scores between adult dyslexics, adult compensated dyslexics, and adult control readers. Siegel

(1988) studied reading disabled and non-disabled children ages 7-16, with varying IQ levels. She found that regardless of IQ level, reading disabled children still had significantly lower scores on tasks dealing with syntactic and morphological features of English, as well as standardized and experimental measures of reading and spelling, when compared to non-reading disabled children. IQ was not a significant predictor of outcome on reading, spelling, language, and memory tasks. The participants with dyslexia in our study showed deficits on phonological processing, despite average nonverbal reasoning skills.

In the current study, phonological awareness/sensitivity was found to be a unique statistical predictor of the reading ability measures, reading fluency and reading accuracy, in adults with and without dyslexia. These findings are consistent with previous research showing the strong relationship between phonological awareness and reading reported in the literature (Stanovich & Siegel, 1994). Lovett et al. (1994) found that phonological training in children improved phonological segmenting, blending, and letter-sound learning. Gottardo et al. (1997) also found that phonological processing ability was a significant predictor of reading in adults. Deficits in phonological processing make it very difficult for individuals with dyslexia to decode unfamiliar words or pseudowords. Being presented with unfamiliar words, individuals with dyslexia cannot rely on memory to identify new words and because of the difficulty with letter-sound associations they cannot construct sufficient orthographic information to allow words to be recognized on a direct visual basis (see Clark & Uhry, 1995 for a discussion of models of skilled reading).

Individuals with dyslexia often cannot form adequate self-teaching strategies for recognizing words (Bruck, 1990; Share, 1995). Phonological processing skills facilitate the rapid decoding of words. An inability to decode slows down reading times. This effect was observed in the differences between the reading fluency measures, which are timed speed- reading tasks. Ransby and Swanson (2003) also found that adults with childhood diagnoses of dyslexia had phonological awareness skills that were comparable to that of younger children when matched on word recognition performance. Bell and Perfetti (1994) found that skilled readers were as quick at decoding short pseudowords as low skilled readers were at decoding familiar English words. Low skilled readers were defined as low in reading ability, or as having problems related specifically to reading. Even at the college level, less skilled readers still performed poorly in identifying words quickly and accurately, when compared to more skilled readers.

Lefly and Pennington (1991) found that readers with dyslexia had significantly slower reading speed compared to control readers. Compensated dyslexics (i.e., individuals who had a history of reading problems as children but are not diagnosably dyslexic as adults) still had significantly slower reading speeds when compared to normal readers, despite having similar scores in terms of reading accuracy (Lefly & Pennington, 1991). It was suggested that these compensated dyslexics still have some phonological processing deficits that affect reading speed.

In the current study, print exposure was a unique predictor for the Word Identification subtest, which is the identification of real English words. While print exposure accounted for less unique variance when predicting reading accuracy as measured by the Woodcock Word Identification subtest, it still accounted for a statistically significant proportion of unique variance when vocabulary and phonological awareness were taken into account. An increase in exposure to print may increase the word base that individuals have committed to memory, therefore increasing the volume of words that they are able to identify. McBride-Chang, Manis, Seidenberg, Custodio, and Doi (1993) found that for children in grades 5 through 9 print exposure contributed unique variance for predicting word recognition, even after phonological and orthographic processing were taken into account. However, an increase in print exposure cannot help recognition of new or pseudowords if the word has not been committed to memory. Lovett et al. (1994) found that training children with dyslexia to identify words such as ‘pine’ and ‘shark’ did not help in their ability to decode similar words such as ‘fine’ or ‘bark’. Even though the new words were very similar in structure to the training words, the decoding skills are still needed to identify the new phonemes.

Print exposure and vocabulary were found to be unique statistical predictors of reading comprehension in adults with and without dyslexia. Print exposure was also found to be a unique statistical predictor of reading rate. Cunningham and Stanovich (1997) found that when the print exposure measures MRT and ART were administered to high school students, the scores predicted growth in reading comprehension during elementary school and beyond. In addition, print exposure may affect reading comprehension through increased familiarity with text discourse and text genre (Byrnes, 2001).

Vocabulary did account for 6% of unique variance when predicting reading rate, however this failed to reach traditional levels of statistical significance. Again, these findings are consistent with previous research. Ransby and Swanson (2003) found that listening comprehension, vocabulary, and general knowledge played an important role in predicting reading comprehension accuracy in adults with childhood diagnoses of dyslexia.

Phonological awareness accounted for less variance in reading comprehension accuracy and fluency. While it may be difficult to improve comprehension if deficits in decoding ability are present, general knowledge may be used to compensate for weak decoding skills (Clark & Uhry, 1995). Bruck (1990) found that some individuals with dyslexia had high comprehension scores despite having difficulties with decoding skills. It was proposed that word recognition skills may only play a part in the variance of reading comprehension performance if they are below a criterion level. Once a critical level in word recognition is met, variation in comprehension skills may be best accounted for by other skills such as vocabulary and general knowledge.

The second component of the study was the syntactic processing task involving the recording of participants' ERP waves while they performed the syntactic processing task. Measuring ERPs during a reading task allows the course of processing entire sentences to be examined and allows researchers to pinpoint where in a sentence processing begins to differ and the nature of that difference (Muller et al., 1997). By using ERP, researchers are not required to rely on self-report measures of what readers believe they are doing when reading sentences with different difficulty levels. To measure syntactic processing participants were presented with sentences that differed in their level of difficulty (i.e., subject relative sentences are less difficult than object relative sentences). The ERP components of interest were the left anterior negativity (LAN), the slow cortical waves, and the N400. Both slow wave analysis and single word analyses were conducted in order to give a complete understanding of sentence processing at multiple time scales (King & Kutas, 1995). The results of the slow wave analysis will be discussed first, followed by single word analysis, and finally the correlational analysis.

Slow Wave Analysis

For the slow wave analyses, sentences were divided into single word regions for each of the ten words in the two sentence types. The control participants and the participants with dyslexia did not show any significant main effects or significant interaction effects of sentence type by electrode site when the stimuli were presented to them visually. Although the sentence main effects did not reach significance, there was as expected, a trend for the control participants towards greater frontal negativity in processing the object relative sentences. This finding is similar to a study by King and Kutas (1995), who found that there was a slow positive shift for subject relative sentences relative to object relative sentences as the whole sentence progressed, particularly for good comprehenders. Good comprehenders also showed more anterior negativity for the object relative sentences in the main verb phrase region than the poor comprehenders.

As expected there were no significant sentence type effects for the participants with dyslexia in the visual condition. However, trends were found in which the subject relative sentences showed greater negativity than the object relative sentences for the participants with dyslexia. This result is contrary to results found in other studies with average readers. It is likely that the participants with dyslexia are unable to process the object relative sentences due to the memory load and their decoding deficits. Therefore, the task becomes one of decoding words. In contrast, the subject relative sentences appear more difficult because the participants with dyslexia are attempting to process and comprehend them. It is believed that the working memory load induced by having to read even the less difficult subject relative sentences, was too great for the participants with dyslexia, resulting in difficulties processing the complex sentences. Similarly, Petsche, Etlinger, and Filz (1993; as cited in Weiss & Mueller, 2003) found that there were fewer changes in EEG when sentences were not understood. It is also possible that the difficulty level of the task was too high for the participants with dyslexia and that the results we found are due to floor effects. The words in the sentences may have been too difficult for participants with dyslexia to decode. Also, since the words appeared at a fixed rate of presentation on the screen, participants with dyslexia may have not had enough time to decode the word. Had less difficult words been chosen, and a slower rate of word presentation been used, the participants with dyslexia may have performed similarly to the control participants.

A test of whether the participants with dyslexia were not able to understand these syntactically complex sentences is to administer similar sentences auditorily and then to compare the auditory and visual performance. Therefore, the auditory sentences were also divided into ten single word regions for each of the two sentence types. The control participants showed no significant main effects of sentence type and no interactions between sentence type and electrode site. Although the sentence type main effects were not significant, the pattern of processing showed the expected greater frontal negativity for the more complex object relative sentences. Müller et al. (1997) also found that object relative sentences elicited greater negativity compared to the subject relative sentences, for both good and poor comprehenders. For the participants with dyslexia there was a significant main effect of sentence type for the article of the main verb phrase with greater negativity for the object relative sentences. There was also a significant interaction between sentence type and electrode site for the second article of the object relative sentence versus the first verb of the subject relative sentence. King and Kutas (1995) found similar results for visually presented stimuli in that during the early relative clause the object relative sentences showed more frontal negativity as compared to the subject relative sentences.

The final step of the slow wave analysis compared the ERPs from visually presented sentences to the ERPs of auditorily presented sentences for both the control participants and the dyslexic participants. For both control participants and participants with dyslexia effects of stimulus condition were significant for the words in the pre-relative and relative clauses. In each case, the greater negativity was seen in ERPs of auditory presented stimuli than for sentences that were presented visually. For the participants with dyslexia the pattern of slow waves for the auditory presentation were fairly similar to the control participants, demonstrating that unlike the visual presentation they could actually comprehend the sentences.

Single Word Analysis

Article of relative clause

The first single word region of interest was the second article in the relative clause. This region was of interest because the presentation of the article in the two sentences is in different contexts. In the object relative sentences, a greater working memory load is induced due to the irregular sentence format of subject-object-verb, and this is not the case for the subject relative sentences. Therefore, an N400 response is expected for the more difficult object relative sentences. The article in the subject relative clause is more consistent with and thus expected for English word order constraints (subject-verb-object) than in the object relative clause. In the visual condition, control participants did not show any effects of sentence type or interactions of sentence type and electrode site. The participants with dyslexia showed marginal sentence type effects, with greater negativity occurring for object relative sentences than for subject relative sentences. King and Kutas (1995) found similar results when comparing good and poor comprehenders. For good comprehenders, an N400-like response was not present, but poor comprehenders did show this response for the object relative sentences. One possible explanation of a greater N400 effect for participants with dyslexia at the article of the relative clause is the unexpected occurrence of the object relative sentence structure. When presented with the stimuli in the auditory format, both the control participants and the participants with dyslexia showed no main effects of sentence type or interaction effects for the article of the relative clause. When comparing the two stimuli presentation conditions, both control participants and participants with dyslexia showed no significant differences between the stimuli presentation conditions. These results suggest that when processing the auditory versions of the sentences, both the participants with dyslexia and the control participants showed similar levels of difficulty understanding the relative clauses, with the object relative clause being more difficult than the subject relative clause.

Main verb

The visual presentation the verb of the main verb phrase did show an interaction of sentence type with electrode site for the control participants. Object relative sentences displayed greater LAN in the left hemisphere, and at the frontal and prefrontal sites. King and Kutas (1995) found similar results, with object relative sentences showing greater negativity over left anterior regions of the scalp than for the subject relative sentences. For the dyslexic participants, there was no effect of sentence type or interaction of sentence type and electrode site. This finding is in line with the hypothesis that no differences would be seen between the two sentence types for the dyslexic participants when presented with visual stimuli and is similar to the results of the analyses conducted with the slow wave and single word article data. The visual single word analyses for the control participants were consistent with the research by King and Kutas (1995). Subject relative sentences showed more positive shift over front electrode locations, while the object relative sentences displayed greater negativity at the front electrode sites. Matzke et al. (2002) examined ERPs of normal readers who were presented with German sentences that deviated from standard word order (subject-verb-object). These sentences did not follow standard rules, but were still grammatically correct. It was expected that there would be an increased LAN for those sentences that deviated from the standard word order. As expected, there was an increased LAN for those deviation sentences, indicating that the readers must maintain more information in working memory, up to where the verb and noun phrase have been encountered. Object first sentences were more difficult to process than the regular subject first sentences.

As expected, the control participants and the participants with dyslexia displayed similar ERP results when the sentences were presented to them in an auditory format. There were no significant main effects of sentence type or interactions of sentence type and electrode site for the second article of the relative clause. Both control participants and participants with dyslexia had main effects for sentence type at the main verb, with greater negativity found for the object relative sentences.

The final step of the single word analysis compared the ERPs from visually presented sentences to the ERPs of auditorily presented sentences for both the control participants and the dyslexic participants. It was expected that control participants would not differ significantly in their ERPs when the sentences were presented in different formats and this was seen in the results. There were no significant effects of stimulus presentation for the control participants for both the second article in the relative clause and the main verb. The participants with dyslexia did not show any main effects of stimulus condition or interaction effects for the article, but a marginal interaction of stimulus condition and sentence type was found for the main verb. Greater negativity occurred for the auditory object relative sentences than the visual object relative sentences. Greater negativity occurred for the visual subject relative sentences than for the auditory subject relative sentences. Together, these results show that the control participants had similar patterns of processing for visual and auditory stimuli. In contrast, the participants with dyslexia did not differentiate sentence types for the written stimuli due to their difficulty in decoding the words. However, participants with dyslexia were able to process the auditory versions of the sentences and discern their different levels of difficulty.

Correlational Analyses

The final step of the analysis involved examining the correlations between the behavioural measures and the ERP measures, in order to see if a relationship existed between syntactic processing abilities and phonological processing. The results from the behavioural measures have shown that individuals' phonological awareness/sensitivity was found to be a unique statistical predictor of the reading ability measures, reading fluency and reading accuracy for both control participants and participants with dyslexia. It was also shown that control participants performed better than participants with dyslexia on all the behavioural measures except those measuring nonverbal reasoning, where there was no difference between the groups. The most significant correlations between the behavioural measures and the ERP electrode sites occurred during the main verb word region in the slow wave analysis. This region was predicted to require greater processing (King & Just, 1991). The results of the slow wave and single word visual analysis are supported by reading time study results by King and Just (1991). Reading times were longer for the more complex object relative sentences. When reading subject relative sentences, both comprehension level groups showed an increase in reading times at the main verb. Reading times also increased at this region for the object relative sentences, however this increase was much larger. The high span readers also showed increased comprehension over the low span readers, particularly for the main verb region.

It is important to remember that difficulties may arise in the processing of object relative sentences due to an increase in working memory load. Readers must determine which noun is the subject of the sentence and errors may be made when matching verbs with their proper agents (King & Kutas, 1995). Subject relative sentences have less working memory load because the agent of the relative clause is also the agent of the main verb phrase, therefore eliminating the conflicting role assignment that occurs in the object relative sentences (King & Just, 1991).

As expected, in the visual condition for the control participants, vocabulary and verbal working memory produced strong correlations with electrodes at the frontal and central regions of the head, for both subject relative and object relative sentences. The object relative sentences also showed strong correlations with the reading accuracy word identification measures at the central and parietal electrodes. For the participants with dyslexia however, strong correlations were shown among the reading fluency measures only, for both sentence types, with the subject relative sentences correlating with the electrodes in the frontal region of the head, while the object relative sentences correlated with the electrodes in the central and parietal regions of the head. It appears that by the main verb, participants with dyslexia are just working on trying to decode and read the sentences, and are unable to comprehend what they are reading, particularly for the object relative sentences. The control participants, on the other hand, are using their verbal working memory skills to process and comprehend what they are reading. These results again, are in line with the belief that readers with processing difficulties will have trouble with complex sentences due to a bottle-neck cause by their weak decoding skills (Shankweiler et al., 1992).

Control participants in the auditory condition again showed strong correlations among vocabulary and the electrodes in the frontal region for both subject relative and object relative sentences. Strong correlations were seen between the frontal, central, and parietal electrodes and one of the nonverbal reasoning measures for the subject relative sentences. Verbal working memory again showed strong correlations with the frontal and central electrodes for the object relative sentences. It appears that working memory skills are again playing an important role in the processing object relative sentences, even in the auditory format, for control participants. For the participants with dyslexia, the reading accuracy and reading fluency measures were strongly correlated with the front electrodes. It appears that even for auditory processing, skills related to reading decoding and fluency such as possibly phonological processing play an important role.

Limitations

It is important to address several limitations of the present study. The small sample size may have affected the significance levels of the slow wave analysis. It is possible that with a larger sample, more significant results could be found. Also, for the auditory analyses, many trials had to be rejected because of blinking or movement causing artifacts. This was the case particularly for the participants with dyslexia. For both participant groups, refraining from blinking and moving seemed to be more difficult during the auditory presentation task. A possible solution to this would be to include a fixation point to remain on screen while the sentences were playing, therefore giving participants something to focus on other than a blank screen.

Conclusion

These results address the debate as to whether dyslexia is related to a specific deficit in phonological processing or a general linguistic deficit by using ERP data to compare processing in participants with dyslexia and control participants. The behavioural data show that our groups were internally consistent and replicate relationships between reading, phonological processing, vocabulary and print exposure found in the literature (Gottardo et al., 1996; Stanovich & Cunningham, 1993). The ERP data allow us to glimpse at the level of difficulty that participants with dyslexia have when processing two complex syntactic structures presented in auditory and written formats. The participants with dyslexia showed difficulty in comprehending the written versions of the syntactically complex sentences while they were able to differentiate these syntactic structures when they were presented auditorily. The control participants showed similar patterns across the auditory and written versions of the task and showed performance consistent with previous studies conducted with university students. Correlational analyses suggest that the bottleneck for control participants exists at the level of working memory while participants with dyslexia were limited by their phonological processing skills in general and specifically their reading skills for the written syntactic processing tasks. Our results support the phonological processing deficit hypothesis (Stanovich & Siegel, 1994) in explaining the processing weaknesses of participants with dyslexia in contrast to a general linguistic deficit as being the underlying difficulty in persons with dyslexia (Dickinson et al., 2003).

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Table 1

Definition of Sentence Regions of SO and SS sentences.

		Sentence Regions	
Sentence Type	*Pre Relative Clause*	*Relative Clause*	*Main Verb Phrase*
SS	The senator who	disliked the assistant	admitted the costly error
SO	The assistant who	the senator disliked	admitted the costly error

Table 2

Means, Standard Deviations, and F-values for Behavioural Measures Comparing Participants with Dyslexia to Normally Achieving Control Participants.

	Reading Condition				
	Dyslexic		Normal		
Measure	M	SD	M	SD	F
	Reading Accuracy				
Word Attack raw score	27.00	10.33	41.86	1.51	28.32***
Word Attack standard score	85.27	18.56	119.50	6.79	42.27***
Word ID raw score	81.13	15.68	102.79	2.60	25.98***
Word ID standard score	79.53	22.85	116.57	8.44	32.57***
	Reading Fluency				
Sight Word Efficiency raw score	74.20	19.01	99.07	8.26	20.34***
Sight Word Efficiency standard score	80.47	15.16	106.00	10.98	26.64***
Phonemic Decoding raw score	34.87	13.24	58.50	5.47	38.38***
Phonemic Decoding standard score	80.60	13.35	110.21	9.89	45.51***
	Reading Comprehension				
Passage Comprehension raw score	29.87	15.74	47.57	10.32	12.63**
Passage Comprehension standard score	47.80	13.56	62.64	7.49	13.04**
Reading Rate (words/min)	163.33	83.70	270.79	66.50	14.51**
	Print Exposure				
Author Recognition	6.60	6.30	16.29	6.40	16.85***
Magazine Recognition	18.07	12.52	28.57	7.74	7.26*
	Phonological Awareness/Sensitivity				

Pseudoword Phoneme Deletion raw score	21.47	6.66	28.21	1.53	13.65**

Lexical Decision raw score	22.27	6.05	26.36	2.68	5.40*
Lexical Decision average reaction time (ms)	7086.67	4155.54	3558.01	1475.68	7.42*
			Vocabulary		
PPVT raw score	177.47	14.98	191.71	6.63	10.60**
PPVT standard score	105.00	19.20	120.00	12.94	6.00*
			Nonverbal Reasoning		
Serial Reasoning raw score	14.47	2.17	14.93	1.49	0.44
Serial Reasoning standard score	9.67	2.55	10.21	2.16	0.39
Spatial Visualization raw score	10.33	4.76	12.14	3.01	1.47
Spatial Visualization standard score	8.93	3.22	9.71	2.09	0.59
			Working Memory		
Digits Backwards raw score	6.53	2.03	8.79	2.26	7.99**
Verbal Working Memory words recalled	25.60	6.94	36.36	4.25	24.90***
Verbal Working Memory questions correct	31.00	7.43	39.50	3.96	14.48**

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table 3.

Intercorrelations Among the Behavioural Variables for Individuals with Dyslexia and Control Participants.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Reading Accuracy																	
1. Word Attack st. score	-	0.59*	0.63*	0.46	0.51	0.55*	0.78*	0.55*	0.28	0.27	-0.21	0.69*	0.46	0.15	0.02	-0.17	-0.02
2. Word ID st. score	0.88**	-	0.62*	0.71**	0.10	0.48	0.64*	0.55*	0.26	0.01	-0.51	0.39	-0.03	-0.02	0.09	0.17	0.24
Reading Fluency																	
3. Sight Word Efficiency st. score	0.38	0.46	-	0.78*	0.45	0.68**	0.64*	0.53	0.23	0.29	-0.47	0.47	-0.04	0.17	0.12	-0.04	0.08
4. Phonemic Decoding st. score	0.60*	0.63*	0.90**	-	0.50	0.61*	0.50	0.75**	0.44	0.31	-0.64*	0.35	-0.02	-0.14	0.45	0.25	0.17
Reading Comprehension																	
5. Passage Comprehension st. score	0.04	0.30	0.41	0.47	-	0.57*	0.38	0.53	0.40	0.55*	-0.26	0.68**	0.43	0.31	0.43	0.15	0.16
6. Reading Rate	0.02	0.30	0.68*	0.56*	0.66*	-	0.77**	0.56*	0.23	0.32	-0.39	0.74**	-0.22	0.23	0.28	0.20	0.44
Print Exposure																	
7. Magazine Recognition	0.01	0.27	-0.01	-0.05	0.45	0.40	-	0.70**	0.30	0.12	-0.29	0.76**	0.03	0.15	0.07	0.14	0.30
8. Author Recognition	0.13	0.44	0.39	0.35	0.77**	0.64*	0.60*	-	0.42	0.34	-0.27	0.52	0.24	-0.08	0.49	0.14	0.30
Phonological Awareness/ Sensitivity																	
9. Pseudoword Phoneme Deletion	0.92**	0.86**	0.38**	0.59*	0.07	0.12	-0.06	0.12	-	0.36	-0.54*	0.27	0.24	-0.03	0.44	0.20	-0.07
10. Lexical Decision score	0.78**	0.85**	0.47**	0.57*	0.06	0.25	0.17	0.35	0.78*	-	0.26	0.21	0.31	0.35	0.33	0.08	-0.01
11. Lexical Decision Reaction Time	0.15	0.09	-0.44	-0.41	-0.76**	-0.45	-0.27	-0.37	0.16	0.23	-	-0.20	0.23	0.32	-0.40	-0.08	-0.07
Vocabulary																	
12. PPVT st. score	0.08	0.35	0.30	0.44	0.62*	0.44	0.12	0.56*	0.15	0.27	-0.17	-	0.32	0.56*	-0.02	0.25	0.42
Nonverbal Reasoning																	
13. Serial Reasoning st. score	0.27	0.21	-0.26	-0.14	-0.35	-0.30	0.25	-0.09	0.14	0.48	0.35	-0.18	-	0.27	-0.01	0.07	-0.11
14. Spatial Visualization st. score	0.50	0.48	0.20	0.34	-0.16	-0.03	-0.40	-0.03	0.59*	0.68**	0.41	0.32	0.37	-	-0.39	0.12	0.23
Working Memory																	
15. Digits Backwards	0.63	0.68**	0.46	0.50	-0.02	0.22	0.17	0.11	0.72**	0.72**	0.07	-0.02	0.20	0.24	-	0.40	0.19
16. Verbal Working memory recall	0.24	0.05	-0.32	-0.18	-0.27	-0.48	-0.12	-0.06	0.15	0.19	0.43	-0.01	0.26	0.12	0.03	-	0.84*
17. Verbal working memory correct	0.09	-0.05	-0.18	-0.12	-0.14	-0.33	-0.07	0.01	-0.02	0.13	0.23	-0.03	0.20	0.03	-0.02	0.92**	-

*p < 0.05; **p < 0.01 Note: above diagonal – controls participants, below diagonal – participants with dyslexia

Table 4

Multiple Regression Analyses Predicting Reading Accuracy using Vocabulary, Phonological Awareness, and Print Exposure Measures for All Participants (N = 29).

Model	Total R^2	β	t value
Word Attack Standard Score	0.79		
1. Vocabulary		0.02	0.16
2. Phonological Awareness		0.77	7.51***
3. Print Exposure		0.21	1.83
Word ID Standard Score	0.86		
1. Vocabulary		0.07	0.75
2. Phonological Awareness		0.72	8.44***
3. Print Exposure		0.31	3.31**

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table 5

Multiple Regression Analyses Predicting Reading Fluency using Vocabulary, Phonological Awareness, and Print Exposure Measures for All Participants (N = 29).

Model	Total R^2	β	t value
Sight Word Efficiency Standard Score	0.54		
1. Vocabulary		0.19	1.14
2. Phonological Awareness		0.42	2.73*
3. Print Exposure		0.30	1.78
Phonetic Decoding Standard Score	0.64		
1. Vocabulary		0.22	1.46
2. Phonological Awareness		0.51	3.79**
3. Print Exposure		0.26	1.76

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table 6

Multiple Regression Analyses Predicting Reading Comprehension and Reading Rate using Vocabulary, Phonological Awareness, and Print Exposure Measures for All Participants (N = 29).

Model	Total R^2	β	t value
Passage Comprehension Standard Score	0.65		
1. Vocabulary		0.45	3.12**
2. Phonological Awareness		0.34	0.28
3. Print Exposure		0.44	3.03**
Reading Rate	0.63		
1. Vocabulary		0.31	2.05
2. Phonological Awareness		0.12	0.88
3. Print Exposure		0.52	3.41**

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table 7

Hierarchical Regression Analysis Predicting Reading Accuracy using Vocabulary, Phonological Awareness, and Print Exposure Measures (N = 29).

Step Variable	Mult R	Mult R^2	ΔR^2	F change
Word Attack Standard Score				
1. Vocabulary	0.44	0.19	0.19	6.47*
2. Phonological Awareness	0.87	0.76	0.57	61.87***
3. Print Exposure	0.89	0.79	0.03	3.35
2. Print Exposure	0.56	0.32	0.13	4.63*
3. Phonological Awareness	0.89	0.79	0.47	56.34***
Word ID Standard Score				
1. Vocabulary	0.52	0.28	0.28	10.27**
2. Phonological Awareness	0.69	0.80	0.52	65.99***
3. Print Exposure	0.93	0.86	0.06	10.93**
2. Print Exposure	0.67	0.45	0.17	8.37**
3. Phonological Awareness	0.93	0.86	0.41	71.15***

* $p < 0.05$; ** $p < 0.01$, *** $p < 0.001$

Table 8

Hierarchical Regression Analysis Predicting Reading Fluency using Vocabulary, Phonological Awareness, and Print Exposure Measures (N = 29).

Step Variable	Mult R	Mult R^2	ΔR^2	F ratio
Sight Word Efficiency				
1. Vocabulary	0.53	0.28	0.28	10.34**
2. Phonological Awareness	0.69	0.48	0.20	9.89**
3. Print Exposure	0.73	0.54	0.06	3.19
2. Print Exposure	0.63	0.40	0.12	5.16*
3. Phonological Awareness	0.73	0.54	0.14	7.47*
Phonetic Decoding				
1. Vocabulary	0.57	0.32	0.32	12.68**
2. Phonological Awareness	0.77	0.59	0.27	17.56***
3. Print Exposure	0.80	0.64	0.05	3.11
2. Print Exposure	0.66	0.43	0.11	5.13*
3. Phonological Awareness	0.80	0.64	0.21	14.34***

* $p < 0.05$; ** $p < 0.01$, *** $p < 0.001$

Table 9

Hierarchical Regression Analysis Predicting Reading Comprehension and Reading Rate using Vocabulary, Phonological Awareness, and Print Exposure Measures (N = 29).

Step Variable	Mult R	Mult R^2	ΔR^2	F ratio
Reading Comprehension				
1. Phonological Awareness	0.40	0.16	0.16	5.05*
2. Vocabulary	0.73	0.53	0.37	20.30***
3. Print Exposure	0.81	0.65	0.12	9.18**
2. Print Exposure	0.72	0.52	0.36	19.53***
3. Vocabulary	0.81	0.65	0.13	9.76**
Reading Rate				
1. Phonological Awareness	0.45	0.20	0.20	6.93*
2. Vocabulary	0.68	0.46	0.26	12.23**
3. Print Exposure	0.79	0.63	0.17	11.61**
2. Print Exposure	0.75	0.57	0.37	21.93***
3. Vocabulary	0.79	0.63	0.06	4.20

* $p < 0.05$; ** $p < 0.01$, *** $p < 0.001$

Table 10

Control Participants Grand Average (n=12) visual slow wave results for each of the 10 word regions (500 ms epochs) in the sentences.

	Sentence Type	Sentence Type x Electrode Site
Word		
1st	F < 1	F < 1
2nd	F < 1	F < 1
3rd	F < 1	F < 1
4th	F (1, 10) = 2.91	F (61, 610) = 1.21
5th	F (1, 10) = 1.27	F (61, 610) = 1.28
6th	F < 1	F (61. 610) = 1.43
7th	F < 1	F (61, 610) = 1.10
8th	F (1, 10) = 2.41	F < 1
9th	F < 1	F < 1
10th	F < 1	F < 1

Table 11

Dyslexic Participants Grand Average (n=12) visual slow wave results for each of the 10 word regions (500 ms epochs) in the sentences.

	Sentence Type	Sentence Type x Electrode Site
Word		
1st	F < 1	F < 1
2nd	F < 1	F (61,610) = 1.64
3rd	F < 1	F (61,610) = 1.05
4th	F < 1	F < 1
5th	F < 1	F < 1
6th	F < 1	F (61,610) = 1.18
7th	F < 1	F < 1
8th	F < 1	F < 1
9th	F < 1	F < 1
10th	F < 1	F < 1

Table 12

Control Participants Grand Average LAN/N400 (300-500 ms) results for visual stimuli article and main verb.

	Sentence Type	Sentence Type x Electrode
Word		
Article	$F < 1$	$F(61,610) = 1.67$
Main verb	$F < 1$	$F(61,610) = 6.22$ ***

* $p < .05$

** $p < .01$

*** $p < .001$

Table 13

Control Participants topographic distribution results for the visual single word averages at the main verb region.

	Main Verb Region
S x A	F (3,30) = 9.47 **
S x L	F < 1
S x H	F (1,10) = 6.14 *
S x A x L	F < 1
S x A x H	F < 1
S x L x H	F (1,10) = 4.41
S x A x L x H	F < 1

* p < .05

** p < .01

*** p < .001

Table 14

Dyslexic Participants Grand Average LAN/N400 (300-500 ms) results for visual stimuli article and main verb.

	Sentence Type	Sentence Type x Electrode
Word		
Article	F (1,10) = 3.77	F (61,610) = 2.24
Main verb	F (1,10) = 1.34	F (61,610) = 1.34

* p < .05

** p < .01

*** p < .001

Table 15

Control Participants Grand Average (n=12) auditory slow wave results for each of the 10 word regions in the sentences.

	Sentence Type	Sentence Type x Electrode Site
Word		
1st	F < 1	F < 1
2nd	F (1,10) = 3.78	F < 1
3rd	F (1,10) = 1.32	F < 1
4th	F (1,10) = 1.52	F (61,610) = 1.62
5th	F (1,10) = 1.79	F < 1
6th	F (1,10) = 2.08	F < 1
7th	F (1,10) = 1.10	F < 1
8th	F (1,10) = 1.58	F (61,610) = 1.01
9th	F (1,10) = 1.22	F (61,610) = 1.16
10th	F < 1	F < 1

Table 16

Dyslexic Participants Grand Average (n=12) auditory slow wave results for each of the 10 word regions in the sentences.

	Sentence Type	Sentence Type x Electrode Site
Word		
1st	F (1,10) = 1.02	F (61,610) = 2.23
2nd	F (1,10) = 3.65	F (61,610) = 1.03
3rd	F < 1	F (61,610) = 1.18
4th	F < 1	F (61,610) = 4.22 **
5th	F (1,10) = 1.69	F (61,610) = 2.24
6th	F (1,10) = 1.51	F < 1
7th	F (1,10) = 2.63	F (61,610) = 1.03
8th	F (1,10) = 5.34 *	F < 1
9th	F (1,10) = 3.62	F (61,610) = 1.33
10th	F (1,10) = 3.35	F < 1

* $p < .05$
** $p < .01$

Table 17

Dyslexic Participants topographic distribution results for the auditory slow wave averages at the fourth word region.

	Main Verb Region
S x A	F (3,30) = 11.54 **
S x L	F < 1
S x H	F (1,10) = 2.26
S x A x L	F < 1
S x A x H	F < 1
S x L x H	F < 1
S x A x L x H	F < 1

* p < .05

** p < .01

*** p < .001

Table 18

Control Participants Grand Average LAN/N400 (300-500 ms) results for auditory stimuli article and main verb.

	Sentence Type	Sentence Type x Electrode
Word		
Article	F < 1	F < 1
Main verb	F (1,10) = 8.29 *	F (61,610) = 2.14

* p < .05

** p < .01

*** p < .001

Table 19

Control Participants topographic distribution results for the auditory single word averages at the main verb region.

	Main Verb Region
S x A	F < 1
S x L	F (1,10) = 5.25 *
S x H	F (1,10) = 7.94 *
S x A x L	F (3,30) = 2.22
S x A x H	F < 1
S x L x H	F (1,10) = 1.71
S x A x L x H	F < 1

* p < .05

** p < .01

*** p < .001

Table 20

Dyslexic Participants Grand Average LAN/N400 (300-500 ms) results for auditory stimuli article and main verb.

	Sentence Type	Sentence Type x Electrode
Word		
Article	F < 1	F < 1
Main verb	F (1,10) = 9.52 *	F (61,610) = 1.70

* p < .05

** p < .01

*** p < .001

Table 21

Control Participants Grand Average (n=24) comparison slow wave results for each of the 10 word regions in the sentences.

	Stimuli Condition	Stimuli Condition x Sentence Type
Word		
1st	$F(1,20) = 4.95$ *	$F < 1$
2nd	$F(1,20) = 3.80$	$F(1,20) = 2.35$
3rd	$F(1,20) = 6.69$ *	$F < 1$
4th	$F(1,20) = 5.04$ *	$F < 1$
5th	$F(1,20) = 4.50$ *	$F < 1$
6th	$F(1,20) = 4.25$	$F(1,20) = 2.68$
7th	$F(1,20) = 2.84$	$F < 1$
8th	$F(1,20) = 1.80$	$F < 1$
9th	$F(1,20) = 1.23$	$F < 1$
10th	$F(1,20) = 1.57$	$F < 1$

* $p < .05$

** $p < .01$

*** $p < .001$

Table 22

Dyslexic Participants Grand Average (n=24) comparison slow wave results for each of the 10 word regions in the sentences.

	Stimuli Condition	Sentence Type x Stimuli Condition
Word		
1st	F (1,20) = 29.56 ***	F < 1
2nd	F (1,20) = 12.69 **	F < 1
3rd	F (1,20) = 12.75 **	F < 1
4th	F (1,20) = 9.83 **	F < 1
5th	F (1,20) = 6.35 *	F < 1
6th	F (1,20) = 3.65	F (1,20) = 1.28
7th	F (1,20) = 3.38	F (1,20) = 1.12
8th	F (1,20) = 1.70	F (1,20) = 2.79
9th	F < 1	F (1,20) = 2.33
10th	F (1,20) = 1.25	F (1,20) = 1.36

* $p < .05$

** $p < .001$

*** $p <$ or $= .0001$

Table 23

Control Participants Grand Average LAN/N400 (300-500 ms) results for stimuli condition comparison article and main verb.

	Stimuli Condition	Stimuli Condition x Sentence Type
Word		
Article	F < 1	F < 1
Main verb	F < 1	F (1,20) = 1.83

* p < .05

** p < .01

*** p < .001

Table 24

Control Participants topographic distribution results for the single word comparison at the main verb region.

	Main Verb Region
S x A x C	F (3,63) = 2.63
S x L x C	F (1,21) = 3.45
S x H x C	F (1,21) = 13.25**
S x A x L x C	F < 1
S x A x H x C	F < 1
S x L x H x C	F (1,21) = 3.85
S x A x L x H x C	F < 1

* p < .05

** p < .01

*** p < .001

Table 25

Dyslexic Participants Grand Average LAN/N400 (300-500 ms) results for stimuli condition comparison article and main verb.

	Stimuli Condition	Stimuli Condition x Sentence Type
Word		
Article	F < 1	F (1,20) = 3.79
Main verb	F < 1	F (1,20) = 4.01

* p < .05

** p < .01

*** p < .001

Table 26

Summary of ERP Correlational Analysis.

	Visual Condition				**Auditory Condition**			
	Control Participants		**Participants with Dyslexia**		**Control Participants**		**Participants with Dyslexia**	
Electrode Site	**Subject Relative**	**Object Relative**	**Subject Relative**	**Object Relative**	**Subject Relative**	**Object Relative**	**Subject Relative**	**Object Relative**
Frontal	vocabulary verbal working memory	vocabulary verbal working memory print exposure MRT	reading fluency		vocabulary non verbal reasoning	vocabulary verbal working memory		reading accuracy word attack reading fluency
Central	verbal working memory	reading accuracy Word ID		reading fluency	vocabulary nonverbal reasoning	verbal working memory	reading accuracy Word Attack	
Parietal		reading accuracy word ID		reading fluency	nonverbal reasoning		reading accuracy Word Attack	

Table 27

Control Participants Correlations Among Behavioural Measures and Electrode Locations for Visual Condition at the slow wave subject relative second verb region.

	Vocabulary raw score	Vocabulary standard score	Verbal Working Memory recall	Verbal Working Memory Correct
FP1	0.641*	0.676*	0.576*	0.666*
FPZ	0.541*	0.615*	0.489	0.561*
FP2	0.482	0.548*	0.551*	0.617*
AF3	0.601*	0.605*	0.593*	0.691*
AF4	0.541*	0.535*	0.492	0.615*
F7	0.42	0.53*	0.181	0.458
F5	0.465	0.457	0.271	0.466
F3	0.588*	0.548*	0.562*	0.652*
F1	0.613*	0.516*	0.615*	0.783*
FZ	0.438	0.561*	0.449	0.602*
F2	0.426	0.446	0.652*	0.717*
F4	0.492	0.472	0.567*	0.641*
F6	0.516*	0.525	0.494	0.597*
F8	0.714*	0.731*	0.417	0.518*
FT7	0.351	0.412	0.061	0.399
FC5	0.506*	0.523*	0.223	0.523*
FC3	0.334	0.397	0.548*	0.441
FC1	0.061	-0.035	0.688*	0.626*
FCZ	-0.053	0.137	0.429	0.508*
FC2	0.24	0.301	0.554*	0.612*
FC4	0.279	0.254	0.675*	0.753*
FC6	0.443	0.467	0.346	0.515*
FT8	0.525*	0.528*	0.389	0.437
T7	0.122	0.245	0.168	0.323
C5	0.438	0.249	0.363	0.362
C3	0.271	0.278	0.673*	0.589*
C1	0.02	-0.133	0.754*	0.709*
CZ	-0.196	-0.154	0.506*	0.564*
C2	-0.011	0.039	0.602*	0.665*
C4	-0.032	-0.177	0.614*	0.514*
C6	0.51*	0.457	0.618*	0.628*
T8	0.423	0.482	0.288	0.266
TP7	0.219	0.044	0.224	0.402
CP5	0.517*	0.525*	0.59*	0.595*
CP3	0.055	-0.189	0.653*	0.506*
CP1	-0.102	-0.175	0.65*	0.567*
CPZ	-0.394	-0.356	0.319	0.253

CP2	-0.067	0.014	0.739*	0.662*
CP4	0.247	0.202	0.653*	0.635*
CP6	0.322	0.356	0.358	0.32
TP8	0.094	0.203	0.124	0.084
P7	-0.224	-0.358	0.369	0.425
P5	0.599*	0.394	0.298	0.309
P3	0.551*	0.329	0.113	0.143
P1	-0.056	0.086	0.505*	0.454
PZ	0.081	0.186	0.587*	0.543
P2	0.041	0.193	0.226	0.264
P4	0.375	0.418	-0.037	0.133
P6	0.338	0.365	-0.024	0.135
P8	0.305	0.27	0.046	0.107
PO7	0.064	-0.12	0.115	-0.012
PO5	0.09	-0.084	0.089	0.067
PO3	0.163	0.179	0.137	0.092
POZ	-0.072	0.033	0.452	0.345
PO4	-0.169	0.027	-0.235	-0.017
PO6	0.208	0.203	-0.13	0.184
PO8	0.17	0.174	-0.129	0.183
CB1	0.246	0.145	0.381	0.503*
O1	0.258	0.202	0.577*	0.461
OZ	7.04E-03	-0.019	0.337	0.197
O2	0.392	0.398	0.039	0.263
CB2	0.198	0.207	-0.143	0.18

Table 28

Control Participants Correlations Among Behavioural Measures and Electrode Locations for Visual Condition at the slow wave object relative second verb region.

	Vocabulary raw score	Vocabulary standard score	Word ID raw score	Word ID standard score	Verbal Working Memory Recall	Verbal Working Memory Correct
FP1	0.633*	0.664*	3.17E-03	-0.018	0.503*	0.546*
FPZ	0.704*	0.69*	0.03	-0.04	0.499*	0.596*
FP2	0.709*	0.727*	0.013	-0.031	0.457	0.569*
AF3	0.565*	0.54*	0.019	0.016	0.513*	0.592*
AF4	0.631*	0.67*	-0.048	-0.047	0.455	0.586*
F7	0.472	0.5*	0.348	0.336	0.228	0.371
F5	0.22	0.32	0.123	0.204	0.197	0.354
F3	0.362	0.379	0.055	0.074	0.42	0.608*
F1	0.279	0.351	0.059	0.177	0.396	0.535*
FZ	0.524*	0.548*	0.163	0.189	0.414	0.491
F2	0.482	0.531*	-4.63E-04	0.049	0.544*	0.668*
F4	0.685*	0.68*	0.069	0.048	0.511*	0.673*
F6	0.794*	0.779*	0.065	0.01	0.48	0.605*
F8	0.594*	0.682*	-0.164	-0.146	0.272	0.373
FT7	0.329	0.486	0.382	0.502*	-8.05E-03	0.282
FC5	0.313	0.493	0.322	0.47	0.203	0.4
FC3	0.541*	0.63*	0.431	0.477	0.428	0.493
FC1	0.337	0.431	0.24	0.36	0.499*	0.607*
FCZ	0.155	0.305	0.241	0.443	0.26	0.433
FC2	0.55*	0.536*	0.409	0.427	0.49	0.583*
FC4	0.42	0.336	0.374	0.385	0.45	0.605*
FC6	0.411	0.461	-0.126	-0.046	0.235	0.532*
FT8	0.59*	0.651*	-0.141	-0.137	0.294	0.395
T7	-0.1	-0.083	0.474	0.543*	0.126	0.204
C5	0.543*	0.43	0.787*	0.696*	0.211	0.41
C3	0.223	0.078	0.507*	0.464	0.516*	0.589*
C1	0.298	0.195	0.558*	0.576*	0.561*	0.687*
CZ	0.312	0.239	0.444	0.482	0.358	0.534*
C2	0.368	0.405	0.381	0.471	0.478	0.629*
C4	0.418	0.268	0.561*	0.528*	0.569*	0.689*
C6	0.632*	0.578*	0.4	0.337	0.52*	0.556*
T8	0.456	0.473	-0.302	-0.37	0.188	0.198
TP7	0.271	0.338	0.494	0.578*	0.104	0.301
CP5	0.385	0.29	0.492	0.464	0.547*	0.716*
CP3	0.549*	0.33	0.614*	0.449	0.529*	0.648*
CP1	0.348	0.306	0.548*	0.573*	0.391	0.57*

CPZ	0.474	0.418	0.618*	0.607*	0.375	0.515*
CP2	0.583*	0.557*	0.55*	0.528*	0.654*	0.706*
CP4	0.463	0.426	0.617*	0.581*	0.464	0.53*
CP6	0.501*	0.5*	0.547*	0.462	0.258	0.301
TP8	0.596*	0.503*	0.063	-0.129	0.289	0.201
P7	0.194	-0.065	0.622*	0.527*	0.098	0.3
P5	0.539*	0.387	0.759*	0.615*	0.248	0.346
P3	0.56*	0.423	0.743*	0.598*	0.25	0.341
P1	0.594*	0.456	0.788*	0.715*	0.552*	0.666*
PZ	0.557*	0.445	0.659*	0.626*	0.488	0.65*
P2	0.609*	0.529*	0.753*	0.679*	0.126	0.239
P4	0.41	0.331	0.783*	0.704*	-0.011	0.123
P6	0.44	0.333	0.845*	0.749*	8.36E-03	0.148
P8	0.377	0.232	0.814*	0.695*	0.016	0.123
PO7	0.122	-0.184	0.124	-0.172	0.123	-1.75E-03
PO5	0.207	-0.089	0.509*	0.316	0.068	0.145
PO3	0.529*	0.311	0.795*	0.604*	0.379	0.319
POZ	0.479	0.315	0.607*	0.501*	0.593*	0.627*
PO4	0.109	0.191	0.219	0.29	-0.282	-0.06
PO6	0.372	0.25	0.786*	0.68*	1.23E-03	0.126
PO8	0.374	0.262	0.785*	0.691*	0.022	0.156
CB1	-0.041	-0.286	0.403	0.303	0.017	0.178
O1	0.324	0.028	0.427	0.215	0.726*	0.562*
OZ	0.027	-0.149	0.259	0.258	0.452	0.418
O2	0.4	0.182	0.86*	0.773*	0.349	0.427
CB2	0.377	0.256	0.79*	0.692*	3.32E-03	0.15

Table 29

Participants with Dyslexia Correlations Among Behavioural Measures and Electrode Locations for Visual Condition at the slow wave subject relative second verb region.

	Sight Word Efficiency raw score	Sight Word Efficiency standard score	Phonetic Decoding raw score	Phonetic Decoding standard score
FP1	-0.495	-0.532*	-0.486	-0.506*
FPZ	-0.348	-0.425	-0.444	-0.452
FP2	-0.482	-0.54*	-0.501*	-0.516*
AF3	-0.467	-0.538*	-0.485	-0.527*
AF4	-0.487	-0.562*	-0.496	-0.544*
F7	-0.324	-0.352	-0.281	-0.328
F5	-0.418	-0.519*	-0.496	-0.585*
F3	-0.461	-0.527*	-0.458	-0.522*
F1	-0.468	-0.512*	-0.41	-0.496
FZ	-0.577*	-0.594*	-0.484	-0.519*
F2	-0.61*	-0.662*	-0.601*	-0.649*
F4	-0.479	-0.52*	-0.386	-0.461
F6	-0.507*	-0.551*	-0.509*	-0.533*
F8	-0.475	-0.479	-0.448	-0.469
FT7	0.014	-0.068	-0.052	-0.15
FC5	-0.085	-0.166	-0.111	-0.218
FC3	-0.498	-0.518*	-0.389	-0.487
FC1	-0.466	-0.485	-0.331	-0.435
FCZ	-0.244	-0.279	-0.139	-0.243
FC2	-0.549*	-0.552*	-0.386	-0.47
FC4	-0.568*	-0.574*	-0.465	-0.525*
FC6	-0.186	-0.321	-0.285	-0.418
FT8	-0.174	-0.284	-0.248	-0.397
T7	0.332	0.229	0.228	0.107
C5	-0.107	-0.178	-0.152	-0.278
C3	-0.284	-0.262	-0.12	-0.19
C1	-0.125	-0.086	0.011	-0.037
CZ	0.104	0.109	0.144	0.06
C2	-0.051	-0.054	0.087	-0.038
C4	0.046	-0.045	-0.016	-0.193
C6	0.103	-0.038	-0.086	-0.254
T8	-0.022	-0.149	-0.178	-0.329
TP7	0.357	0.293	0.209	0.127
CP5	-0.109	-0.05	0.112	0.049
CP3	0.064	0.077	0.173	0.079
CP1	0.053	0.091	0.16	0.093
CPZ	0.06	0.096	0.15	0.085

CP2	0.186	0.22	0.201	0.141
CP4	0.206	0.212	0.237	0.13
CP6	0.152	0.123	0.142	0.037
TP8	0.062	0.055	0.092	0.011
P7	0.207	0.248	0.279	0.246
P5	0.101	0.139	0.316	0.21
P3	-0.137	-0.089	-0.076	-0.089
P1	0.098	0.151	0.306	0.211
PZ	0.254	0.308	0.363	0.298
P2	0.128	0.196	0.268	0.217
P4	0.024	0.102	0.267	0.207
P6	0.081	0.14	0.294	0.223
P8	0.098	0.092	0.212	0.115
PO7	-0.218	-0.15	0.07	0.04
PO5	-0.115	-0.048	0.203	0.129
PO3	0.073	0.16	0.372	0.299
POZ	-0.141	-0.039	0.22	0.187
PO4	-0.102	-0.026	0.176	0.102
PO6	-0.168	-0.112	0.014	-0.055
PO8	-0.268	-0.195	-0.067	-0.093
CB1	0.183	0.224	0.266	0.226
O1	0.095	0.127	0.265	0.178
OZ	-0.316	-0.26	-0.042	-0.054
O2	-0.474	-0.454	-0.319	-0.389
CB2	-0.147	-0.12	0.025	-0.059

Table 30

Participants with Dyslexia Correlations Among Behavioural Measures and Electrode Locations for Visual Condition at the slow wave object relative second verb region.

	Sight Word Efficiency raw score	Sight Word Efficiency standard score	Phonetic Decoding raw score	Phonetic Decoding standard score
FP1	-0.16	-0.201	-0.238	-0.233
FPZ	0.103	0.028	-0.053	-0.033
FP2	-0.205	-0.27	-0.316	-0.302
AF3	-0.173	-0.215	-0.235	-0.221
AF4	-0.025	-0.082	-0.159	-0.155
F7	0.017	-0.048	-0.134	-0.134
F5	0.096	-3.24E-03	-0.14	-0.162
F3	0.091	0.026	-0.07	-0.08
F1	0.195	0.188	0.07	0.07
FZ	0.074	0.069	-1.37E-03	0.055
F2	0.178	0.129	-0.029	-0.023
F4	0.033	-4.19E-03	-0.083	-0.096
F6	-0.08	-0.105	-0.102	-0.112
F8	-0.186	-0.197	-0.176	-0.198
FT7	0.32	0.321	0.355	0.28
FC5	0.226	0.141	0.103	9.87E-03
FC3	0.092	0.181	0.206	0.19
FC1	0.448	0.506*	0.408	0.404
FCZ	0.271	0.324	0.267	0.316
FC2	0.074	0.097	-0.055	-0.01
FC4	-0.04	-0.013	-0.081	-0.07
FC6	-0.178	-0.166	4.75E-03	-0.064
FT8	-0.164	-0.139	-0.215	-0.216
T7	0.434	0.413	0.436	0.361
C5	0.656*	0.658*	0.576*	0.526*
C3	0.43	0.466	0.464	0.439
C1	0.383	0.434	0.403	0.411
CZ	0.445	0.477	0.454	0.428
C2	0.35	0.402	0.35	0.353
C4	0.542*	0.547*	0.43	0.372
C6	0.377	0.342	0.256	0.17
T8	0.344	0.303	0.176	0.092
TP7	0.496	0.466	0.502*	0.406
CP5	0.489	0.519*	0.54*	0.481
CP3	0.495	0.527*	0.584*	0.507*
CP1	0.589*	0.626*	0.621*	0.576*

CPZ	0.67*	0.691*	0.653*	0.619*
CP2	0.586*	0.651*	0.606*	0.575*
CP4	0.663*	0.672*	0.598*	0.525*
CP6	0.593*	0.588*	0.558*	0.47
TP8	0.402	0.388	0.271	0.213
P7	0.547*	0.508*	0.543*	0.411
P5	0.624*	0.63*	0.735*	0.621*
P3	0.37	0.411	0.453	0.383
P1	0.529*	0.576*	0.676*	0.576*
PZ	0.54*	0.587*	0.626*	0.555*
P2	0.384	0.477	0.548*	0.512*
P4	0.355	0.441	0.522*	0.494
P6	0.447	0.522*	0.577*	0.557*
P8	0.465	0.441	0.344	0.276
PO7	-0.026	0.015	0.274	0.207
PO5	0.082	0.136	0.35	0.266
PO3	0.362	0.434	0.586*	0.517*
POZ	0.16	0.189	0.342	0.236
PO4	0.495	0.578*	0.611*	0.574*
PO6	0.347	0.361	0.28	0.243
PO8	-0.179	-0.086	0.073	0.071
CB1	0.483	0.476	0.625*	0.513*
O1	0.496	0.47	0.234	0.221
OZ	-0.061	-3.48E-03	0.121	0.122
O2	0.089	0.172	0.306	0.271
CB2	0.443	0.447	0.353	0.334

Table 31

Control Participants Correlations Among Behavioural Measures and Electrode Locations for Auditory Condition at the slow wave subject relative second verb region.

	Vocabulary Raw Score	Vocabulary Standard Score	Spatial Visualization Raw Score	Spatial Visualization Standard Score
FP1	0.692*	0.769*	0.469	0.466
FPZ	0.711*	0.778*	0.476	0.472
FP2	0.726*	0.78*	0.528*	0.485
AF3	0.672*	0.77*	0.476	0.416
AF4	0.608*	0.683*	0.682*	0.657*
F7	0.553*	0.695*	0.606*	0.498*
F5	0.48	0.664*	0.575*	0.41
F3	0.587*	0.735*	0.552*	0.433
F1	0.538*	0.736*	0.654*	0.632*
FZ	0.619*	0.77*	0.667*	0.658*
F2	0.536*	0.73*	0.661*	0.567*
F4	0.403	0.598*	0.607*	0.472
F6	0.432	0.612*	0.671*	0.526*
F8	0.631*	0.754*	0.72*	0.644*
FT7	0.08	0.257	0.284	0.141
FC5	0.363	0.541*	0.542*	0.345
FC3	0.442	0.658*	0.61*	0.628*
FC1	0.376	0.572*	0.622*	0.562*
FCZ	0.397	0.613*	0.611*	0.674*
FC2	0.418	0.625*	0.766*	0.681*
FC4	0.5*	0.667*	0.751*	0.68*
FC6	0.51*	0.674*	0.852*	0.801*
FT8	0.648*	0.726*	0.745*	0.68*
T7	0.055	0.195	0.101	0.031
C5	0.23	0.402	0.409	0.302
C3	0.411	0.575*	0.546*	0.646*
C1	0.404	0.562*	0.54*	0.611*
CZ	0.507*	0.673*	0.664*	0.571*
C2	0.393	0.548*	0.568*	0.502*
C4	0.348	0.542*	0.716*	0.625*
C6	0.441	0.643*	0.656*	0.638*
T8	0.545*	0.691*	0.697*	0.716*
TP7	0.234	0.385	0.448	0.344
CP5	0.357	0.517*	0.517*	0.461
CP3	0.369	0.489	0.503*	0.543*
CP1	0.38	0.463	0.603*	0.708*
CPZ	0.488	0.663*	0.593*	0.681*
CP2	0.44	0.585*	0.595*	0.702*

CP4	0.396	0.557*	0.685*	0.711*
CP6	0.628*	0.777*	0.793*	0.823*
TP8	0.605*	0.708*	0.796*	0.722*
P7	0.101	0.296	0.493	0.35
P5	0.332	0.469	0.481	0.414
P3	0.236	0.34	0.425	0.298
P1	0.428	0.552*	0.63*	0.539*
PZ	0.412	0.501*	0.634*	0.574*
P2	0.453	0.566*	0.669*	0.619*
P4	0.403	0.585*	0.746*	0.803*
P6	0.341	0.502*	0.791*	0.758*
P8	0.254	0.452	0.731*	0.736*
PO7	0.051	0.088	0.484	0.352
PO5	0.091	0.163	0.476	0.268
PO3	0.405	0.502*	0.657*	0.587*
POZ	0.344	0.413	0.593*	0.518*
PO4	0.314	0.466	0.676*	0.65*
PO6	0.316	0.486	0.781*	0.749*
PO8	0.325	0.489	0.779*	0.745*
CB1	-0.188	-0.19	0.218	0.021
O1	0.33	0.245	0.496	0.432
OZ	0.497	0.469	0.431	0.476
O2	0.402	0.457	0.754*	0.739*
CB2	0.298	0.458	0.875*	0.85*

Table 32

Control Participants Correlations Among Behavioural Measures and Electrode Locations for Auditory Condition at the slow wave object relative second verb region.

	Vocabulary Raw Score	Vocabulary Standard Score	Verbal Working Memory Recall	Verbal Working Memory Correct
FP1	0.59*	0.643*	0.564*	0.598*
FPZ	0.687*	0.685*	0.573*	0.634*
FP2	0.712*	0.681*	0.573*	0.621*
AF3	0.566*	0.638*	0.589*	0.65*
AF4	0.637*	0.658*	0.599*	0.594*
F7	0.536*	0.68*	0.266	0.447
F5	0.282	0.489	0.081	0.169
F3	0.507*	0.598*	0.427	0.411
F1	0.483	0.633*	0.407	0.377
FZ	0.418	0.595*	0.245	0.187
F2	0.368	0.503*	0.534*	0.521*
F4	0.377	0.51*	0.481	0.456
F6	0.344	0.498*	0.313	0.305
F8	0.715*	0.764*	0.365	0.397
FT7	0.195	0.299	0.1	0.231
FC5	0.257	0.486	0.145	0.207
FC3	0.309	0.496	0.32	0.254
FC1	0.104	0.248	0.34	0.224
FCZ	0.215	0.423	0.287	0.216
FC2	0.24	0.36	0.401	0.3
FC4	0.294	0.443	0.451	0.363
FC6	0.563*	0.64*	0.173	0.217
FT8	0.655*	0.695*	0.37	0.409
T7	0.181	0.331	0.069	0.146
C5	-0.057	0.173	0.185	0.155
C3	0.145	0.325	0.385	0.332
C1	0.152	0.165	0.851*	0.768*
CZ	0.243	0.401	0.602*	0.603*
C2	0.237	0.332	0.632*	0.541*
C4	0.29	0.313	0.707*	0.595*
C6	0.404	0.489	0.504*	0.441
T8	0.481	0.566*	0.24	0.204
TP7	0.225	0.31	0.317	0.288
CP5	0.206	0.301	0.604*	0.516*
CP3	0.186	0.268	0.595*	0.468
CP1	0.174	0.212	0.719*	0.572*
CPZ	0.241	0.347	0.476	0.357
CP2	0.296	0.339	0.798*	0.695*

CP4	0.261	0.366	0.634*	0.512*
CP6	0.513	0.595*	0.363	0.302
TP8	0.487	0.555*	0.378	0.308
P7	0.103	0.102	0.38	0.325
P5	-0.025	0.114	0.272	0.139
P3	-0.137	-0.054	0.358	0.229
P1	-0.038	0.044	0.525*	0.384
PZ	0.064	0.125	0.547*	0.37
P2	0.14	0.186	0.581*	0.412
P4	0.263	0.374	0.326	0.247
P6	0.222	0.311	0.331	0.244
P8	0.262	0.409	0.319	0.299
PO7	-0.344	-0.321	0.292	0.164
PO5	-0.332	-0.312	0.274	0.133
PO3	0.173	0.302	0.312	0.23
POZ	0.06	0.121	0.69	0.571*
PO4	0.074	0.243	0.214	0.292
PO6	0.216	0.33	0.311	0.264
PO8	0.189	0.305	0.318	0.255
CB1	-0.438	-0.437	0.297	0.178
O1	-0.351	-0.464	0.336	0.252
OZ	-0.116	-0.15	0.641*	0.608*
O2	-0.034	0.043	0.547*	0.41
CB2	0.219	0.325	0.372	0.333

Table 33

Dyslexic Participants Correlations Among Behavioural Measures and Electrode Locations for Auditory Condition at the slow wave subject relative second verb region.

	Word Attack raw score	Word Attack standard score
FP1	-0.531*	-0.541*
FPZ	-0.392	-0.416
FP2	-0.416	-0.435
AF3	-0.467	-0.465
AF4	-0.394	-0.391
F7	-0.315	-0.324
F5	-0.648*	-0.648*
F3	-0.411	-0.408
F1	-0.362	-0.334
FZ	-0.41	-0.377
F2	-0.167	-0.143
F4	-0.306	-0.29
F6	-0.243	-0.253
F8	-0.188	-0.197
FT7	-0.246	-0.239
FC5	-0.032	-0.011
FC3	-0.326	-0.272
FC1	-0.167	-0.102
FCZ	-0.123	-0.092
FC2	-0.464	-0.421
FC4	-0.349	-0.308
FC6	-0.279	-0.268
FT8	-0.177	-0.141
T7	0.218	0.212
C5	0.246	0.258
C3	0.323	0.391
C1	9.48E-03	0.094
CZ	0.633	0.668*
C2	-0.219	-0.152
C4	0.066	0.123
C6	-0.27	-0.25
T8	-0.117	-0.103
TP7	0.396	0.394
CP5	-1.46E-04	0.038
CP3	0.595	0.628*
CP1	0.482	0.536*
CPZ	0.777*	0.811*
CP2	0.548*	0.591*

CP4	0.204	0.256
CP6	0.145	0.162
TP8	-0.106	-0.104
P7	0.265	0.282
P5	0.437	0.464
P3	0.466	0.512*
P1	0.52*	0.561*
PZ	0.682*	0.719*
P2	0.698*	0.739*
P4	0.406	0.416
P6	0.537*	0.557*
P8	0.509*	0.491
PO7	0.511*	0.568*
PO5	0.535*	0.598*
PO3	0.296	0.336
POZ	0.382	0.429
PO4	0.253	0.274
PO6	0.516*	0.529*
PO8	0.574*	0.567*
CB1	0.229	0.273
O1	0.223	0.233
OZ	0.48	0.464
O2	0.139	0.142
CB2	0.145	0.135

Table 34

Dyslexic Participants Correlations Among Behavioural Measures and Electrode Locations for Auditory Condition at the slow wave object relative second verb region.

	Word Attack raw score	Word Attack standard score	Sight Word Efficiency raw score	Sight Word Efficiency standard score	Phonetic Decoding raw score	Phonetic Decoding standard score
FP1	-0.582*	-0.574*	-0.47	-0.509*	-0.528*	-0.532*
FPZ	-0.554*	-0.555*	-0.465	-0.515*	-0.556*	-0.548*
FP2	-0.542*	-0.535*	-0.505*	-0.542*	-0.559*	-0.563*
AF3	-0.546*	-0.531*	-0.5*	-0.535*	-0.531*	-0.541*
AF4	-0.333	-0.313	-0.441	-0.472	-0.413	-0.452
F7	-0.655*	-0.656*	-0.279	-0.347	-0.383	-0.398
F5	-0.731*	-0.721*	-0.18	-0.248	-0.337	-0.373
F3	-0.51*	-0.496	-0.193	-0.262	-0.252	-0.32
F1	-0.446	-0.416	-0.272	-0.299	-0.228	-0.287
FZ	-0.337	-0.302	-0.639*	-0.639*	-0.556*	-0.556*
F2	-0.111	-0.082	-0.467	-0.494	-0.391	-0.455
F4	-0.246	-0.218	-0.408	-0.442	-0.335	-0.403
F6	-0.425	-0.414	-0.57*	-0.6*	-0.522*	-0.543*
F8	-0.438	-0.422	-0.611*	-0.638*	-0.554*	-0.575*
FT7	-0.693*	-0.687*	-0.118	-0.212	-0.282	-0.338
FC5	-0.613*	-0.606*	-0.21	-0.306	-0.329	-0.419
FC3	-0.222	-0.205	-0.498*	-0.512*	-0.372	-0.437
FC1	-0.189	-0.166	-0.577*	-0.574*	-0.389	-0.442
FCZ	0.142	0.17	-0.439	-0.428	-0.192	-0.254
FC2	0.28	0.302	-0.448	-0.429	-0.188	-0.259
FC4	-0.225	-0.199	-0.568*	-0.589*	-0.424	-0.497*
FC6	-0.379	-0.348	-0.47	-0.52*	-0.392	-0.465
FT8	-0.308	-0.273	-0.563*	-0.598*	-0.468	-0.537*
T7	-0.165	-0.172	0.276	0.166	0.144	0.014
C5	0.111	0.096	0.149	0.063	0.088	-0.053
C3	0.162	0.17	-0.019	-0.049	0.117	-3.71E-03
C1	0.094	0.122	-0.191	-0.16	0.024	-0.025
CZ	0.331	0.342	-0.267	-0.222	0.022	-0.025
C2	0.134	0.154	-0.305	-0.267	2.45E-03	-0.047
C4	-0.178	-0.154	-0.323	-0.336	-0.14	-0.214
C6	-0.33	-0.323	-0.321	-0.36	-0.245	-0.315
T8	-0.311	-0.302	-0.15	-0.239	-0.184	-0.309
TP7	-0.061	-0.104	0.428	0.327	0.215	0.12
CP5	-0.32	-0.357	0.172	0.138	0.078	0.014
CP3	-0.07	-0.08	0.312	0.277	0.33	0.22
CP1	0.038	0.04	-0.042	-0.041	0.101	0.016

CPZ	0.486	0.515*	-8.21E-03	0.037	0.296	0.227
CP2	0.408	0.408	0.116	0.16	0.41	0.33
CP4	0.095	0.105	0.082	0.109	0.322	0.25
CP6	-0.08	-0.091	0.097	0.091	0.214	0.123
TP8	-0.018	-0.036	0.137	0.124	0.18	0.107
P7	0.016	-0.047	0.425	0.412	0.232	0.221
P5	0.103	0.04	0.444	0.407	0.333	0.253
P3	-0.036	-0.098	0.303	0.284	0.216	0.151
P1	0.306	0.277	0.218	0.252	0.414	0.331
PZ	0.422	0.404	0.3	0.354	0.528*	0.454
P2	0.356	0.343	0.285	0.344	0.537*	0.483
P4	-0.029	-0.057	0.151	0.188	0.315	0.287
P6	0.03	6.01E-03	0.346	0.369	0.487	0.443
P8	-0.149	-0.142	-0.047	5.05E-03	0.091	0.082
PO7	-0.03	-0.102	0.145	0.17	0.133	0.134
PO5	0.025	-0.038	0.302	0.316	0.281	0.262
PO3	0.082	0.026	0.283	0.349	0.335	0.33
POZ	-0.078	-0.12	0.52	0.572	0.477	0.474
PO4	0.112	0.072	0.406	0.467	0.531	0.51*
PO6	0.27	0.222	0.199	0.262	0.376	0.357
PO8	0.213	0.183	0.062	0.137	0.275	0.279
CB1	-0.049	-0.084	0.48	0.483	0.399	0.359
O1	-0.028	-0.072	0.126	0.177	0.189	0.182
OZ	0.177	0.168	5.75E-03	0.121	0.254	0.268
O2	0.393	0.369	0.243	0.304	0.45	0.408
CB2	0.108	0.075	0.197	0.266	0.342	0.338

Figure Captions

Figure 1. Visual presentation slow wave grand averages for control participants at frontal electrode site.

Figure 2. Visual presentation slow wave grand averages for control participants at all electrode sites.

Figure 3. Visual presentation slow wave grand averages for participants with dyslexia at frontal electrode site.

Figure 4. Visual presentation slow wave grand averages for participants with dyslexia at all electrode sites.

Figure 5. Visual presentation main verb region single word grand averages for control participants at frontal electrode site.

Figure 6. Auditory presentation slow wave grand averages for participants with dyslexia at frontal electrode site.

Figure 7. Auditory presentation slow wave grand averages for control participants at frontal electrode site.

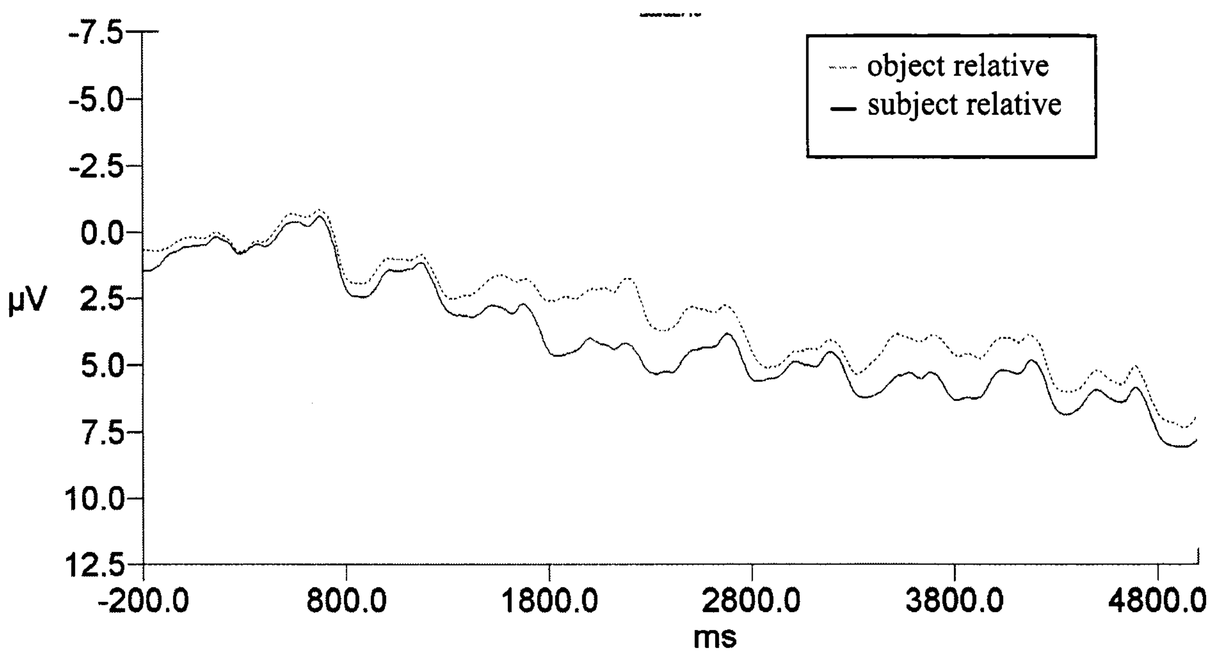
Figure 8. Auditory presentation single word averages for participants with dyslexia at frontal electrode site.

Figure 9. Auditory presentation main verb region single word grand averages for control participants at frontal electrode site.

Figure 10. Auditory presentation second article region single word grand averages for participants with dyslexia at central electrode site.

Figure 11. Auditory presentation main verb region single word grand averages for participants with dyslexia at frontal electrode site.

Figure 1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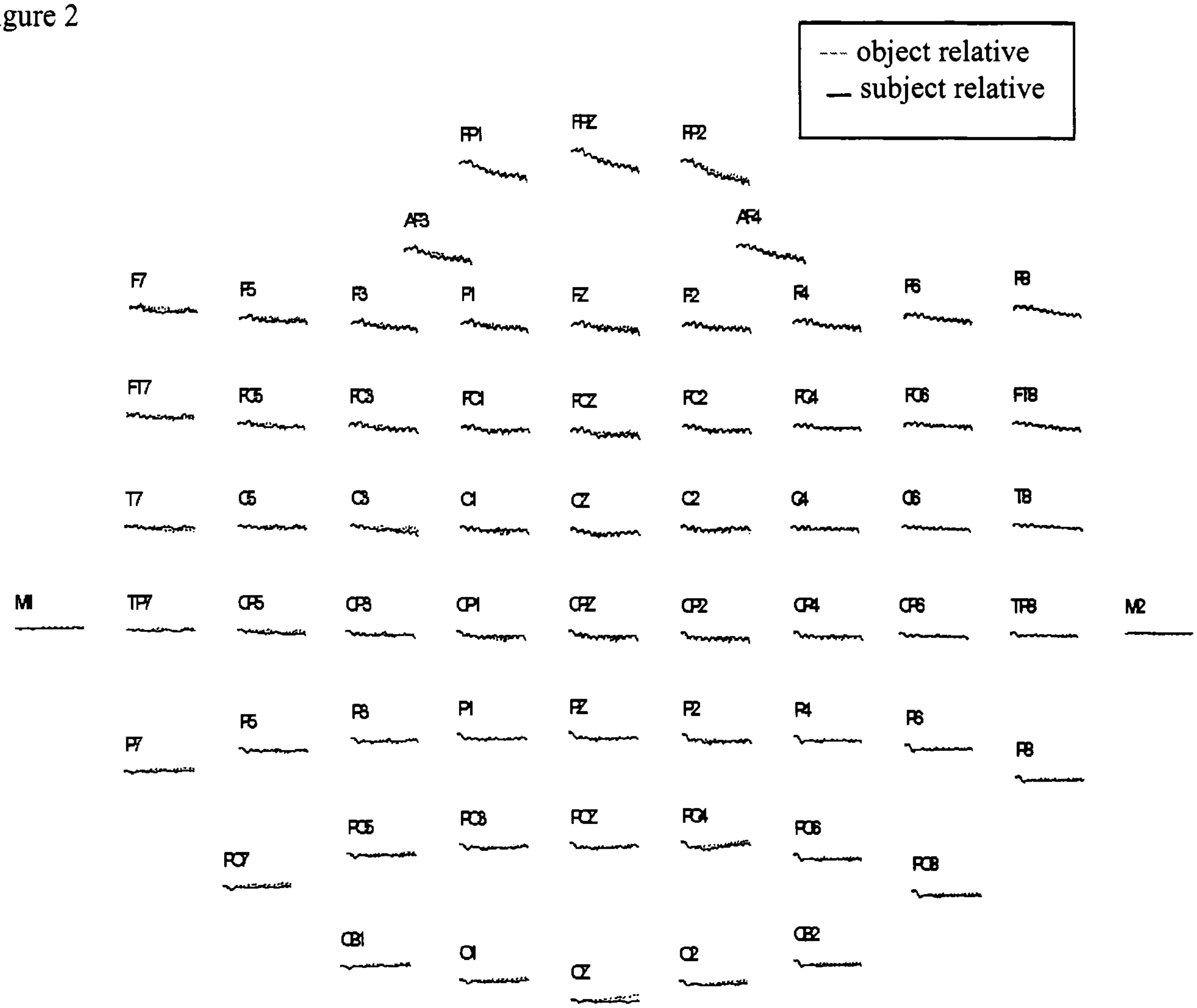

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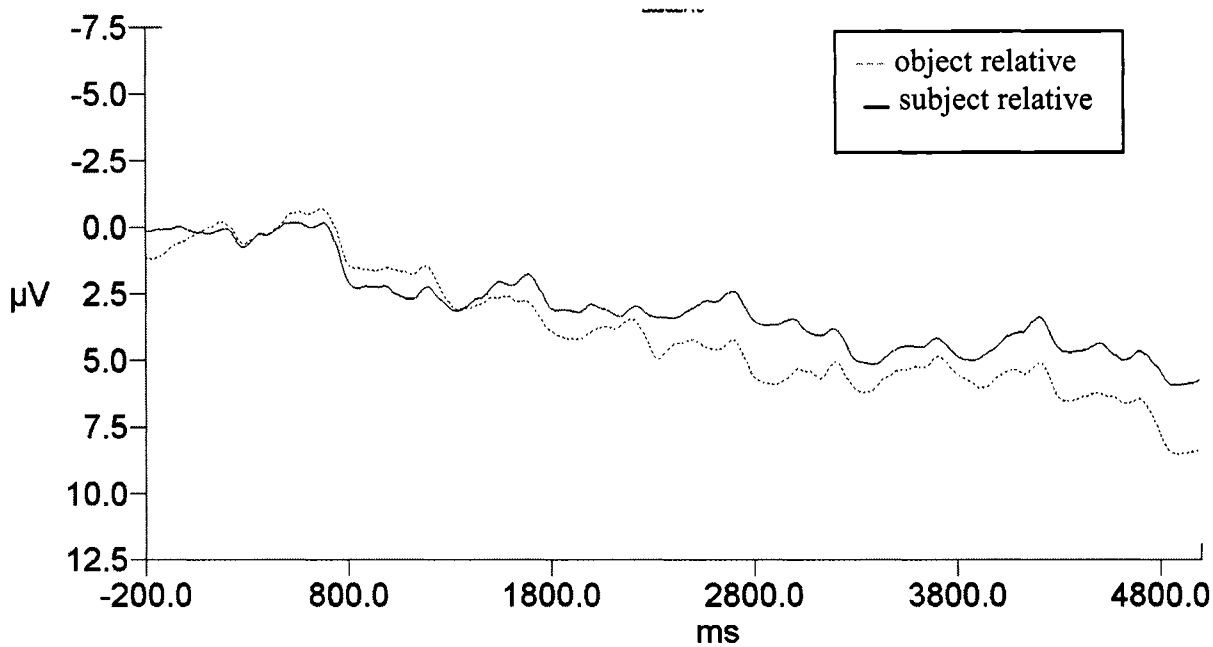
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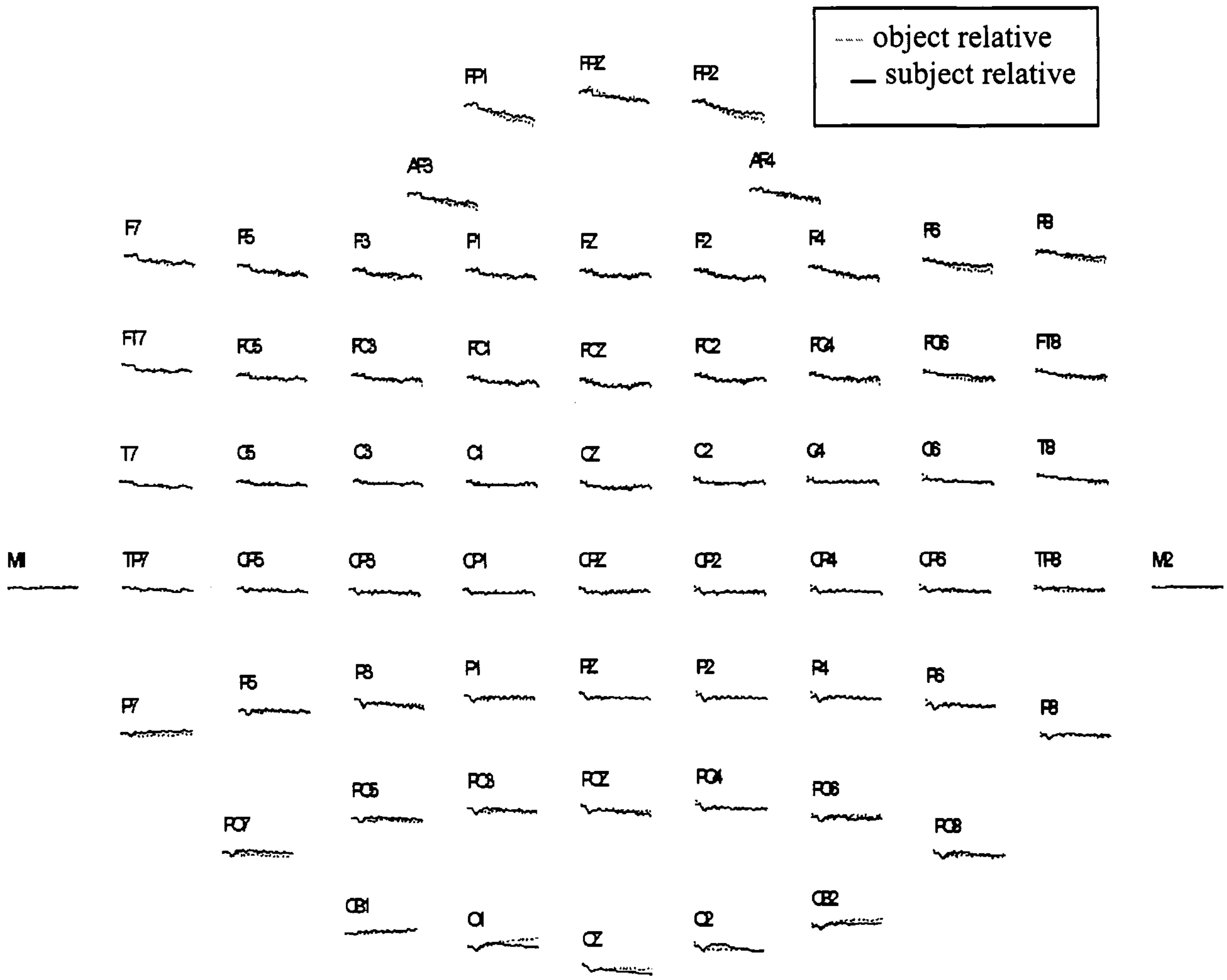

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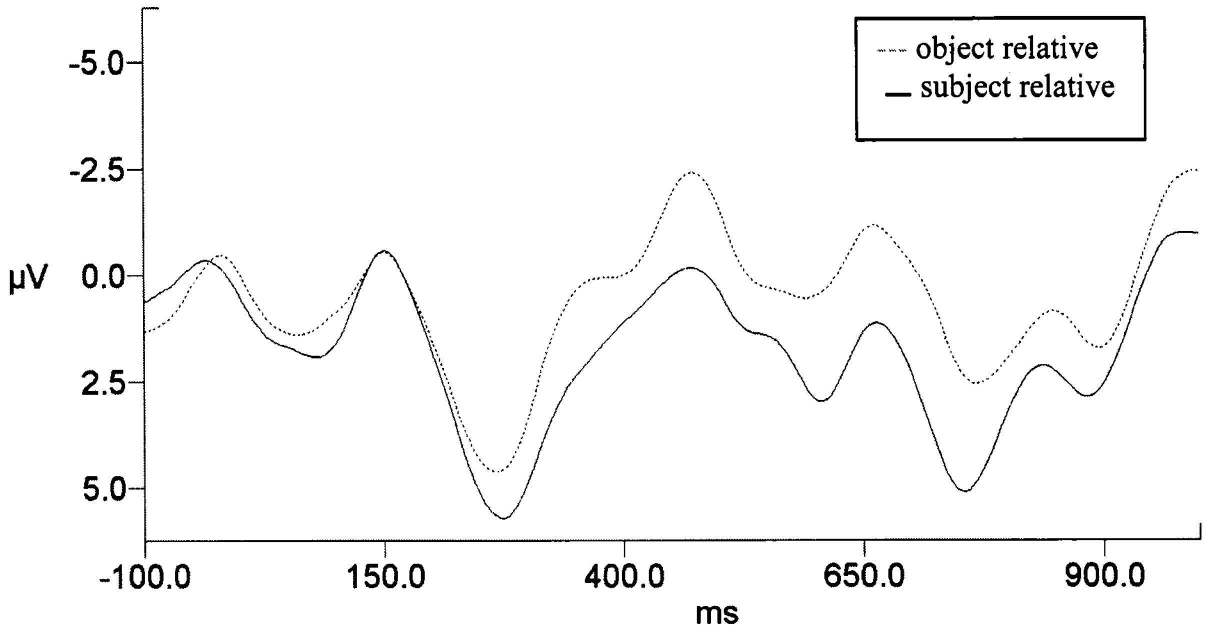
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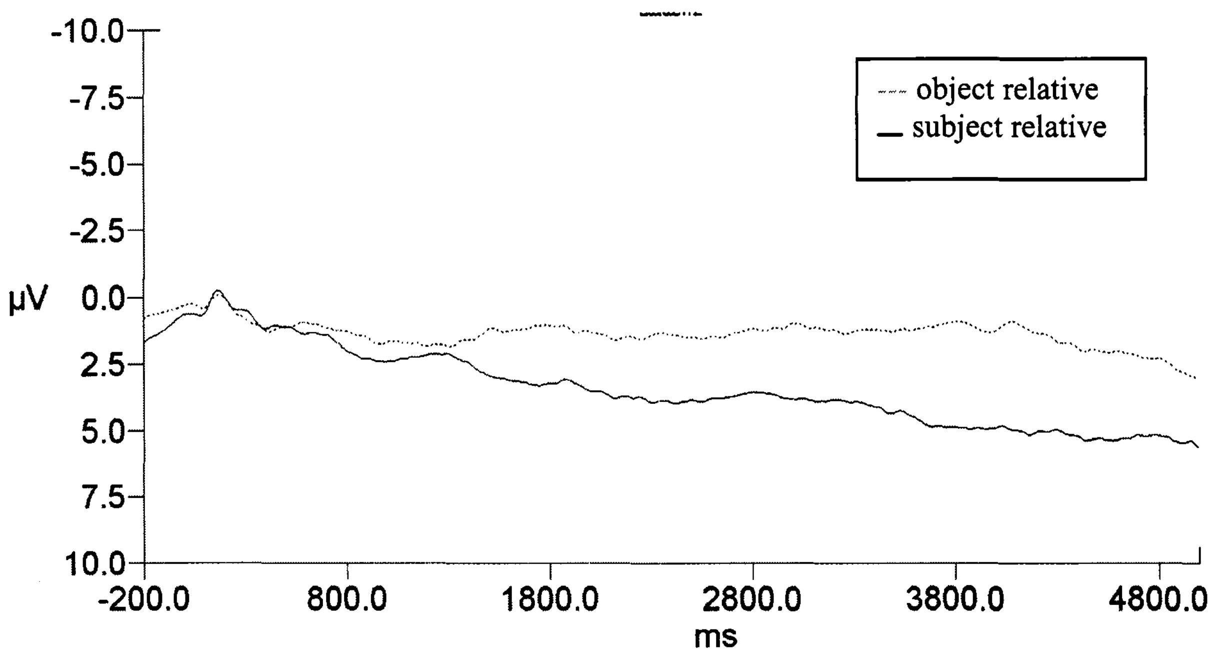
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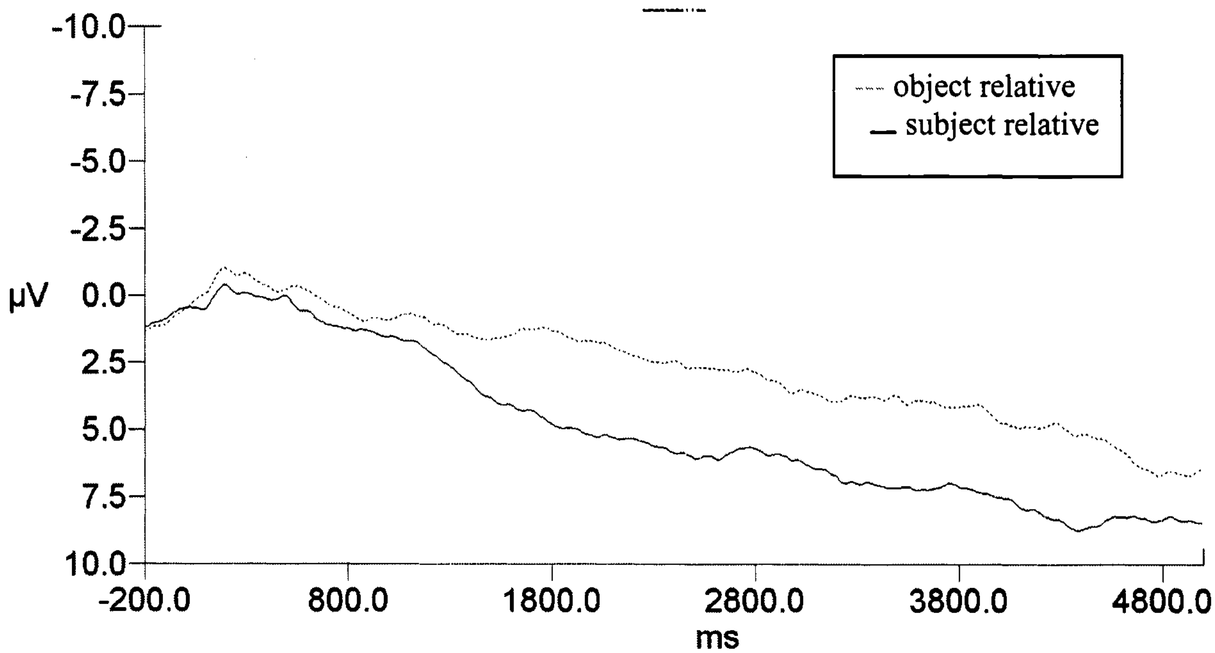
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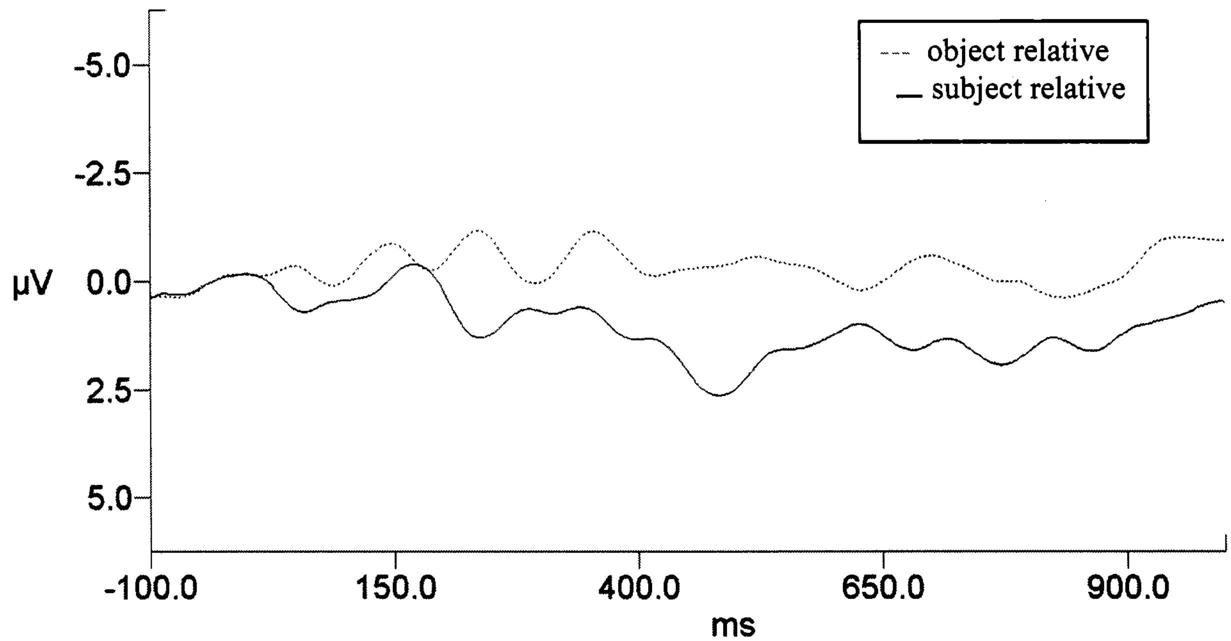
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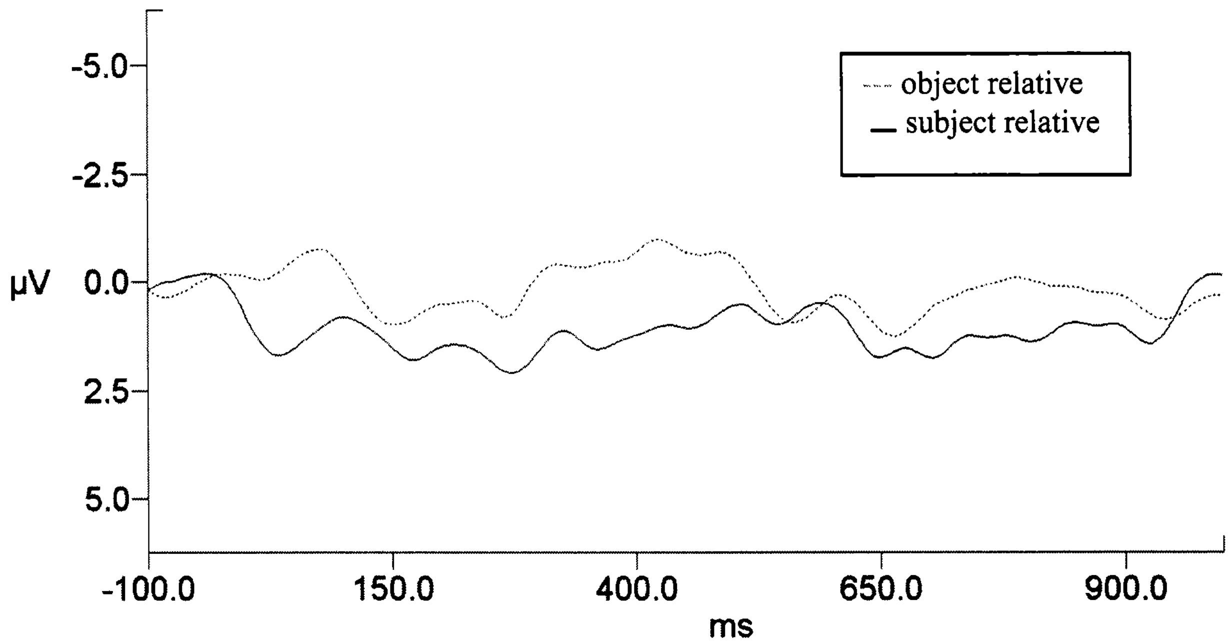
ms

Figure 9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ms

Figure 10

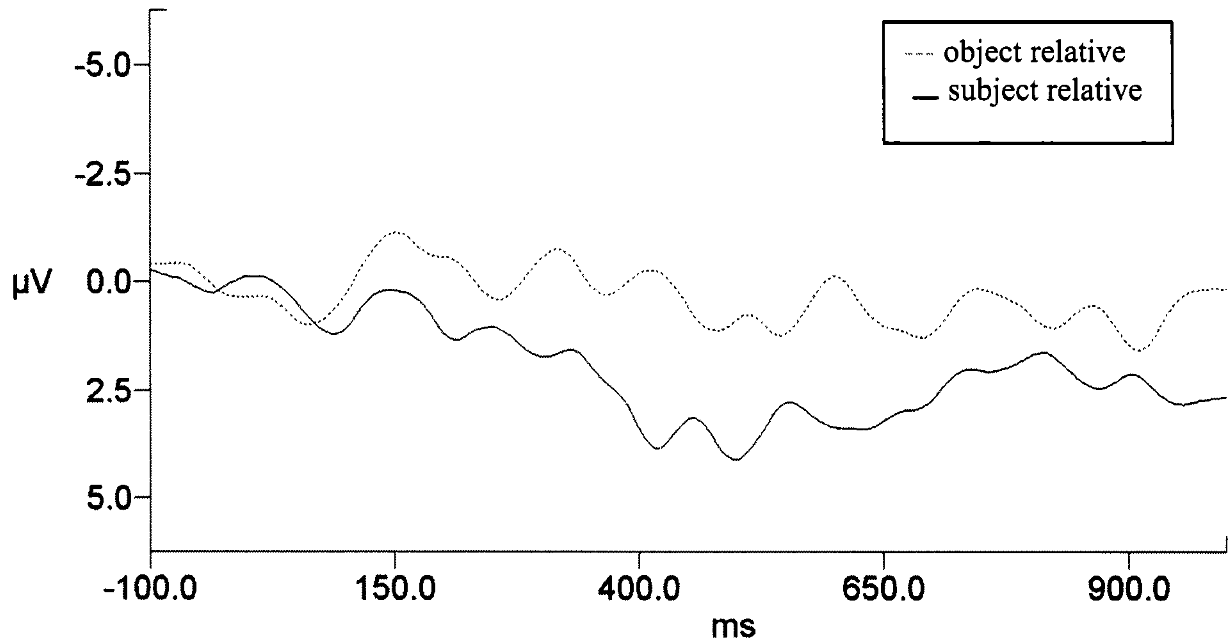
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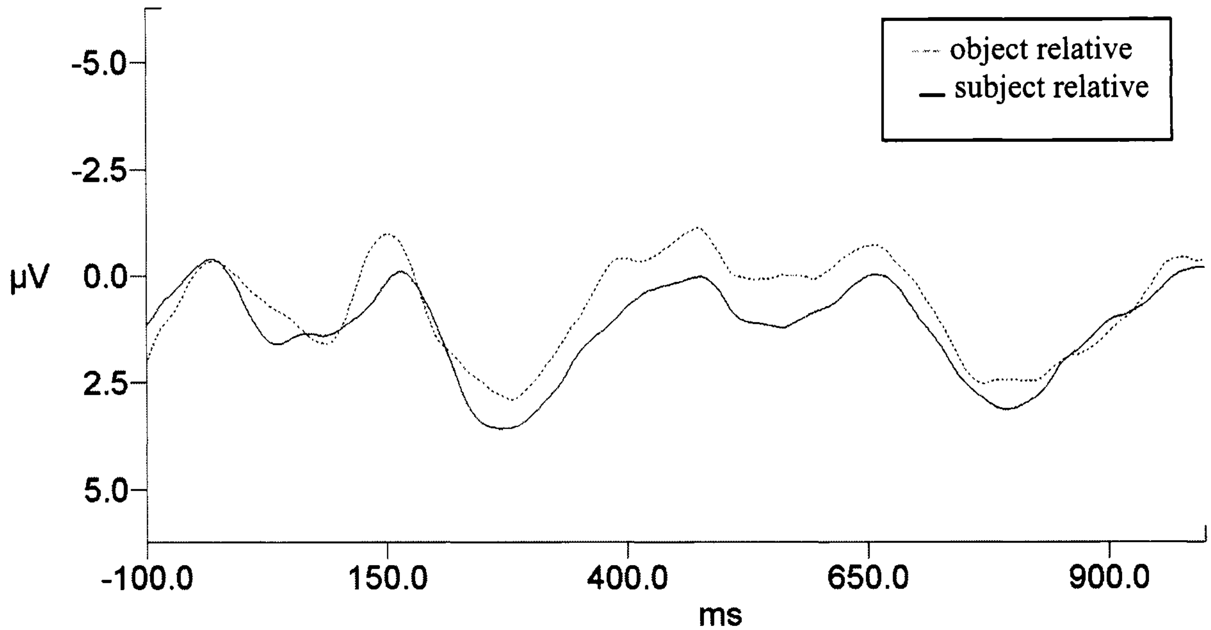
Figure 11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900.0
ms

Appendices

Appendix A Ethics Materials

Appendix A_1 Recruitment Posters

Appendix A_2 Invitation Letters

Appendix A_3 Informed Consent Letter

Appendix A_4

Appendix A_1


DEPARTMENT OF PSYCHOLOGY
WILFRID LAURIER UNIVERSITY

Learn more about how brains work when people read

Adults with dyslexia required for reading research
Must be between the ages of 18 and 35

As a participant you will be asked to complete several tests of reading ability, comprehension, memory, and reasoning.
While you are asked to read or listen to sentences you will be fitted with a cap that contains electrodes, which will allow your brainwaves to be recorded.

This experiment will be carried out over 2 sessions and requires a total time commitment of 4 hours.

As compensation for your participation you will receive $40.00

For more information, or to volunteer for this study please contact:

Hilary Brown brow1774@wlu.ca
(519) 884-0710 ext. 2933
Faculty Supervisor: Alexandra Gottardo, agottard@wlu.ca
(519) 884-0710 ext. 2169

This research has received approval from the Research Ethics Board, file # 1966

Research Ethics Chair contact information: Dr. Bill Marr
(519) 884-0710 ext. 2468

DEPARTMENT OF PSYCHOLOGY
WILFRID LAURIER UNIVERSITY

Learn more about how brains work when people read

Adults required for reading research
Must be between the ages of 18 and 35

As a participant you will be asked to complete several tests of reading ability, comprehension, memory, and reasoning.
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(519) 884-0710 ext. 2468

Appendix A_2

(To appear on Wilfrid Laurier University Letterhead)

To whom it may concern,

The Disabilities Services Office of Conestoga College has agreed to distribute this package to students registered with their office who have documented reading disabilities. Conestoga College has not provided Wilfrid Laurier University with your name or any contact information. The only way that Wilfrid Laurier University will have access to your name is if you decide to call them or email them. You are being invited to participate in a research study at Wilfrid Laurier University examining syntactic processing in individuals with and without dyslexia. This research study is being conducted by Hilary Brown, a Masters Student in the Department of Psychology, under the supervision of Dr. Alexandra Gottardo, a professor in the Department of Psychology.

As a participant you will be asked to complete several tests of reading ability, comprehension, working memory, and nonverbal reasoning.
You will also be asked to read sentences or words presented on a computer screen. While you are presented with these sentences and words you will be fitted with a cap that contains electrodes, which will allow your brainwaves to be recorded. The electrodes will be attached to your head in the following manner. First, a cap containing 64 electrodes will be fitted onto your head. Second, a conductive gel will be placed on the contact areas of each electrode. Finally after all electrodes have been attached, it may be necessary to rub areas of the scalp beneath certain electrodes with a cue tip to ensure proper conductivity. This may cause some tenderness of the scalp area.

This experiment will be carried out over 2 sessions and requires a total time commitment of 4 hours. The experiment will take place at Wilfrid Laurier University. As compensation for your participation you will receive $40.00.

This research project complies with the requirements of the Research Ethics Board of Wilfrid Laurier University. Your participation in this study is completely voluntary and you will not be identified to the researchers unless you choose to participate in this study. All participants will be given an identification number that will be used for all data entry and data analysis purposes. No other identifying information will be available. Data will be stored securely in a locked filing cabinet at the university. Only the principal investigator and supervisors will have access to the data. Raw data will be destroyed 10 years after publication.

For more information, or to volunteer for this study please contact:

Hilary Brown: brow1774@wlu.ca (519) 884-0710 ext. 2933

or
Faculty Supervisor: Alexandra Gottardo, agottard@wlu.ca (519) 884-0710 ext.2169

Thank you,

Hilary Brown
Department of Psychology
Wilfrid Laurier University

(To appear on Wilfrid Laurier University Letterhead)

To whom it may concern,

The Learning Disabilities Association of Kitchener-Waterloo (LDAKW) has agreed to distribute this package to individuals registered with their office who have documented reading disabilities. LDAKW has not provided Wilfrid Laurier University with your name or any contact information. The only way that Wilfrid Laurier University will have access to your name is if you decide to call them or email them.

You are being invited to participate in a research study at Wilfrid Laurier University examining syntactic processing in individuals with and without dyslexia. This research study is being conducted by Hilary Brown, a Masters Student in the Department of Psychology, under the supervision of Dr. Alexandra Gottardo, a professor in the Department of Psychology.

As a participant you will be asked to complete several tests of reading ability, comprehension, working memory, and nonverbal reasoning. You will also be asked to read sentences or words presented on a computer screen. While you are presented with these sentences and words you will be fitted with a cap that contains electrodes, which will allow your brainwaves to be recorded. The electrodes will be attached to your head in the following manner. First, a cap containing 64 electrodes will be fitted onto your head. Second, a conductive gel will be placed on the contact areas of each electrode. Finally after all electrodes have been attached, it may be necessary to rub areas of the scalp beneath certain electrodes with a cue tip to ensure proper conductivity. This may cause some tenderness of the scalp area.

This experiment will be carried out over 2 sessions and requires a total time commitment of 4 hours. The experiment will take place at Wilfrid Laurier University. As compensation for your participation you will receive $40.00.

This research project complies with the requirements of the Research Ethics Board of Wilfrid Laurier University. Your participation in this study is completely voluntary and you will not be identified to the researchers unless you choose to participate in this study. All participants will be given an identification number that will be used for all data entry and data analysis purposes. No other identifying information will be available. Data will be stored securely in a locked filing cabinet at the university. Only the principal investigator and supervisors will have access to the data. Raw data will be destroyed 10 years after publication.

For more information, or to volunteer for this study please contact:

Hilary Brown: brow1774@wlu.ca (519) 884-0710 ext. 2933

or
Faculty Supervisor: Alexandra Gottardo, agottard@wlu.ca (519) 884-0710 ext.2169

Thank you,

Hilary Brown
Department of Psychology
Wilfrid Laurier University

Appendix A_3 Informed Consent Letter

WILFRID LAURIER UNIVERSITY
INFORMED CONSENT STATEMENT
Syntactic Processing in Individuals with Dyslexia
Principal Investigator: Hilary Brown, Graduate Student, Department of Psychology
Advisor: Dr. Alexandra Gottardo

You are invited to participate in a research study that looks at syntactic processing in individuals with dyslexia. Syntactic processing involves processing of words into sentences in order to determine their grammatical function. You will be asked to perform a number of different tasks that involve reading and to answer questions. The goal of this study is to understand how individuals with dyslexia process syntactic information.
This study is being conducted by Psychology Graduate Student Hilary Brown, and Dr. Alexandra Gottardo and Dr. Todd Ferretti in the Department of Psychology at Wilfrid Laurier University.

INFORMATION

This study involves taking measures of reading ability, phonological processing, and syntactic processing. To measure baseline reading ability, a variety of standardized tests will be used to measure vocabulary, reading accuracy, non-verbal reasoning, reading fluency, working memory, reading comprehension, and author recognition.

For the second component of the study, phonological processing and syntactic processing will be measured using Event Related Potentials (ERP). Event Related Potentials are recordings of the brain's electrical activity that are linked to the occurrence of an event, such as a reading task. To measure syntactic and phonological processing, you will be asked to read sentences or words displayed on a computer screen. These sentences or words will be presented one word at a time at a predetermined rate. You will be asked to answer questions about these sentences or words by pushing buttons on a keyboard. Brain waves will be recorded via 64 electrodes placed on your head as you are reading. This information will be recorded onto a computer screen in the adjacent room.

The electrodes will be attached to your head in the following manner. First, a cap containing 64 electrodes will be fitted onto your head. Second, a conductive gel will be placed on the contact areas of each electrode. Finally after all electrodes have been attached, it may be necessary to rub areas of the scalp beneath certain electrodes with a cue tip to ensure proper conductivity. This may cause some tenderness of the scalp area.

This study will be completed in two sessions. The first session the behavioural baseline measures will be taken and baseline reading rate will be measured. This session will take approximately 1 hour to complete. In the second session the ERP measurements will be taken. This session will take approximately 2 hours to complete. You are one of approximately 50 people participating in this experiment. Half of the participants will have dyslexia and the other half will be a control group of individuals who do not have dyslexia. Your data will only be viewed by the principle investigator (Hilary Brown) and the supervising professors (Dr. Alexandra Gottardo and Dr. Todd Ferretti).

RISKS

Before we can begin recording ERP signals from the electrodes, it may be necessary to abrade any contact areas on the scalp in order to maximize conductivity. In certain situations, this may cause slight irritation and redness of the skin, and under very rare circumstances, may cause light bleeding.
In order to minimize these risks, all electrode components that come into contact with your scalp will be thoroughly disinfected between uses. Additionally, the researcher will wear disposable rubber gloves at all times during the set-up process, and material used for disinfecting and abrading will be disposed of after every use. A first aid kit will be on hand at all times.
You may feel some frustration or fatigue when performing the baseline reading measures. To decrease stress and frustration, breaks will be provided throughout the testing session.

BENEFITS

By furthering our understanding of dyslexia we will be better equipped to assist individuals with dyslexia in finding efficient strategies for reading and writing. By studying university and college aged students with dyslexia we can examine the strategies used and the difficulties faced by students who are in post-secondary education. Studies involving syntactic processing have been done with Hebrew speaking students but not with English speaking students. Therefore, this study will further our understanding of syntactic processing in English speaking university and college students with and without dyslexia.
You may also benefit by learning first hand how experimental research in psychology is conducted.

CONFIDENTIALITY

All participants will be given an identification number that will be used for all data entry and data analysis purposes. No other identifying information will be available. Group scores will be reported at professional conferences and in journal articles, but no individual scores will be reported or discussed with anyone at any time. Data will be stored securely in a locked filing cabinet at the university. Only the principal investigator and supervisors will have access to the data. Raw data will be destroyed 10 years after publication.

COMPENSATION

For participation in this study you will receive $10 for participating in the first session and $20 for participating in the second session, for a total of $30. If you withdraw from the study prior to its completion you will receive compensation for the sessions you did participate in.

CONTACT

If you have any questions at any time about the study or the procedures, (or you experience adverse effects as a results of participating in this study) you may contact the researcher, Hilary Brown in the Psychology Department of Wilfrid Laurier University at (519) 884-1970, extension 2351 or brow1774@wlu.ca or Dr Alexandra Gottardo, extension (519) 884- 1970 extension 2169, or agottard@wlu.ca. This project has been reviewed and approved by the University Research Ethics Board at Wilfrid Laurier University. If you feel you have not been treated according to the description in this form, or your rights as a participant in research have been violated during the course of this project, you may contact Dr. Bill Marr, Chair, University Research Ethics Board, Wilfrid Laurier University, (519) 884-0710, extension 2468.

PARTICIPATION

Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at any time without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed your data will be returned to you or destroyed. You have the right to omit any question(s)/procedures you choose.

FEEDBACK

The results of this study will be presented at the principal investigator's Masters Thesis Defence, and may be published in journal articles and presented at conferences. If you wish to obtain information about the results of this research, it will be available to you in May 2006. If you have any questions about any aspect of this study at any time, you should feel free to contact Hilary Brown, via email brow1774@wlu.ca or Dr. Alexandra Gottardo at agottard@wlu.ca.

CONSENT

I have read and understand the above information. I have received a copy of this form. I agree to participate in this study.

Participant's signature ______________________________ Date ______________

Investigator's signature ______________________________ Date ______________

If you would like feedback regarding the general findings of the study by May 2006, please include your name and email address in the space provided below.

Name: ______________________________

Email: ______________________________

Appendix B ERP Stimuli

Appendix B_1 Visual Lists and Questions

Appendix B_2 Auditory Lists and Questions

Appendix B1

List 1
The reporter who attacked the senator admitted the serious error.
The chef who instructed the manager washed the dirty dishes.
The accountant who represented the client filed the urgent claim.
The client who fired the lawyer missed the important appointment.
The doctor who cured the mother bought the fresh flowers.
The actress who introduced the director won the challenging game.
The boy who chased the girl caught the slimy fish.
The nanny who watched the child cleaned the messy house.
The traveler who followed the locals missed the early train.
The musician who serenaded the crowd visited the charming village.
The waitress who served the family watched the exciting game.
The teacher who challenged the student painted the lovely picture.
The swimmer who dared the coach won the close race.
The president who addressed the senators walked the excited dog.
The officer who arrested the criminal climbed the steep stairs.
The pilot who dated the actress missed the final flight.
The nurse who bandaged the patient visited the old museum.
The examiner who disciplined the student administered the difficult test.
The dogcatcher who captured the animal located the new house.
The boss who fired the employee ran the demanding marathon.
The judge who threatened the defendant dismissed the ridiculous case.
The technician who confronted the boss deleted the important file.
The surgeon who examined the patient postponed the tropical vacation.
The salesman who surprised the buyer displayed the fantastic product.
The driver who assisted the hitchhiker crashed the old truck.
The runner who passed the opponent won the crucial race.
The fan that encouraged the player exited the packed building.
The student who corrected the speaker left the cramped room.
The girl who avoided the mailman returned the damaged package.
The dean who hired the professor quit the frustrating job.
The goalie who the player pushed fought the angry referee.
The student who the principal punished met the concerned parents.
The champion who the competitor challenged lost the deciding match.
The boss who the worker helped injured his aching back.
The woman who the conman tricked lost the stolen money.
The heckler who the comedian ignored pushed the annoying woman.
The guest who the hostess greeted employed the kind man.
The host who the contestant frightened answered the difficult question.
The teenager who the child spied on recalled the terrifying event.
The witness who the detective questioned called the worried office.
The mayor who the journalist interviewed beat the old record.
The assistant who the scientist invited won the top prize.
The driver who the officer stopped dispensed the expensive ticket.
The child who the mother calmed made the delicious coffee.
The audience who the speaker bored questioned the confused man.
The team who the engineer met designed the original aircraft.
The director who the writer called waved to the excited children.
The client who the florist visited decorated the fancy house.
The groom who the bride kissed requested the loud music.
The swimmer who the lifeguard saved watched the private beach.

The thief who the owner charged lost the significant case.
The defendant who the lawyer attacked celebrated the thrilling win.
The batter who the pitcher walked drove the fast car.
The model who the seamstress measured ordered the tasty pizza.
The architect who the carpenter questioned reviewed the complicated plans.
The child who the babysitter entertained answered the ringing phone.
The mother who the baby loved hugged the soft bear.
The star who the interviewer questioned watched the late show.
The couple who the priest counselled blessed the happy marriage.
The students who the librarian instructed shelved the heavy books.

List 2

The senator who the reporter attacked admitted the serious error.
The manger who the chef instructed washed the dirty dishes.
The client who the accountant represented filed the urgent claim.
The lawyer who the client fired missed the important appointment.
The mother who the doctor cured bought the fresh flowers.
The director who the actress introduced won the challenging game.
The girl who the boy chased caught the slimy fish.
The child who the nanny watched cleaned the messy house.
The locals who the traveler followed missed the early train.
The crowd who the musician serenaded visited the charming village.
The family who the waitress served watched the exciting game.
The student who the teacher challenged painted the lovely picture.
The coach who the swimmer challenged won the close race.
The senators who the president addressed walked the excited dog.
The criminal who the officer arrested climbed the steep stairs.
The actress who the pilot dated missed the final flight.
The patient who the nurse bandaged visited the old museum.
The student who the examiner disciplined administered the difficult test.
The animal who the dogcatcher captured located the new house.
The employee who the boss fired ran the demanding marathon.
The defendant who the judge threatened dismissed the ridiculous case.
The boss who the technician confronted deleted the important file.
The patient who the surgeon examined postponed the tropical vacation.
The buyer who the salesman surprised displayed the fantastic product.
The hitchhiker who the driver assisted crashed the old truck.
The opponent who the runner passed won the crucial race.
The player who the fan encouraged exited the packed building.
The speaker who the student corrected left the cramped room.
The mailman who the girl avoided returned the damaged package.
The professor who the dean hired quit the frustrating job.
The player who beat the goalie fought the angry referee.
The principal who punished the student met the concerned parents.
The competitor who challenged the champion lost the deciding match.
The worker who helped the boss injured his aching back.
The conman who tricked the woman lost the stolen money.
The comedian who ignored the heckler pushed the annoying woman.
The hostess who greeted the guest employed the kind man.
The contestant who frightened the host answered the difficult question.
The child who spied on the teenager recalled the terrifying event.
The detective who questioned the witness called the worried office.
The journalist who interviewed the mayor beat the old record.
The scientist who invited the assistant won the top prize.
The officer who stopped the driver dispensed the expensive ticket.
The mother who calmed the child made the delicious coffee.
The speaker who bored the audience questioned the confused man.
The engineer who met with the team designed the original aircraft.
The writer who called the director waved to the excited children.
The florist who visited the client decorated the fancy house.
The bride who kissed the groom requested the loud music.
The lifeguard who saved the swimmer watched the private beach.
The owner who charged the thief lost the significant case.
The lawyer who attacked the defendant celebrated the thrilling win.

The pitcher who walked the batter drove the fast car.
The seamstress who measured the model ordered the tasty pizza.
The carpenter who questioned the architect reviewed the complicated plans.
The babysitter who entertained the child answered the ringing phone.
The baby who loved the mother hugged the soft bear.
The interviewer who questioned the star watched the late show.
The priest who counselled the couple blessed the happy marriage.
The librarian who instructed the students shelved the heavy books.

Visual Questions

1. Did someone admit to an error?
2. Were the clothes washed?
3. Was an urgent claim filed?
4. Did someone miss an appointment?
5. Were fake flowers bought?
6. Was the game lost?
7. Did someone catch a cat?
8. Was the house cleaned?
9. Did someone miss the bus?
10. Did the crowd see a musician?
11. Was a boring game being watched?
12. Was a fence being painted?
13. Did the coach and the swimmer race?
14. Was the dog lonely?
15. Did someone fall down the stairs?
16. Was someone on time for their flight?
17. Did someone visit the art museum?
18 Was an easy test administered?
19. Was an animal returned to the pound?
20. Did someone run in a marathon?
21. Was the case dismissed?
22. Was the file recovered?
23. Did someone postpone the vacation?
24. Was the product displayed?
25. Did someone stay crash the truck?
26. Did someone compete in a race?
27. Did someone leave the building?
28. Did someone hurry from the room?
29. Did someone wait for the doctor?
30. Did someone get fired from their job?
31. Was the referee involved in a fight?
32. Were the teachers met with?
33.Did someone lose the match?
34. Did someone injure their leg?
35. Did someone win some money?
36. Did someone pay for breakfast?
37. Was the man employed?
38. Did someone answer a difficult question?
39. Was someone spied on?
40. Did someone call the worried office?
41. Was an old record beaten?
42. Did someone lose the prize?
43. Did someone get a ticket?
44. Was someone making tea?
45. Was someone on time for dinner?
46. Was an aircraft designed?
47. Were the children waved to by someone?
48. Did someone decorate the house?
49. Did someone sing along with the music?
50. Was the beach a public beach?
51. Did someone lose the case?

52. Did someone celebrate their first win?
53. Did someone shop for a table?
54. Did someone order a pizza?
55. Did someone change the plans?
56. Was someone watching television?
57. Did someone hug the dog?
58. Was someone watching the late show?
59. Was the marriage blessed?
60. Were magazines put out on shelves?

Appendix B_2

List 1
The senator who disliked the assistant admitted the costly error.
The parents who paid the babysitter ate the delicious food.
The child who visited the grandmother wrecked the old car.
The criminal who assaulted the runner continued the long journey.
The fireman who rescued the man attended the expensive college.
The editor who criticized the reporter consulted the opinionated owner.
The accountant who helped the businessman thanked the rich man.
The student who disliked the instructor studied the hidden answers.
The child who bit the dentist cleaned the messy office.
The sheriff who guarded the prisoner issued the public statement.
The chairman who contacted the actor represented the worthwhile charity.
The hostess who fired the planner cancelled the glamorous party.
The child who ignored the mother broke the antique lamp.
The passenger who tipped the driver carried the large suitcases.
The manager who hired the electrician solved the tricky problem.
The director who cast the star watched the pilot show.
The jogger who passed the man enjoyed the quiet park.
The criminal who identified the witness arranged the new deal.
The coach who benched the player planned the new strategy.
The doctor who dismissed the patient called the yellow cab.
The child who admired the star passed the rushing river.
The speaker who introduced the woman posted the updated schedule.
The boy who bothered the girl moved the heavy chair.
The leader who instructed the scout climbed the tall tree.
The father who missed the grandfather rocked the sleeping baby.
The captain who mentored the sailor reserved the best table.
The customer who ignored the handyman built the beautiful house.
The enemy who captured the soldier destroyed the secret plans.
The cheerleader who disliked the athlete crashed the private party.
The investigator who organized the committee ignored the upsetting results.
The author who the child adored visited the tiny shop.
The pharmacist who the doctor recommended administered the experimental drug.
The captain who the team nominated explained the different rules.
The visitor who the local greeted invented the fun game.
The expert who the secretary thanked fixed the broken computer.
The employee who the employer fired supplied the missing data.
The landlord who the tenant sued issued the final warning.
The volunteer who the family welcomed found the lost dog.
The cartoonist who the artist trained designed the colourful flier.
The nanny who the mother hired carried the adorable baby.
The cashier who the butcher tricked donated the stolen money.
The golfer who the agency recruited promoted the entertaining event.
The politician who the assistant invited evaluated the new program.
The farmer who the nurse married operated the heavy machinery.
The painter who the surveyor called completed the lengthy questionnaire.
The mechanic who the chef annoyed started the noisy car.
The professional who the coach hired trained the motivated team.
The editor who the writer acknowledged reviewed the latest article.
The expert who the policeman called disabled the explosive device.
The carpenter who the supplier monitored corrected the dangerous mistake.

The contractor who the designer consulted provided the fair estimate.
The mover who the chairman praised centered the valuable picture.
The singer who the audience watched enjoyed the amazing performance.
The staff who the purchaser reached conducted the risky experiment.
The programmer who the child interviewed invented the new toy.
The adventurer who the guide assisted climbed the snowy mountain.
The psychiatrist who the detective introduced interrogated the tired suspect.
The supplier who the storeowner requested demanded the detailed receipt.
The engineer who the company consulted eliminated the challenging problem.
The saleswoman who the manager assigned wrapped the beautiful present.

List 2

The assistant who the senator disliked admitted the costly error.
The babysitter who the parents paid ate the delicious food.
The grandmother who the child visited wrecked the old car.
The runner who the criminal assaulted continued the long journey.
The man who the fireman rescued attended the expensive college.
The reporter who the editor criticized consulted the opinionated owner.
The businessman who the accountant helped thanked the rich man.
The instructor who the student disliked studied the hidden answers.
The dentist who the child bit cleaned the messy office.
The prisoner who the sheriff guarded issued the public statement.
The actor who the chairman contacted represented the worthwhile charity.
The planner who the hostess fired cancelled the glamorous party.
The mother who the child ignored broke the antique lamp.
The driver who the passenger tipped carried the large suitcases.
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The star who the director cast watched the pilot show.
The man who the jogger passed enjoyed the quiet park.
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The player who the coach benched planned the new strategy.
The patient who the doctor dismissed called the yellow cab.
The star who the child admired passed the rushing river.
The woman who the speaker introduced posted the updated schedule.
The girl who the boy bothered moved the heavy chair.
The scout who the leader instructed climbed the tall tree.
The grandfather who the father missed rocked the sleeping baby.
The sailor who the captain mentored reserved the best table.
The handyman who the customer ignored built the beautiful house.
The soldier who the enemy captured destroyed the secret plans.
The athlete who the cheerleader disliked crashed the private party.
The committee who the investigator organized ignored the upsetting results.
The child who adored the author visited the tiny shop.
The doctor who recommended the pharmacist administered the experimental drug.
The team who nominated the captain explained the different rules.
The local who greeted the visitor invented the fun game.
The secretary who thanked the expert fixed the broken computer.
The employer who fired the employee supplied the missing data.
The tenant who sued the landlord issued the final warning.
The family who welcomed the volunteer found the lost dog.
The artist who trained the cartoonist designed the colourful flier.
The mother who hired the nanny carried the adorable baby.
The butcher who tricked the cashier donated the stolen money.
The agency who recruited the golfer promoted the entertaining event.
The assistant who invited the politician evaluated the new program.
The nurse who married the farmer operated the heavy machinery.
The surveyor who called the painter completed the lengthy questionnaire.
The chef who annoyed the mechanic started the noisy car.
The coach who hired the professional trained the motivated team.
The writer who acknowledged the editor reviewed the latest article.
The policeman who called the expert disabled the explosive device.
The supplier who monitored the carpenter corrected the dangerous mistake.
The designer who consulted the contractor provided the fair estimate.
The chairman who praised the mover centered the valuable picture.

The audience who watched the singer enjoyed the amazing performance.
The purchaser who reached the staff conducted the risky experiment.
The child who interviewed the programmer invented the new toy.
The guide who assisted the adventurer climbed the snowy mountain.
The detective who introduced the psychiatrist interrogated the tired suspect.
The storeowner who requested the deliveryman demanded the detailed receipt.
The company who consulted the engineer eliminated the challenging problem.
The manager who assigned the saleswoman wrapped the beautiful present.

Auditory Questions

Was a costly error made?
Was the food eaten?
Did someone wreck the new car?
Was someone's journey stopped?
Did someone graduate from high school?
Did someone consult the owner?
Was the man poor?
Were the answers studied?
Was the child at the doctor's?
Was a statement issued?
Did someone donate to the hospital?
Was the party cancelled?
Did someone break the TV?
Was someone reading a book?
Was a plumbing problem solved?
Did someone watch the pilot show?
Did the jogger pass a child?
Did someone arrange a new deal?
Was someone benched?
Did someone call a cab?
Did someone swim in the lake?
Did someone sleep in late?
Was the girl being bothered?
Did someone climb a tree?
Did the grandmother rock the baby?
Was the best table reserved?
Was a barn being built?
Was the soldier captured?
Did someone crash the party?
Were the results considered?
Did the child dislike the author?
Was the drug experimental?
Did the team nominate the captain?
Did the visitor greet the local?
Did someone buy the computer?
Did someone supply the missing data?
Was the landlord being sued?
Did someone find the cat?
Was a menu designed?
Did the mother confide in the doctor?
Was the money donated?
Did the agency recruit a movie star?
Was the new program being evaluated?
Was the farmer married to a teacher?
Was a questionnaire being filled out?
Was the car quiet?
Was the team being evaluated?
Was the latest article reviewed?
Did the policeman call an expert?
Did someone correct the mistake?
Was an expensive estimate provided?

Was the picture being centred?
Did the audience watch the singer?
Was an experiment being conducted?
Did the child interview a programmer?
Did the adventurer go rock climbing?
Was the suspect full of energy?
Did someone ask for a receipt?
Did the company consult a plumber?
Was a birthday present wrapped?