Phonological and Orthographic Processing: One or Both Hemispheres?

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Abstract

Laterality refers to the contention that the left and right hemisphere of the brain process information differently. Currently under debate is whether there is laterality of phonological and orthographic processing. Two experiments used a lexical decision task and a priming procedure along with a distractor to the left or right visual field to test laterality. Experiment I manipulated sound similarity between strings whereas Experiment II manipulated visual similarity between strings. Both experiments tested three hypotheses. First, primed letter strings would be faster and more accurate than non-primed letter strings. Second, both hemispheres would show priming. Third, the left hemisphere in Experiment I would show greater priming than the right hemisphere, whereas the right hemisphere in Experiment II would show greater priming than the left hemisphere.
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Phonological and Orthographic Processing: One or Both Hemispheres?

Language for most humans is the primary source of communication and as a result is regarded as an important part of human life. Language can be broken down into two parts: processing of language and the production of language. The processing of language involves the appropriate sequencing of mental steps in order to understand language. The production of language involves the verbal, written, or signed forms of the specific language. Due to its importance, language has been widely studied by linguists, psychologists, as well as neurologists. One of the most highly researched areas in language is the laterality of reading.

Laterality of reading refers to the contention that the left and right side of the brain process information differently. These differences are also known as asymmetries. Some of the first reports of language lateralization began with Broca and Wernicke who introduced the idea of a unilateral left hemisphere control over language functions (Broca, 1861; Wernicke, 1911, as cited by Szaflarski, Holand, Schmithorst, & Byars, 2006). This idea is also known as an absolute model and suggests that only the left hemisphere can process language. Other findings that have been interpreted to support this absolute model are the costs to time and accuracy of language processing when the language is presented to the right hemisphere (Beeman & Chiarello, 1998, as cited by Chiarello, Hasbrook, & Maxfield, 1999). These findings have been suggested to be the result of callosal relay from the illiterate right hemisphere to the more language dominant left hemisphere (Efron, 1963). However, there are alternate interpretations of these findings. For example, relative models suggest that while the left hemisphere is dominant for language processing (e.g., Iacoboni & Zaidel, 1996; Leiber, 1976; Rutherford & Lutz, 2004), the right hemisphere does have some limited linguistic competence (Chiarello, Hasbrooke, & Maxfield, 1999; Rutherford, 2006; Underwood, Rusted, & Thwaites, 1983). According to this view, the costs to time and accuracy of language processing by the right hemisphere is
due to the use of inefficient and less specialized strategies compared to the left hemisphere (Rutherford & Lutz, 2004).

Research investigating the laterality of reading has, in the past, been typically conducted on neurologically impaired humans. In fact, one of the major findings in this line of research was discovered this way. For example, research with commissurotomy patients (e.g., Sidtis, Volpe, Wilson, Rayport, & Gazzaniga, 1981; Zaidel & Peters, 1981) has revealed that there are different processing strategies used by each hemisphere. One of these strategies is known as the lexical strategy. The lexical strategy involves the matching of a whole letter string to a memory representation in the brain (Iacoboni & Zaidel, 1996). This type of processing occurs with familiar words (Iacoboni & Zaidel, 1996) and is believed to be available to both the left and right hemisphere (Rutherford, 2006). The second strategy is known as the non-lexical strategy. This strategy involves the sounding out of words and usually occurs with unfamiliar words (Iacoboni & Zaidel, 1996). It is believed that the non-lexical strategy is only available to the left hemisphere. It is important to note that not only are individuals with different neurological abilities used to study the laterality of reading but multiple experimental methods are used as well.

Many different types of experimental methods have been used to analyze the laterality of reading, some of which include the Wada test (e.g., Watson, Pusakulich, Ward, & Hermann, 1998), dichotic listening tasks (e.g., Asbjornsen & Helland, 2006), and fMRI techniques (e.g., Szaflarski, Holland, Schmithorst, & Byars, 2006). The most widely employed method, however, is the lexical decision task (e.g., Bloch & Zaidel, 1996; Paap & Newsome, 1981; Rutherford, 2006; Rutherford & Lutz, 2004). The lexical decision task involves the presentation of a group of letters, known as a letter string, to a participant. The participant is instructed to respond if the letter string is, or is not, a word. In a typical lexical decision task there are two types of letter strings: words and pseudowords. Word letter
strings represent groups of letters that spell a word. Pseudowords are letter strings that follow the rules of spelling but are not actual words (e.g., Darp).

In the traditional lexical decision experiment a fixation point is presented in the middle of the screen and the letter string is presented to either the left or the right side of this fixation point. If the letter string is presented to the left side of the fixation point it is a left visual field presentation (LVF). If the letter string is presented to the right of the fixation point it is a right visual field presentation (RVF). By presenting the letter string to only one of the visual fields, researchers are able to localize which hemisphere is processing the letter string. The reason for this has to do with the visual and neuronal connections of the brain. That being said, it should be noted that lateralized displays bias processing to the contralateral hemisphere but cannot constrain processing to that hemisphere because the corpus callosum relays information from one to the other hemisphere. Notwithstanding the relay, researchers determine which hemisphere is better, worse, or the same at processing certain types of letter strings by comparing processing by each hemisphere.

Despite the wide spread use of this type of lexical decision task the results may not accurately generalize to the normal reading situation. The reason for this is that the words are presented to the left or right of centre. Due to the fact that people read with a central fixation on the word, this type of experiment has questionable ecological validity. In order to account for this issue, Rutherford and Lutz (2004) developed a more ecologically valid version of the lexical decision task.

In this version of the lexical decision task (Rutherford & Lutz, 2004) the letter string is presented to the center of the participant’s visual field. At the onset of the letter string a blinking distractor is presented to the left, right, or neither side of the letter string. The purpose of this distractor is to temporarily disengage the processing of the contralateral hemisphere leaving the unaffected ipsilateral hemisphere to process the letter string (Cowan 1995, as cited by Rutherford & Lutz, 2004).
In other words, if the distractor is presented to the left side of the letter string, this will temporarily disengage the right hemisphere allowing the left hemisphere to process the letter string. The participant is to respond if the letter string does or does not spell a word as occurs in the typical lexical decision task. In order to respond, participants are instructed to press certain keys on a computer keyboard that will correspond to if the letter string does or does not spell a word.

There are three important features to this novel version of the lexical decision task. First, it is more ecologically valid as it allows the letter string to be presented centrally, rather than in the participant’s periphery, therefore more closely mimicking how people read. Second, the no distractor condition permits researchers to understand how the hemispheres interact when they are both allowed to process the letter string at the same time. Third, as was the case with lateralized displays, the procedure provides evidence of relative hemispheric competence (e.g., Rutherford, 2006; Rutherford & Lutz, 2004).

Within the field of laterality of reading, what is still not fully understood and needs further investigation is whether the hemispheres differ in the ability for phonological (i.e., non-lexical) and orthographic (i.e., lexical) processing. For example, past research conducted on neurologically impaired individuals such as commissurotomy patients (e.g., Sidtis, Volpe, Wilson, Rayport, & Gazzaniga, 1981; Zaidel & Peters, 1981) and neurologically intact individuals (e.g., Sasanuma, Itoh, Kobyashi, & Mori, 1980) have demonstrated that only the left hemisphere is capable of processing phonological information, whereas only the right hemisphere is capable of orthographic processing. More recent research conducted by Lavidor and Ellis (2003) further supports this view.

Lavidor and Ellis (2003) investigated the laterality of phonological and orthographic processing using a priming procedure. Priming involves the presentation of two consecutive stimuli in which the first stimulus, the prime, facilitates the processing of the succeeding target stimulus because the prime
activates a lexical representational system in the brain (Forster, 1987, as cited by Lavidor and Ellis, 2003) that contains the same characteristics as the target. As has been empirically demonstrated, the participant should be faster and more accurate to the primed target in comparison to the non-primed target (Chiarello, 1985; Hutchins & Palmer, 2008; Lavidor & Ellis, 2001; Perfetti & Bell, 1991). In their study, Lavidor and Ellis (2003) presented the prime letter string to the center of the participant’s visual field, while the target was presented to either the left or the right visual field. The two letter strings were manipulated by phonological or orthographic similarity with one another and the participants were instructed to respond only to the central letter string. Phonologically similar letter strings sound alike whereas orthographically similar letter strings look alike. The results revealed increased speed and accuracy of lexical decision when a phonologically related lateralized target was presented to the RVF, but not the LVF. Also revealed was an increase in speed and accuracy of lexical decision when an orthographically related lateralized target was presented to the LVF, but not the RVF. These results suggest that only the left hemisphere has phonological processing capabilities while only the right hemisphere has orthographic processing capabilities.

Not all research, however, is in agreement with the findings that only the left hemisphere can process phonology and only the right hemisphere can process orthography (e.g., Chiarello, Hasbrooke, & Maxfield, 1999; Crossman & Polich, 1988). Chiarello et al. (1999) conducted a study that investigated the effects of an unattended distractor on the pronunciation of a target word in both the left and right visual fields. The unattended distractor and target words were phonologically and orthographically manipulated to be similar or dissimilar to one another. The target and distractor words were presented in a crossword fashion in which the participant was instructed before hand on which axis was the target (i.e., vertical or horizontal) and that they were to verbally pronounce the target word. The results showed that both the left and the right hemispheres are capable of phonological and orthographic processing.
A possible reason for these conflicting results for orthographic lateralization may involve the control of extraneous variables such as orthographic neighborhood size. Orthographic neighborhood size refers to how many new words can be created by manipulating one letter of a target word, where high neighborhood size denotes more words. As shown in past research (Lavidor & Ellis, 2001), neighborhood size can affect asymmetries in orthographic processing, with large neighborhood sizes favoring the right hemisphere. In returning to the research presented above, Chiarello, et al., (1999) did not control for neighborhood size. This lack of third variable control could have potentially biased hemispheric asymmetry.

Due to these conflicting results, it is still not understood whether the hemispheres differ in competence for processing phonological and orthographic information. Thus, the purpose of the present study is to investigate the question and to further the literature within the field of laterality of reading. In order to accomplish these two separate studies will be conducted using the more ecologically valid lexical decision task in combination with a priming procedure. The first study will analyze the laterality of phonological processing whereas the second study will analyze the laterality of orthographic processing while controlling for neighborhood size.

Experiment I

The purpose of the first experiment is to test hemispheric asymmetry in phonological processing. Three hypotheses are tested: First, primed letter strings will be faster and more accurate than non-primed letter strings. Second, both hemispheres will show phonological priming. Third, the left hemisphere will show greater priming than the right hemisphere.

Method
Participants

A convenience sample of 65 students (20 Men and 45 Women) from the University of British Columbia – Okanagan campus participated. Six participants’ data were excluded from the analysis due to violation of study requirements – they were on medication. Thus, a total of 59 students (18 Men and 41 Women) participated. The age of participants ranged from 17 years and three months to 24 years and four months ($M = 18.83, SD = 1.49$). Participation was restricted to students at the university who had never participated in the study before, who were right handed (as deemed by a positive score on the handedness questionnaire), who spoke English as their first language, who were not on medication with the possible exception of hormones for birth control, and who had no reading disability. Participants were able to sign up for the study through one of three ways; (1) through an online website known as SONA, (2) drop in to the psychology laboratory and book a time slot or (3) email the researcher directly to indicate interest in the study.

Participation in this study was completely voluntary, but incentives were provided in two ways. First, participants enrolled in a psychology course were eligible to receive .5% course credit towards their psychology class through participation in this study. Second, participants not enrolled in a psychology course or those in a psychology course who declined credit were eligible to receive a $10 incentive for completion of the study.

Materials

Adult participants were given a battery of tests that included a demographic form, a handedness questionnaire, a phonological processing test, and a computer task.

Demographic form.
The demographic form (see Appendix A) consisted of a 5-item checklist that provided general information about the participant. The researcher read each question to the participant and asked the participant to verbally respond. Each response was recorded by the researcher on the demographic form and retained for records. The purpose of this form was to determine if the participant had a known reading disability, was on any medication with the possible exception of hormones for birth control, and if English was their first language.

Handedness Questionnaire

The handedness questionnaire (see Appendix B) consisted of a 12-item checklist to operationally determine if a participant was left handed, right handed, or ambidextrous. Each item identified an activity and the participant reported (R) if he/she would use their right hand, (L) if he/she would use their left hand or (E) if he/she would use either hand for each activity. Right hand responses were scored as +1, left hand with -1, either hand with 0. The scores were then totaled. To be classified as right handed the participant needed to have a score of +1 or greater. To be classified as left handed the participant needed to have a score of -1 or less. To be classified as ambidextrous the participant needed a score of 0.

Word Attack

The word attack form (see Appendix C) was a standardized phonological pronunciation task consisting of a list of 30 nonsense words. These nonsense words, also known as pseudowords, were letter strings that followed the rules of spelling but did not spell an actual word (e.g., kash). A correct response was defined as pronouncing the proper grapheme – phoneme conversion for the letter string. Correct answers were denoted by a +1 whereas incorrect answers were denoted by a 0. The correct responses were totaled out of a possible 30 correct. The score was compared to age or grade norms in
order to determine a standardized measure of phonological ability. A cut-off percentile score of 50% was necessary for participation in the study.

Computer Task

Inquisit 3 was used to program the stimuli to appear on an IBM compatible Pentium I computer. Strings of 4-6 white letters in System Times New Roman size 14 font were presented to center of monitor against a black background. There were a total of 196 stimuli, half were words and half were pseudowords.

A distractor was presented at the onset of each letter string consisting of a 1 dg visual angle white square. The distractor blinked on and off at 50 ms intervals for 300 ms. The distractor was presented to either the left or right visual field 7 cm from the center screen as measured from the medial position of the distractor. A left or right distractor condition occurred with an equal probability across all trials.

Procedure

The demographic form, handedness questionnaire, word attack, and computer task were completed in this order once the informed consent (see Appendix D) was signed. After the computer task was completed, the participant was fully debriefed and given a copy of both the informed consent as well as the debriefing form (see Appendix E).

During the computer task, participants were seated in a quiet and darkened testing room with their chin positioned in a chin rest at exactly 57 cm from the center of the computer monitor. To begin each trial the participant was instructed to press the spacebar. At the start of each trial a fixation cross appeared in the center of the computer monitor for a duration of 500 ms after which a letter string replaced the fixation cross. The letter string, which spelled either a word or a pseudoword, was
accompanied by a blinking distractor to either the left or right side of the computer monitor. The participant was instructed to answer if the letter string did or did not spell a word. Affirmative responses were indicated by simultaneously pressing the f and j keys with their index finger of the left and right hand, respectively. Negative responses were indicated by simultaneously pressing the d and k keys with their middle finger of their left and right hand, respectively. A trial was finished after the participant answered or after 2 s of no response, whichever came first. During this task accuracy and response times were measured.

The first block was a practice block consisting of 32 trials. This block was followed by three test blocks consisting of 64 randomized trials each. Out of the total 64 stimuli per test block, 32 trials were words and 32 were pseudowords. One half of each string type was accompanied by a left distractor and half by a right distractor. Within each string and distractor type, four trials were phonologically primed and 12 were not primed. Phonological priming involves the presentation of two consecutive similar sounding stimuli in which the first stimulus, the prime, facilitates the processing of the succeeding target stimulus because the prime activates a lexical representational system in the brain (Forster, 1987, as cited by Lavidor and Ellis, 2003) that contains the same characteristics (i.e., sound) as target. Where primed strings sounded similar to one another, not primed strings sounded dissimilar.

Design

The present experiment used a 2 X 2 X 2 repeated measures ANOVA design. Thus, there were three independent variables each consisting of two levels. The first independent variable, letter string, contained word strings and pseudoword strings. The second independent variable, distractor location, contained a left visual field distractor and a right visual field distractor. The third independent variable, phonological priming, contained phonologically primed letter strings and phonologically not primed letter strings. Both accuracy and reaction time were measured as dependent variables.
Results

Separate repeated-measures analyses of string type, distractor location, and prime type were conducted for reaction time and accuracy at an alpha of .05.

Reaction Time

The overall analyses revealed a significant main effect for string type \([F (1, 58) = 41.13, p < .001, \eta_p^2 = 42\%]\). The means of string type found words \((M = 718.272, SD = 14.703)\) to be significantly faster than pseudowords \((M = 793.520, SD = 18.557)\). A main effect of prime type \([F (1, 58) = 63.67, p < .001, \eta_p^2 = 52\%]\) was also found. The means of prime type revealed primed strings \((M = 735.404, SD = 15.667)\) were significantly faster than non-primed \((M = 776.487, SD = 16.112)\) strings. These main effects, however, were modified by a significant visual field X string type X prime type interaction \([F (1, 58) = 5.61, p < .05, \eta_p^2 = 8\%]\). To elucidate the source of the interaction, separate analyses of each string type were conducted.

Pseudowords

The results unveiled a visual field X prime type interaction \([F (1, 58) = 5.97, p < .05, \eta_p^2 = 9\%]\). Separate analyses of each visual field exposed a significant effect of prime type within left distractor condition \([F (1, 58) = 31.24, p < .001, \eta_p^2 = 35\%]\), but not the right distractor condition \([F (1, 58) = .95, p > .05, \eta_p^2 = 2\%]\). The means of the left distractor condition were faster to primed \((M = 763.98, SD = 161.17)\) than non-primed \((M = 818.93, SD = 160.59)\) pseudowords, suggesting that the left hemisphere does show priming. In contrast, the right hemisphere does not.

Words

A significant main effect of prime type \([F (1, 58) = 52.84, p < .001, \eta_p^2 = 48\%]\) was found for word strings. Responses were significantly faster to primed \((M = 693.87, SD = 15.11)\) than non-primed
words ($M = 742.68, SD = 15.05$) suggesting that both hemispheres show phonological priming of word letter strings.

**Accuracy**

The overall analyses revealed a significant main effect for prime type [$F(1, 58) = 56.06, p < .001, \eta_p^2 = 49\%$], with higher accuracy to primed ($M = .947, SD = .006$) than non-primed letter strings ($M = .908, SD = .006$). These results suggest that both hemispheres showed priming and there was no difference between words and pseudowords.

**Discussion**

The results from Experiment I supported all three hypotheses. Consistent with previous research (e.g., Chiarello, 1985; Hutchins & Palmer, 2008; Lavidor & Ellis, 2001; Perfetti & Bell, 1991) and our first hypothesis, responses were processed faster and more accurately to a letter string that followed a similar sounding string (i.e., primed), than one that was not similar in sound (i.e., non-primed). The enhancement was likely due to the prime activating a lexical representational system in the brain that contains the same characteristics as the target (Forster, 1987, as cited by Lavidor & Ellis, 2003), which speeds responses because there is no need to reactivate the lexical representational system and makes them more accurate because there is less likelihood of the target activating a different, incorrect, system.

Also consistent with previous research (e.g., Chiarello, et al, 1999; Underwood, et al., 1983) and our second hypothesis, both the left and right hemisphere showed phonological priming for words. This finding is consistent with evidence that both the left and the right hemispheres contain lexical processing strategies and suggests both hemispheres have simple phonological processing abilities. Understanding basic human language processing, enables one to understand the suggestion that both hemispheres have simple phonological processing abilities. Under normal reading conditions, letter strings are typically familiar words. Due to this familiarity, readers process each letter string using
orthographic (i.e., lexical) processing strategies that are available to both hemispheres. Since the letter string is familiar to the reader, information such as the look (i.e., orthography), the sound (i.e., phonology), and the meaning (i.e., semantics) are stored in interconnected neural networks within the brain. Even though the reader is using the orthographic processing strategy, there is a spread of activation to the phonological and semantic neural networks. It is this spread in activation toward the phonological neural network that makes the phonological processing of words simple. The words phonology are already known, thus, the simultaneous activation of orthographic and phonological codes allows a more simplistic top-down processing rather than the more complex, print-to-sound, bottom-up processing required for unfamiliar words.

Consistent with our third hypothesis, the left hemisphere showed greater priming than the right, but only for pseudowords. This finding is consistent with evidence suggesting that the left hemisphere can invoke a non-lexical process that converts print-to-sound (e.g., Chiarello, et al, 1999; Iacoboni & Zaidel, 1996; Rutherford, 2006) in order to match a letter string to entries in the mental lexicon. This finding also suggests that only the left hemisphere is capable of complex phonological processing. As stated above, readers typically invoke orthographic processing when reading familiar words. However, when words are unfamiliar, this type of processing will be ineffective because the letter string orthography is unknown. Instead, the print-to-sound, phonological conversion process is invoked in order to determine the sound of the letter string and find a match, if there is one, to other entries in the mental lexicon. It is this print-to-sound, bottom-up processing, that requires more complex phonological processing abilities.

There are two possible explanations for the left hemisphere superiority of phonological processing. First, the superiority may be the result of asymmetries in lexical and non-lexical processing strategies, as suggested above. More specifically, past research has demonstrated that both hemispheres have access to lexical processing which is invoked for the processing of familiar letter strings. Only the
left hemisphere, however, is capable of the non-lexical, print-to-sound, processing required for unfamiliar letter strings. Second, the left hemisphere superiority may be caused by the asymmetries in sequential processing abilities. Prior research has demonstrated that the left hemisphere has faster and more accurate sequential processing abilities than the right hemisphere (Efron, 1963; Rutherford, 2003). Since phonological processing requires the quick and accurate ordering of sounds, superior sequential processing abilities should lead to both a fast and accurate processing of stimuli requiring the conversion of letters to sounds.

Experiment II

The purpose of the second experiment is to test hemispheric asymmetry in orthographic processing. Three hypotheses are tested: First, primed letter strings will be faster and more accurate than non-primed letter strings. Second, both hemispheres will show orthographic priming. Third, the left hemisphere will show greater priming than the right hemisphere.

Method

Participants

A convenience sample of 68 students (21 Men and 47 Women) from the University of British Columbia – Okanagan campus participated. Nine participants’ data were excluded from the analysis due to violation of study requirements – they were on medication, were left handed, or could not properly see the stimuli. Thus, the data from a total of 59 subjects were analyzed (19 Men and 40 Women). The age of participant’s ranged from 18 years and three months to 36 years and five months ($M = 19.056$, $SD = 2.523$). The restrictions in the present experiment were the same as the first, as were the sign up procedures, and the incentives for participation.

Materials
All materials were the same as in Experiment I, except for the stimuli. The word letter string stimuli were four-to-five letters in length and were all obtained from a study conducted by Lavidor & Ellis (2003). The stimuli in the present experiment consisted of orthographically primed and orthographically not primed letter strings. Orthographic priming involves the presentation of two consecutive similar looking stimuli in which the first stimulus, the prime, facilitates the processing of the succeeding target stimulus. All orthographically primed words in the present study contain high orthographic neighborhood size. Orthographic neighborhood refers to the number of words that can be created by changing one letter of a target word. In the present study high orthographic neighborhood size is defined as words in which 10 or more other words can be created by changing one letter of the target word. For example, the letter string *cover* contains a high orthographic neighborhood size because it has 13 orthographic neighbors, some of which include coven, covet, cower, and lover (Lavidor & Ellis, 2001).

The first block was a practice block consisting of 32 trials. This block was followed by three test blocks consisting of 64 randomized trials each. Out of the total 64 stimuli per test block, 32 trials were words and 32 were pseudowords. Half of each string type was accompanied by a left distractor and half by a right distractor. Within each string and distractor type four trials were orthographically primed and 12 were orthographically not primed.

**Procedure**

All procedures were identical to the procedures used in Experiment I

**Design**

The present experiment used a 2 X 2 X 2 repeated measures ANOVA design. Thus, there were three independent variables each consisting of two levels. The first independent variable, letter string, contained word letter strings and pseudoword letter strings. The second independent variable, distractor
location, contained a left visual field distractor and a right visual field distractor. The third independent
variable, orthographic priming, contained orthographically primed letter strings and orthographically
not primed letter strings. Both accuracy and reaction time were measured as dependent variables.

Results

As in Experiment I, separate repeated-measures analyses of string type, distractor location, and
prime type were conducted for reaction time and accuracy at an alpha of .05.

Reaction Time

The overall analyses revealed three significant main effects. First, a main effect for string type
\[ F(1, 58) = 54.21, p < .001, \eta^2_p = 48\% \] was found. Assessing the means of string type exposed words
\( M = 694.525, SD = 16.446 \) to be significantly faster than pseudowords \( M = 755.451, SD = 17.044 \).
Second, a significant main effect for prime type \[ F(1, 58) = 2.48, p < .001, \eta^2_p = 81\% \] was also
uncovered. The means of prime type revealed primed strings \( M = 683.721, SD = 16.022 \) were
significantly faster than non-primed strings \( M = 766.255, SD = 16.845 \). However, these main effects
were modified by a significant visual field X prime type interaction \[ F(1, 58) = 28.46, p < .001, \eta^2_p =
33\% \] and a significant string type X prime type interaction \[ F(1, 58) = 4.19, p < .05, \eta^2_p = 7\% \]. To
expose the source of these interactions, separate analyses were conducted for each string type and prime
type.

Pseudowords

A significant visual field X prime type interaction \[ F(1, 58) = 10.99, p < .01, \eta^2_p = 16\% \] was
found for pseudowords. Separate analyses of each visual field revealed a significant effect of prime type
within the left distractor condition \[ F(1, 58) = 1.100, p < .001, \eta^2_p = 66\% \]. The means of the left
distractor condition were faster to primed ($M = 702.198, SD = 17.42$) than non-primed ($M = 811.275, SD = 19.672$) pseudowords. A significant effect of prime type within the right distractor condition $[F (1, 58) = 49.71, p < .001, \eta_p^2 = 46\%]$ was also revealed. The means of the right distractor condition were faster to primed ($M = 659.914, SD = 18.559$) than non-primed ($M = 716.772, SD = 15.604$) pseudowords. These results suggest that both hemispheres show priming for pseudowords.

Separate analyses of each prime type revealed significantly faster processing of non-primed pseudowords in the right ($M = 791.012, SD = 139.065$) compared to the left hemisphere ($M = 811.275, SD = 1851.10$), with $[t(58) = 2.60, p < .05, \eta^2 = 10.30\%]$. This suggests that the right hemisphere relies on a speedier strategy than used by the left when the priming context is removed.

Words

A significant visual field X prime interaction $[F (1, 58) = 7.613, p > .01, \eta_p^2 = 12\%]$ was found for words. Separate analyses of each visual field revealed a significant effect of prime type within the left distractor condition $[F (1, 58) = 1.362, p < .001, \eta_p^2 = 70\%]$. The means of the left distractor condition were faster to primed ($M = 655.453, SD = 16.740$) than non-primed ($M = 745.962, SD = 17.904$) words. A significant effect of prime type within the right distractor condition $[F (1, 58) = 49.71, p < .001, \eta_p^2 = 46\%]$ was also uncovered. The means of the right distractor condition were faster to primed ($M = 659.914, SD = 18.559$) than non-primed ($M = 716.772, SD = 15.604$) words. These results suggest that both hemispheres show priming for words.

Separate analyses of each prime type revealed significantly faster processing of non-primed words in the right hemisphere ($M = 716.772, SD = 119.858$) than the left hemisphere ($M = 745.962, SD = 137.526$), with $[t(58) = 3.86, p < .001, \eta^2 = 2.04\%]$. This suggests that the right hemisphere relies on a speedier strategy than used by the left when the priming context is removed.
Accuracy

The overall analysis revealed two significant main effects. First, there was a significant main effect of visual field \( F(1, 58) = 61.405, p < .001, \eta_p^2 = 51\% \) with the means revealing the right visual field \((M = .954, SD = .004)\) was more accurate than the left visual field \((M = .923, SD = .005)\). Second, a significant main effect for prime type \( F(1, 58) = 1.727, p < .001, \eta_p^2 = 75\% \) was also found. According to the means, primed strings \((M = .946, SD = .004)\) were significantly more accurate than non-primed strings \((M = .902, SD = .005)\). However, these main effects were modified by a significant visual field X prime interaction \( F(1, 58) = 16.917, p < .001, \eta_p^2 = 23\% \), a significant string type X prime type interaction \( F(1, 58) = 5.538, p < .05, \eta_p^2 = .9\% \) and a significant visual field X string type X prime type interaction \( F(1, 58) = 14.794, p < .001, \eta_p^2 = 20\% \). To uncover the source of these interactions, separate analyses were conducted for each string type and each prime type.

Pseudowords

Within the pseudoword letter strings there was a significant main effect of visual field \( F(1, 58) = 30.279, p < .001, \eta_p^2 = 34\% \). The means revealed pseudowords were more accurate in the right distractor condition \((M = .954, SD = .005)\) than the left distractor condition \((M = .922, SD = .007)\). Also within the pseudoword condition there was a significant main effect of prime type \( F(1, 58) = 93.593, p < .001, \eta_p^2 = 59\% \). The means revealed both hemispheres were more accurate to primed \((M = .970, SD = .005)\) than non-primed \((M = .907, SD = .008)\) pseudowords. These results suggest that pseudowords are more accurately processed in the right than the left hemisphere and that both hemispheres show priming for pseudowords.

Words

The results revealed a significant visual field X prime interaction \( F(1, 58) = 28.838, p < .001, \eta_p^2 = 33\% \). Separate analyses of each visual field revealed a significant effect of prime type within the
left distractor condition \[ F (1, 58) = 1.278, p < .001, \eta_p^2 = 69\% \]. The means of the left distractor condition were more accurate to primed \((M = .983, SD = .006)\) than non-primed \((M = .865, SD = .009)\) words. A significant effect of prime type within the right distractor condition \[ F (1, 58) = 32.781, p < .001, \eta_p^2 = 36\% \] was also revealed. The means of the right distractor condition were more accurate to primed \((M = .982, SD = .007)\) than non-primed \((M = .928, SD = .006)\) words. These results suggest that both hemispheres showed priming for words.

Separate analysis of prime types revealed that the right hemisphere \((M = .928, SD = .049)\) was more accurate than the left \((M = .865, SD = .065)\) in processing non-primed words \[ t(58) = -7.475, p < .001, \eta^2 = 49.06\% \], but not primed words. This finding suggests that the strategy used by the right hemisphere is different than the left, in a context where there is no priming. These results imply that not only is non-lexical processing a slower strategy, but a less accurate one as well.

**Discussion**

The results from Experiment II supported all three hypotheses. Consistent with Experiment I, past research (Chiarello, 1985; Hutchins & Palmer, 2008; Lavidor & Ellis, 2001; Perfetti & Bell, 1991) and our first hypothesis, letter strings which were similar in appearance (i.e., primed) were processed faster and more accurately than letter strings not similar in appearance (i.e., non-primed). As with Experiment I, this enhancement in processing is likely due to the prime activating a lexical representational system in the brain which contains similar characteristics to the target string (Forster, 1987, as cited by Lavidor & Ellis, 2003). Thus, the target will be processed faster because it no longer needs to reactivate the representational system and will be more accurate because there is less likelihood that the target string will activate a different, incorrect, system.

The current results are also in line with past research (Chiarello, et al., 1999) and our second hypothesis, that both hemispheres would show orthographic priming. This was supported by the findings that both hemispheres showed priming for words and pseudowords. These results suggest that
both hemispheres have access to orthographic processing abilities and are consistent with evidence (e.g., Iacoboni & Zaidel, 1996; Rutherford, 2006), as well as Experiment I, that both hemispheres contain lexical processing strategies that are required for orthographic processing. Lexical processing involves a whole word matching strategy to a mental lexicon. More specifically, it involves looking at the overall shape and size of a letter string and matching this to a string with the same shape and size within the mental lexicon. This is precisely the strategy that is needed for orthographic processing. Thus, the finding that both hemispheres are capable of orthographic processing further supports past research on the laterality of lexical processing (e.g., Iacoboni & Zaidel, 1996; Rutherford, 2006).

In accordance with previous research (e.g., Chiarello, 1985; Lavidor & Ellis, 2001, 2003) as well as our third hypothesis, the right hemisphere revealed greater orthographic priming than the left hemisphere. This was demonstrated by three findings. First, non-primed pseudowords were processed quicker in the right compared to the left hemisphere. Second, non-primed words were processed faster in the right compared to the left hemisphere. Third, non-primed words were processed more accurately in the right compared to the left hemisphere. These results appear counterintuitive at first. However, it is believed that participants noticed the visual similarity between primed strings and consequently began focusing on the visual appearance of all letter strings regardless of priming. This bias would compel the participant to rely more heavily on orthographic processing strategies rather than other language strategies such as phonological or semantic processing. Thus, with the results demonstrating quicker and more accurate processing of non-primed strings in the right hemisphere the implication is that the right hemisphere is superior at orthographic processing.

The three findings presented above also demonstrate fundamental differences between lexical and non-lexical processing strategies. The first two findings that non-primed pseudowords and words were processed faster in the right hemisphere compared to the left hemisphere suggests that lexical processing is faster than non-lexical processing. As discussed above, it is believed that participants were
biased to focus on the visual aspects of the letter strings. This bias would imply that all stimuli presented to the right hemisphere, primed or non-primed, words or pseudowords, would be processed orthographically whereas the left hemisphere would maintain normal processing abilities. Thus, the finding that the right hemisphere, using lexical strategies, was faster than the left hemisphere, using non-lexical strategies, to process both non-primed pseudowords and words, suggest that non-lexical processing is slower than lexical processing. The third finding, that non-primed words are more accurate in the right compared to the left hemisphere, implies that not only is non-lexical processing a slower strategy, but a less accurate one as well. Again, taking bias into account, the right hemisphere, which uses lexical processing, performed more accurately than the left hemisphere, which can use both lexical and non-lexical processing. It appears that non-lexical processing hinders rather than facilitates accurate processing. This finding makes both theoretical and empirical sense. Non-lexical processing, as discussed above, requires a much more complex process of sounding out each letter of a word and then combining these sounds in order to sound out the word. Such a process requires multiple steps, making it slower, and increasing the likelihood of error.

The finding that words and pseudowords showed significant priming in both hemispheres casts doubt on the past argument that hemispheric asymmetries in orthographic processing are due to neighborhood size. There are two reasons for this. First, orthographic neighborhood size refers to the number of new words that can be created by manipulating one letter of the original word. According to this definition, it is not entirely certain if pseudowords can have a neighborhood size. While a single letter of a pseudoword can be manipulated to form another pseudoword they are not actual words and would not have a lexical representation within the mental lexicon. Consequently, orthographic priming should not have been seen in pseudoword strings. Second, high orthographic neighborhood is believed to be processed only by the right hemisphere. Thus, the finding that high neighborhood stimuli revealed priming in both hemispheres suggests neighborhood size may not produce hemispheric asymmetries.
These reasons alone are not enough to disprove the orthographic neighborhood argument; however, past research has also found conflicting evidence for this argument. More specifically, Forster and Davis (1991, as cited by Lavidor & Ellis, 2001) found that words with few or no orthographic neighbors, produced facilitation effects if the two letter strings were only one letter different from one another. This finding, as well as our own, suggests a better explanation for asymmetries in orthographic processing is orthographic density (Lavidor & Ellis, 2001). Orthographic density refers to the number of letters a string shares with another letter string (e.g., targ vs. harg). The primed stimuli in the present study contained high orthographic density to one another, which would explain why priming was found for pseudowords.

A possible explanation for right hemisphere superiority may involve asymmetries in spatial processing. Orthographic processing requires the ability to process the spatial aspects of a word and to match these same spatial aspects to the word stored in the mental lexicon. As past research has demonstrated, the right hemisphere specializes at this type of processing (Witelson, 1976). Thus, since the orthographic process relies on spatial processing and the right hemisphere has superior abilities in this process, it is logical that the right hemisphere is better at this task than the left hemisphere.

**General Discussion**

Two experiments were undertaken to clarify conflicting results on the laterality of phonological and orthographic processing. The results of Experiment I suggested phonologically primed letter strings are processed more quickly and accurately than phonologically non-primed strings. More importantly, the results revealed that while both hemispheres have access to simple phonological processing abilities, only the left hemisphere is capable of complex phonological processing. Besides clarifying conflicting results, these findings also lend support to what can be named the *right hemisphere argument* of phonological dyslexia. Phonological dyslexia is a reading disorder in which individuals have trouble converting letters-to-sound. One argument that has been proposed to explain phonological dyslexia is
that they rely on their inferior right hemisphere to process phonological information. The results from the present experiment support this argument in a number of ways. First, while individuals with phonological dyslexia have trouble converting letters-to-sound, they are not completely lacking this ability. This may be explained by the fact that both hemispheres have access to simple phonological processing. Second, the results from Experiment I demonstrated that only the left, not the right hemisphere, contains complex phonological processing abilities. This finding, lends further support to the idea that individuals with phonological dyslexia are relying on their inferior right hemisphere to process phonological information. Potentially, this information could be used in a treatment program for phonological dyslexia. Programs could be tailored to reverse, if possible, the hemispheric asymmetry to favor the phonologically superior left hemisphere.

The results of Experiment II showed that orthographically primed strings were processed faster and more accurately than orthographically non-primed strings. As well, they revealed that both the left and right hemisphere have orthographic processing abilities, through the right hemisphere has superior orthographic processing. An important outcome in Experiment II was the finding that asymmetries in orthographic processing may not be the result of orthographic neighborhood size. While orthographic neighborhood size may play a role in orthographic processing, the current results suggest orthographic density has a greater impact. Future studies on the laterality of reading should test more thoroughly the orthographic neighborhood and orthographic density hypothesis to determine more accurately their hemispheric influences.

When these experiments are taken together they advocate for a relative model of language processing rather than an absolute model. As well, both of these studies inform us about hemispheric specializations beyond that of language processing. They provide support for the laterality of sequential and spatial processing. More specifically, these results support that the left hemisphere is specialized for sequential processing, demonstrated by superior phonological processing in the left hemisphere, while
the right hemisphere is specialized for spatial processing, demonstrated by superior orthographic processing in the right hemisphere.
References


of Language lateralization in children and adults. *Human Brain Mapping, 27,*
202-212.

Underwood, G., Rusted, J., & Thwaites, S. (1983). Parafoveal words are effective in both
hemifields: Pre-attentive processing of semantic and phonological codes.
*Perception, 12,* 213-221.

Watson, G. S., Pusakulich, L. R., Ward, P. J., & Hermann, B. (1998). Handedness,
footedness, and language laterality: Evidence from Wada testing. *Laterality, 3*(4),
323-330.

Witelson, D. F. (1976). Sex and the single hemisphere: specialization of the right hemisphere for

the Disconnected Right Hemisphere: Two Case Studies. *Brain and Language, 14,*
205-234.
Appendix A

The Demographic Form
Demographic Form

Experiment Name:

Participant #

Male/Female

Diagnosed reading disability?

Medication?

English first language?

Birth Date:

Word Attack: Raw Score

    Percentile Rank:

Handedness score
Appendix B

The Annett Handedness Questionnaire
**Handedness Questionnaire** (Annett, 1970)

Which hand do you habitually use for the following tasks? Print left (L), right (R), or either (E) beside each question:

1. To write a letter legibly
2. To throw a ball to hit a target
3. To hold a racket in tennis, squash, or badminton
4. To hold a match whilst striking it
5. To cut with scissors
6. To guide a thread through the eye of a needle (or guide needle on to thread)
7. At the top of a broom while sweeping
8. At the top of a shovel when moving sand
9. To deal playing cards
10. To hammer a nail into wood
11. To hold a toothbrush while cleaning your teeth
12. To unscrew the lid of a jar
Appendix C

Word Attack Form
Supplemental Battery:

**TEST 51**

Word Attack

Score 1.0

<table>
<thead>
<tr>
<th></th>
<th>First Trial</th>
<th>Last Trial</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td>na</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>ib</td>
</tr>
</tbody>
</table>

1. **diff**
2. **nan**
3. **rox**
4. **zooop**
5. **lish**
6. **dright**
7. **jox**
8. **feap**
9. **gusp**

10. **snirk**
11. **yosh**
12. **tayed**
13. **grawl**
14. **ioast**
15. **sluke**

16. **thrept**
17. **wheeg**
18. **mibgus**
19. **splaunch**
20. **quantric**
21. **lindify**

22. **saist**
23. **knoink**
24. **whumb**
25. **mafreatsun**
26. **phigh**
27. **deproteniator**

28. **paraphony**
29. **coge**
30. **apertuate**

<table>
<thead>
<tr>
<th>AGE</th>
<th>Year</th>
<th>Month</th>
<th>Date</th>
</tr>
</thead>
<tbody>
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<td>Testing Date</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birth Date</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difference</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Age: _______ - _______ (Round to whole months)

* If borrowing is needed, change 1 month to 30 days and 1 year to 12 months

**TABLE B (Find appropriate column for age)**

<table>
<thead>
<tr>
<th>Columns</th>
<th>W Ref W SEM(SS) + Diff - Diff DIFF (W-Ref W)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TABLE D**

1. If DIFF =+ then use + diff, else use - diff
2. Go to appropriate column # for pos or neg diff
3. Find diff score in lt or rt row

<table>
<thead>
<tr>
<th>RMI</th>
<th>SS</th>
<th>PR</th>
<th>SS - SEM</th>
<th>SEM SS + SS</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TABLE E (Extended percentile range)**

1. Find scores for SS- SEM and SEM+SS

<table>
<thead>
<tr>
<th>PR</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix D

Informed Consent
Informed Consent

Brain Interhemispheric Communication And Reading

Principal Investigator: Dr. Barbara Rutherford

Psychology Department
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(250) 807-8734
barbara.rutherford@ubc.ca

Sponsor: Natural Sciences and Engineering Research Council

Introduction:

The University of British Columbia-Okanagan subscribes to the ethical conduct of research and to the protection at all times of the interests, comfort, and safety of the study of subjects. The information provided in this form is being given to you for your own protection and full understanding of the procedures, risks and benefits associated with this research.

The consent form is only part of the process of informed consent. It should give you a basic idea of what the research is about and what your participation will involve. If you would like more details, feel free to ask the researcher presenting this form at any time. Please take the time to read this carefully and to understand any accompanying information.

Purpose Of The Study:

This study seeks to better understand how the hemispheres of the brain interact when people read.

Study Procedures:

You will be asked to engage in 3 tasks.

(1) Handedness questionnaire: This asks which hand you habitually use to perform different tasks (e.g. writing, throwing a ball).

(2) Reading Aloud: You will be asked to read aloud a short list of “fake” words (e.g. blurp).

(3) Computer task. You will be seated in front of a computer screen with your chin on a chinrest. A letter string will appear on the monitor. Your job is to decide whether or not the letters spell a word. You will press one or other of a pair of computer keys to indicate the decision. On some of the trials, a distractor located to one or other side of the letter string will blink on and off for a short period of time.

Potential Risks And Benefits:

This project has been reviewed and granted a certificate of approval by the UBCO Research Ethics Board.

This research is important because it will increase our understanding of how the hemispheres of the brain interact when people read. In turn, the findings will be useful to the development of programs to better help those who struggle with reading.
You understand that any risk from participation in this research is minimal because the tasks are those normally associated with everyday living (e.g. filling out a form, speaking aloud, and sitting in front of a computer screen and pressing computer keys).

**Confidentiality:**

You understand that all data collected from you will be coded by a number and not your name; therefore, your identity will be kept confidential. The only people who will have access to the data are the principal investigator and designated research assistant(s). The data will be stored in a locked file cabinet and in a password-protected file on a computer in the psychology laboratory complex. All data will be destroyed 7 years after the findings have been published.

**Remuneration/Compensation:**

Introductory Psychology students at UBCO will receive a 1% course bonus credit/hour of research participation. UBCO students who are either ineligible for bonus credits or do not wish to receive bonus credits may receive $10/hour research participation.

**Contact For Information About The Study:**

If you have any questions about the project, you may address them to Dr. Barbara Rutherford, at telephone number (250) 807-8734.

If you have any concerns about your treatment or rights as a research subject, you may contact the Research Subject information Line in the UBC Office of Research Services at 604.822.8598.

The results of the study will be presented at national/international conferences and published in a peer-reviewed journal in psychology. For details on the publication, contact Dr. Barbara Rutherford at telephone number (250) 807-8734 about 2 years following your participation. For other access to the findings, watch for posters on campus that advertise the time and place of a verbal presentation of the results.

**Consent:**

Your participation in the study is entirely voluntary and you may refuse to participate at any time during the testing session without consequence. Prior to leaving the testing session, you may instruct the researcher to destroy your data and watch while the computer file is deleted and the paper documents are shredded.

Your signature on this form indicates that you understand the information provided regarding this research project including all procedures and the personal risks involved. Your participation in this project is in no way related to your status as a student. You understand that your identity and any identifying information will be kept confidential.

Your signature below indicates that you consent to participate in this study. You will receive a copy of this consent form for your own records.
Your name (Please print): _________________________________________________

Your signature: _____________________________   Date: _______________

Investigator and/or Delegate’s signature: ___________________   Date: ______________
Appendix E

Debriefing Form
Description for Debriefing

There were 3 independent variables that will provide us with insight into how the hemispheres of the brain read.

1. The first is the type of letter string that you saw in the centre of the monitor. There were 3 different types of them:
   A. Word – the words were all ones that had a high meaningfulness rating, so were likely quite familiar to you.
   B. Pseudoword – these letter strings meet the rules of spelling for English, but are not a word. Needless to say, these letter strings would not be familiar to you.

2. The second independent variable is the location of the distractor. There were 2 types of locations:
   A. Left distractor – a blinking distractor to the left captures the attention of the right hemisphere, leaving the left hemisphere to process the centre string.
   B. Right distractor – a blinking distractor to the right captures the attention of the left hemisphere, leaving the right hemisphere to process the centre letter string.

3. The third independent variable is if the priming of a letter string. Priming involves the presentation of two consecutive stimuli in which responses to the second stimulus should be faster and more accurate than responses to the first stimulus as long as the two stimuli share similar characteristics.

There were two dependent variables in the study: the time it took you to respond, and the accuracy of your response.

Goal of the study

By recording the time and accuracy of your responses to the different distractor conditions, we can learn if one hemisphere is better than the other or whether both hemispheres are better or worse than one when processing different types of letter strings. We can also learn whether practice changes how your hemispheres process letter strings and distractors. This information should prove helpful in designing interventions to help people with reading problems.