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The processing of phonological and orthographic representations of print in the left and right cerebral hemispheres

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THE PROCESSING OF PHONOLOGICAL AND ORTHOGRPAHIC REPRESENTATIONS OF PRINT IN THE LEFT AND RIGHT CEREBRAL HEMISPHERES

By

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Abstract

The overall aim of this study was to develop an understanding of the role of each cerebral hemisphere in the orthographic and phonological processing of a printed word. More specifically, three experiments investigated whether the right hemisphere can process the phonology of single printed words. Experiment 1 used the visual half-field primed lexical decision task of Lavidor and Ellis (2003). While interpretation of the results is debatable, it is argued that they show phonological processing that is limited to the left hemisphere. Corroboration was obtained from Experiments 2 and 3, in which a visual half-field forward masked primed lexical decision task was used. In Experiment 2, orthographic priming was obtained regardless of stimulus onset asynchrony and visual field/hemisphere of presentation. In Experiment 3, phonological priming was not obtained at a 50 ms stimulus onset asynchrony, but was obtained at a 150 ms stimulus onset asynchrony for stimuli presented to the right visual field/left hemisphere. These findings are consistent with Chiarello's (2003) view of rapid, deep left hemisphere processing of print and more shallow right hemisphere processing.

Dedications

Mom and Dad, I love you both. Thank you for always showing me unconditional love and support.

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Chapter I

Introduction

The mental lexicon is a store of word identities held in memory that includes orthographic (i.e., visual appearance), phonological (i.e., sound), and semantic (i.e., meaning) representations. The process of reading a printed word involves the deciphering of sublexical clues to access its representations in the lexicon(s). It is assumed that the first clues processed are the constituent physical surface characteristics of a word (i.e., graphemes and phonemes) and that their respective lexical representations are the first contacted (i.e., orthographic and phonological). Accordingly, one important line of research has been aimed at elucidating how the processing of orthography and phonology interact during reading. Some researchers have proposed that the cognitive processes underlying word reading are primarily dependent upon orthography (e.g., Taft & van Graan, 1998), while others have proposed that these processes are primarily dependent upon phonology (e.g., Frost, 1998; Lukatela & Turvey, 1994a; Lukatela & Turvey, 1994b; Van Orden & Goldinger, 1994), while still others have proposed that these processes are dependent upon an interaction between both orthography and phonology (e.g., Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Harm & Seidenberg, 2004; Perry, Ziegler, & Zorzi, 2007; Seidenberg & McClelland, 1989). This line of research extends to include examinations of the putative neurological correlates. It has been demonstrated that both cerebral hemispheres are able to comprehend printed words (Chiarello, Hasbrooke, & Maxfield, 1999). The debate now centers on the cognitive processes that underlie the ability of the left and right hemispheres to recognize words. One question in this debate, and the question of interest herein, is: Can the right hemisphere process the phonology of a printed word; and, if so, what cognitive mechanisms underlie that processing?

Assumptions Underlying Psycholinguistic Tasks and Explicit Versus Implicit Task Demands

A necessary precondition for a comprehensive review of the literature regarding right hemisphere processing of phonology is that the assumptions relating to methodological issues be explicitly laid out. A variety of tasks, including lexical decision (i.e., making a decision as to whether a letter-string is a word or nonword), word naming (i.e., reading aloud), and rhyme judgment (i.e., deciding whether two words rhyme), have been used to study word recognition processes. These tasks are performed through unseen cognitive processes that must be inferred based on an understanding of what a given task measures and on the assumed impact of a given manipulation. The processes and demands underlying various tasks can differ in a multitude of ways and there may be disagreement about what can be inferred from these tasks. Researchers holding differing theoretical perspectives can arrive at different inferences given the same data set. Because of this, it is crucial that assumptions regarding processes underlying a task are made explicit so that their validity, and by extension the manner in which results are interpreted, can be judged.

An important assumption is that some tasks require explicit or overt access to linguistic information (i.e., orthographic, phonological, or semantic), while others merely require implicit access (Buchanan, McEwen, Westbury, & Libben, 2003; Chiarello et al, 1999). Word naming is an explicit task because it requires an overt demonstration of access to phonological articulatory-motor codes. Rhyme judgment (e.g., whether participants can correctly decide whether *RAT* rhymes with *CAT*) is also an explicit task because it requires an overt demonstration that the sound of the printed word has been processed. In contrast, performance on a task with implicit demands shows sensitivity to information without direct reference to the characteristic of interest. An example of a task that reveals implicit processing is primed lexical decision. In the primed lexical decision task, a target letter-string is presented subsequent to presentation of a prime that is either related or unrelated to the target along some experimentally determined dimension (e.g., phonologically similar). The participant is asked to make a lexical decision to the target letter-string (e.g., the question of interest is whether seeing *RAT* has an impact on participants' subsequent identification of *CAT*). The two basic assumptions are: (1) The time needed to make a response reflects the time needed for the lexical representation of a target word to reach a critical activation level whereby a decision can be made that the appropriate representation exists (or that no such entry exists in the case of nonwords), in addition to the time needed to plan and make a motor response; and (2) If the experimentally determined prime-target relation (e.g., phonological overlap) is meaningful in terms of processing requirements, then subsequent recognition of the target will be impacted (facilitated or inhibited). This is considered an implicit task because performance does not require an overt demonstration that the overlapping characteristic is processed – the participant simply indicates whether the target is a word.

An inability to perform an explicit task does not imply a complete inability to process the necessary linguistic information (Buchanan et al., 2003; Chiarello et al., 1999). It merely implies an inability to access the overt metalinguistic knowledge. The distinction between explicit and implicit processing is relevant in examinations of hemispheric processing because evidence of right hemisphere linguistic processing has been much more readily obtained using implicit rather than explicit tasks (for review see Beeman & Chiarello, 1998). Thus, it may be the case that evidence of right hemisphere phonological processing is more readily obtained using implicit tasks.

Data from Experiments Using Explicit Tasks to Investigate Left and Right Hemisphere Phonological Processing of Print in Commisurotomy Patients and Neurologically Intact Participants

A commisurotomy is a procedure in which the neuronal connections between the two hemispheres of the brain are surgically cut to control epileptic seizures. Using commisurotomy patients, researchers can independently evaluate the contributions of the hemispheres for the processing of print because visual stimuli are processed by only the hemisphere contralateral to the visual field of stimulus presentation (i.e., the spatial location to the right or left of where an individual is fixating; for review see Chiarello, 2003). Based on data from commisurotomy patients, the predominant opinion has been that the "...right hemisphere cannot evoke the sound image of a word from the orthographic representation" (Zaidel & Peters, 1981, p.218).

Table 1 lists several experiments in which commisurotomy patients were able to match a rhyming word or picture to a word presented to the right visual field /left hemisphere but not the left visual field/right hemisphere (Baynes, Wessinger, Fendrich, & Gazzaniga, 1995; Sidtis, Volpe, Wilson, Rayport, & Gazzaniga, 1981; Zaidel & Peters, 1981), except in cases where the right hemisphere of patients exhibited the ability to control speech (e.g., Baynes & Eliassen, 1998)[1]. However, Baynes and Eliassen caution that findings from commisurotomy patients may not generalize because a lifetime of pre-surgical epilepsy may have contributed to an abnormal lateralization of functional architecture. This caution is made stronger by the fact that adult patients with callosal agenesis who were born preterm show greater right hemisphere activation on neuroimaging when performing a rhyme judgment task (Rushe et al., 2004). Thus, a demonstration of phonological insensitivity in the right hemisphere of neurologically intact individuals is required to support the claims that have come from work done with commisurotomy patients.

Though the two hemispheres are not isolated from each other in neurologically intact individuals, asymmetrical performance can nonetheless be observed when processing is initiated in either of the hemispheres. These asymmetries are taken as indications that the processing capabilities of the hemispheres differ on processes required by tasks. For example, if making a rhyme decision is easier for words presented to the left hemisphere than the right hemisphere, this asymmetry is taken as evidence that the left hemisphere carries most or all of the phonological processing responsibilities. This pattern of results, however, has not been consistently obtained (Chiarello et al., 1999). Of the experimental examinations of explicit phonological processing in neurologically intact participants listed in Table 1, only one indicates that the right hemisphere is completely insensitive to phonology. Sasanuma, Itoh, Kobayashi, and Mori (1980) obtained poor rhyme judgment accuracy when stimulus presentation was made to

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[1] For the purposes of the present discussion, although the relationship is not exact, stimuli being presented to the right visual field will henceforth be referred to as being presented to the left hemisphere and stimuli being presented to the left visual field will henceforth be referred to as being presented to the right hemisphere.

the right hemisphere. In contrast, the results of Crossman and Polich (1988) and Rayman and Zaidel (1991) merely suggest that the hemispheres achieve a similarity judgment via different processes. Both found that participants were better able to decide that two words rhymed when presentation was made to the left hemisphere, but that participants were better able to decide that two words did not rhyme when presentation was made to the right hemisphere. The results of Banich and Karol (1992) and Hunter and Liederman (1991) suggest that the right hemisphere's phonological processing capabilities are not equivalent to the left hemisphere, but that the right hemisphere does have limited access to phonology. They found that hemisphere of presentation only modulated rhyme judgment when processing demands were high (i.e., a condition in which distracter words were presented simultaneously to the opposite hemisphere) or under conditions where the processing demands were theoretically greater for the left hemisphere (i.e., a condition in which participants were required to perform a secondary verbal memory task). Taken as a whole, the data from tasks with explicit processing demands suggest the right hemisphere is sensitive to phonological information, though a less efficient phonological processor than the left hemisphere.

Data from Experiments Using Implicit Tasks to Investigate Left and Right Hemisphere Phonological Processing of Print in Neurologically Intact Participants

The studies reviewed in Table 1 that have employed implicit tasks collectively provide evidence of the right hemisphere's ability to process phonology. Using a lexical decision paradigm, Barry (1981) found that participants were slower to reject pseudohomophones (i.e., nonwords that sound like a real words; e.g., *WIRD*[2]) than true nonwords as words regardless of hemisphere of presentation. This "pseudohomophone effect" is thought to arise because pseudohomophones activate lexical representations of real words via phonological recoding and this activation must be overcome to judge them correctly. Also, using Serbo-Croat stimuli, Lukatela, Carello, Savic, and Turvey (1986) found that lexical decisions were inhibited for phonologically ambiguous words relative to words with unambiguous pronunciations regardless of hemisphere of presentation, indicating a bilateral sensitivity to phonology. Finally, two studies have investigated right hemisphere phonological processing by examining the influence of simultaneously presented unattended distracter items on phonologically related target items. Underwood, Rusted, and Thwaites (1983) found that laterally presented distractors that were homophones of words semantically related to targets that were presented centrally interfered with lexical decisions relative to unrelated distractors (e.g., *RUBBISH-WAIST* vs. *RUBBISH-WATCH*), which was interpreted as evidence that both the left and right hemispheres process phonology. Chiarello et al. (1999) presented two letter-strings simultaneously, one vertically and one horizontally such that each pair shared an interior letter, to either the left or right hemisphere. Chiarello et al. observed facilitation of naming for words presented with phonologically related distracter items relative to unrelated distracter items (e.g., *FEW-NEW* vs. *FEW-SEA*) regardless of hemisphere. The results of Chiarello et al. are in line with those of Underwood et al., as well as those of

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[2] Where examples of stimuli from previous experiments are given, an attempt has been made to present them in the same case, upper or lower, as they were presented in the experiment being reviewed.

Barry (1981) and Lukatela et al. (1986), as all obtained evidence for bilateral sensitivity to the processing of phonology.

While the results of Barry (1981), Lukatela et al. (1986), Underwood et al. (1983), and Chiarello et al. (1999) support the claim that the right hemisphere is able to process phonology, the nature of the underlying cognitive mechanisms is unknown. An initial understanding of the mechanisms used by each of the cerebral hemispheres may come from studying the respective time courses of the processing of phonology. Halderman and Chiarello (2005) and Halderman (2006) begin to give some insight into the time course of phonological processing in the left and right hemispheres

Halderman and Chiarello (2005) and Halderman (2006) used a visual half-field backward masking paradigm in which a target stimulus is briefly presented and then replaced by a nonword. The assumption is that the nonword acts like a mask and restricts the time available to decode the target, as the presentation of the nonword requires participants to turn processing resources away from the target. If a word target shares characteristics with the nonword mask, it is assumed that this information is reinstated at the time the mask is presented (Frost, 1998). Therefore, if target recognition is facilitated by a related nonword mask relative to an unrelated mask, it is taken as evidence that the related information was decoded during the presentation of the target. Importantly, it is assumed that the length of target presentation is an index of the time course of word processing (i.e., the point in time that orthographic and phonological representations are accessed during the processing of print).

Halderman and Chiarello (2005) presented targets (e.g., *bowl*) laterally for 50 ms and then replaced them with nonword masks for 30 ms that were orthographically and phonologically similar (e.g., *BOAL*), orthographically similar (e.g., *BOOL*), or unrelated (e.g., *MANT*). They obtained evidence of orthographic processing for both left and right hemisphere trials (faster recognition of *bowl* masked by *BOOL* than *MANT*) but obtained evidence of phonological processing only for left hemisphere trials (faster recognition of *bowl* masked by *BOAL* than *BOOL*). However, in a subsequent experiment, Halderman (2006) compared masking of targets (e.g., *crew*) by phonologically related (e.g., *CROO*), orthographically related (e.g., *CRAE*), orthographically and phonologically related (e.g., *CRUE*), and unrelated nonwords (e.g., *FAMS*). Bilateral evidence of both orthographic and phonological processing (faster recognition of *crew* masked by *CRAE* than *FAMS* and faster recognition of *crew* masked by *CROO* than *FAMS*, respectively) was obtained both when targets were presented for 20 ms and 70 ms. However, evidence of more robust phonological than orthographic processing (faster recognition of *crew* masked by *CRUE* than *CRAE*) was obtained for left hemisphere trials when targets were presented for 70 ms. Thus, Halderman concluded that while both phonology and orthography are bilaterally processed early in the time course of processing, orthographic processing is more important for word reading than is phonological processing, except in the case of the left hemisphere later in the time course of processing.

While the results of Halderman (2006) appear to yield some insight into the time course of phonological processing in the two hemispheres, both they and the results of the other studies reviewed that have examined implicit phonological processing contrast with the results of the second experiment of Lavidor and Ellis (2003). Lavidor and Ellis performed a visual half-field primed lexical decision experiment in which a forward mask (i.e., a row of six hash marks) was presented centrally for 500 ms, followed by a prime for 45 ms, then a backward mask for 500 ms, and finally a target presented laterally. The primes were orthographically similar homophones (e.g., *leak-LEEK*), orthographically dissimilar homophones (e.g., *witch-WHICH*), and unrelated words (e.g., *arch-CITE*). Only phonological priming was obtained for the left hemisphere (i.e., equivalent lexical decision times to *leak-LEEK* and *which-WITCH* prime-target pairs and faster decisions to *leak-LEEK* and *which-WITCH* than to *arch-CITE* prime-target pairs). Moreover, only orthographic priming was obtained for the right hemisphere (i.e., equivalent lexical decision times to *arch-CITE* and *which-WITCH* prime-target pairs and faster decisions to *leak-LEEK* than to *which-WITCH* prime-target pairs). From this, Lavidor and Ellis conclude that the left hemisphere is more dependent on phonological processing while the right hemisphere is dependent on orthographic processing.

Given that the overwhelming majority of evidence yielded from implicit tasks indicates that the right hemisphere is able to process phonology, the purpose of Experiment 1 is to examine further the methodology and results of the second experiment of Lavidor and Ellis (2003). Three possible reasons for the absence of right hemisphere phonological priming are identified. The divergent results of Lavidor and Ellis may be due to their experimental methodology. In the typical primed lexical decision task, the target is presented immediately following the offset of the prime, and stimulus onset asynchrony (i.e., the time elapsed between onset of the prime and onset of the target) is assumed to index the time course of word processing, in a manner similar to the backward masking paradigm. There is, however, no empirical data to enable interpretation when a mask is presented for 500 ms between the offset of the prime and onset of the target. Lavidor and Ellis argue that the mask stopped the processing of the prime at 45 ms, and hypothesize that they did not find any evidence of phonological processing in the right hemisphere because information that was initially available decayed by the time the targets were presented.

An additional explanation for the results of Lavidor and Ellis (2003) revolves around their use of pseudohomophones as targets. The use of pseudohomophones is important because participants cannot use phonological information to discriminate between pseudohomophones and real words. Rather, participants must make decisions based upon orthographic information. It may be that Lavidor and Ellis did not obtain right hemisphere phonological priming because their participants were biased against phonological processing (though see Pexman, 2001 for evidence to the contrary). Left hemisphere phonological priming may have been obtained because the left hemisphere is a more efficient processor of phonology.

Another possibility is that the results of Lavidor and Ellis (2003) are an aberration. Ferrand and Grainger (1996) performed an experiment similar to that of Lavidor and Ellis but presented primes and targets centrally, implicating interhemispheric processing rather than processing by either the left hemisphere or right hemisphere in isolation. When pseudohomophones were introduced as the nonwords in their experiment, the effect of homophone primes was inhibitory compared to unrelated primes, which contrasts considerably with the results of Lavidor and Ellis. Although there is some doubt as to whether the processing of print by the left hemisphere or right hemisphere in isolation can be predicted from observations of interhemispheric processing (Banich & Karol, 1992), the results of Ferrand and Grainger are inconsistent with those of Lavidor and Ellis.

Chapter II

Replication of the Second Experiment of Lavidor and Ellis (2003)

Experiment 1 replicates the methodology used in the second experiment of Lavidor and Ellis (2003). The results of Lavidor and Ellis' second experiment are counter to the majority of evidence yielded from experiments using implicit tasks supporting the position that the right hemisphere is able to process phonology. Three possible reasons for Lavidor and Ellis' failure to observe phonological priming in the right hemisphere were reviewed. First, their results may simply be anomalous, an idea that gains support when considering the findings of Ferrand and Grainger (1996). This proposition is directly tested by using their same methodology. Second, their experiment may not have been a fair test of the right hemisphere's ability to process phonological information given the use of pseudohomophone targets. Thus, rather than using pseudohomophones, the current experiment uses true nonword targets. While observation of right hemisphere phonological priming may be less compelling than if obtained in the presence of pseudohomophones, the absence of pseudohomophones results in more favorable conditions for observation of the effect. If no right hemisphere phonological priming is observed and the results of the second experiment of Lavidor and Ellis are replicated, it will then be possible to evaluate the third possible reason for their failure to obtain evidence of right hemisphere phonological processing. Lavidor and Ellis hypothesized that phonological information initially decoded from the primes and available in the right hemisphere decayed by the time the targets were presented because of the intervening mask. This hypothesis can be easily evaluated by gradually reducing the presentation time of the mask intervening between the prime and target.

Experiment 1 Method

Participants

Participants were undergraduate students at the University of Windsor who participated for bonus course credit. Informed consent was obtained from all participants (see Appendix A for a copy of the informed consent form). Twenty-six of 70 participants who had excessive error rates for the experimental trials (> 35% across all trials) were removed from the final analysis. Of the 44 participants included in the final analysis, 12 were males and 32 were females. All participants were right-handed native speakers of English with normal or corrected-to-normal vision and no history of neurological trauma (see Appendix B for a copy of the questionnaire used to collect demographic information)

Materials

The stimuli were similar to those used by Lavidor and Ellis (2003). Three types of critical prime-target pairs were created along two dimensions, phonological and orthographic similarity. Phonological similarity was maximized in this experiment by using pairs that were homophones. The three conditions resulting from this manipulation were: (1) Prime-target pairs that were orthographically similar homophones (e.g., meet-MEAT), (2) Prime-target pairs that were orthographically dissimilar homophones (e.g., loot-LUTE), and (3) Unrelated prime-target pairs (e.g., sand-CASK). Whereas Lavidor and Ellis defined a prime-target pair as having high orthographic similarity if all but one letter occurred in the same position and having low orthographic similarity if two or less letters occurred in the same position, the current stimulus set followed an orthographic similarity measure developed by Weber (1970) and modified by Van Orden (1987). Van

Orden's orthographic similarity index provides a value ranging from 0-1, with 1 being an identical orthographic match. The average orthographic similarity value for the orthographically similar homophone prime-target pairs was .68 (Standard Deviation = .09) and the average orthographic similarity value for the orthographically dissimilar homophone prime-target pairs was .46 (Standard Deviation = .11). The unrelated prime-target pairs had one or zero letters occur in the same position. Word frequency and word length of the targets was also carefully controlled. The word frequencies of the targets were drawn from the WordMine2 database (Durda & Buchanan, 2006). The mean word frequency (i.e., the number of occurrences of a given word per one million words of written text) of the orthographically similar homophone targets was 17.04 (Standard Deviation = 21.58), orthographically dissimilar homophone targets was 10.27 (Standard Deviation = 9.94), and unrelated targets was 12.51 (Standard Deviation = 13.79). The average letter length of the orthographically similar homophone targets was 4.50 (Standard Deviation = 1.04), orthographically dissimilar homophone targets was 4.40 (Standard Deviation = .93), and unrelated targets was 4.40 (Standard Deviation = .93). Thirty pairs of each critical type were created such that there were a total of 90 critical prime-target pairs (see Appendix C), and these were presented along with 90 unrelated word-nonword prime-target pairs (e.g., ball-HOTH) in which all nonwords were pronounceable and consisted of letter combinations found in English words (see Appendix D). Each participant saw all 180 prime-target pairs.

Design

In this lexical decision task participants were asked to decide whether a letter-string (i.e., the target) displayed on the computer screen in the participant's left visual field/right hemisphere or right visual field/left hemisphere was a real English word. Each participant saw a total of 180 target items, each of which was preceded by a centrally presented prime for which no response was required. Across the experiment all target items were presented to both visual fields/hemispheres. To accomplish this, two counter-balanced lists were created such that target items presented in one visual field (e.g., the left visual field/right hemisphere) in the first list were presented to the opposite visual field (e.g., the right visual field/left hemisphere) in the second list. Participants were assigned to one or the other list condition randomly. To eliminate any possibility of simple surface feature priming (i.e., priming resulting from the superfical visual similarity between primes and targets rather than activation of orthographic/phonological representations) all primes appeared in lowercase and all targets appeared in uppercase.

Apparatus and Procedure

A Pentium III PC running Direct RT was used to present the stimuli and collect reaction time and accuracy data. The stimuli were presented in Times New Roman 24 point white font against a black background. Figure 1 is a timeline of the sequence of events for stimuli presented to the right visual field. Each trial began with the 500 ms presentation of a fixation point (+) in the center of the computer screen. Immediately following the presentation of the fixation point, a 500 ms mask (#####) was presented at the center of the computer screen. Immediately following the presentation of the mask, the lowercase prime was presented at the center of the computer screen for 50 ms and was then replaced by a 500 ms mask. The uppercase target was then presented either to the left or right visual field for 165 ms. Following the presentation of the target a blank screen was displayed until the participant responded. The subsequent trial began immediately after the response.

The participants' heads were stabilized by a chin-rest located 152cm from the monitor. This location ensured that the visual angle from the central fixation point to the innermost edge of each word was 2.50°. Limiting the presentation time of the target and manipulating the visual angle ensured that the stimuli were presented laterally and that the participants were not able to foveate toward the stimuli (Bourne, 2006). Also, the short prime presentation duration (making the presence of the primes unknown to the participants), in combination with the fact that only 33% of the prime-target pairs were related per list, helped guard against nonautomatic processing of the stimuli (McNamara & Holbrook, 2003).

Participants were asked to determine whether the target was a word or nonword. Half of the participants responded to words by pressing the "N" key with the index finger of their right hands and to nonword response by pressing the "V" key with the index finger of their left hand. This response/key pairing was reversed for the other half of the participants. Participants were instructed to make their response as quickly and accurately as possible. Participants were not told about the presence of the primes. The experimenter emphasized the importance of focusing on the fixation cross throughout the duration of each trial. Each experimental session began with the presentation of a 50-item practice list. The construction of the practice list mirrored the construction of the experimental lists. The practice list was administered in two parts. After half of the practice trials were administered the experimenter provided the participant with feedback concerning accuracy. The only light in the testing room during each experimental session for all participants was ambient light from outside the room.

Experiment 1 Results

Presentation and background effects

Independent variables gender, responding hand, and list were analyzed to determine whether they had significant effects on performance. Using the dependent variable reaction time, mixed between-within-participants analyses of variance (ANOVAs) were conducted and revealed that these variables produced neither main effects nor interactions with the independent variables of interest, prime-type and hemisphere of presentation (all Fs < 2.00). Therefore, the data from all 44 participants performing above chance levels were collapsed into a single analysis.

Reaction Time Analyses

For each participant, reaction times for incorrect trials were removed (accounting for 35% of the data points). Also, reaction times greater than 2200 ms were considered outliers and removed (accounting for less than 0.5% of the data points). The identification and removal of outliers was done according to the suggestions made by Ulrich and Miller (1994).

Two (hemisphere of presentation: right versus left hemisphere) x 3 (prime-type: orthographically similar homophones, orthographically dissimilar homophones, unrelated) within-participants ANOVAs were performed both for participants[3] (F_1) and

[3] For each participant, the mean score over all items in each condition was calculated and then submitted to analysis.

items[4] (F_2). Performance for left hemisphere targets (Mean = 617 ms) was faster than for right hemisphere targets (Mean = 646 ms) [F_1 (1, 43) = 4.82, $p < .05$, partial $\eta^2 = .10$; F_2 (1, 29) = 5.12, $p < .05$, partial $\eta^2 = .15$]. There was a main effect of prime-type, indicating that the conditions differed from each other, for participants [F_1 (2, 86) = 4.55, $p < .05$, partial $\eta^2 = .10$] but not items [F_2 (2, 58) = 1.58, $p > .05$, partial $\eta^2 = .05$]. The interaction between hemisphere of presentation and prime-type reached significance for participants [F_1 (2, 86) = 3.03, $p < .05$, partial $\eta^2 = .07$], indicating that different patterns of priming occurred across the hemispheres, but it did not for items [F_2 (2, 58) = 1.98, $p > .05$, partial $\eta^2 = .07$].

Planned comparisons were performed in order to further investigate the effects of hemisphere of presentation on orthographic priming. A 2 (hemisphere of presentation: left versus right hemisphere) x 2 (prime-type: orthographically similar homophones versus orthographically dissimilar homophones) within-participants ANOVA revealed a main effect of hemisphere of presentation [F_1 (1, 43) = 6.17, $p < .05$, partial $\eta^2 = .13$], prime-type [F_1 (1, 43) = 4.91, $p < .05$, partial $\eta^2 = .10$], and an interaction between hemisphere of presentation and prime-type [F_1 (1, 43) = 4.71, $p < .05$, partial $\eta^2 = .10$], indicating that hemisphere of presentation modulated orthographic priming. Two-tailed t-tests employing a Bonferroni correction for the number of comparisons made supports this claim ($\alpha = .013$). As Table 2 and Figure 2 indicate, for the left hemisphere, participants responded faster to targets preceded by orthographically similar homophone primes than orthographically dissimilar homophone primes ($p < .01$) and for the right hemisphere no differences were obtained ($p > .013$). Thus, according to the manner in

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[4] For each item, the mean score over all participants in each condition was calculated and then submitted to analysis.

which similar data was interpreted by Lavidor and Ellis (2003; i.e., subtracting the orthographically similar homophone condition from the orthographically dissimilar homophone condition to yield the orthographic processing effect), orthographic priming was limited to the left hemisphere.

Planned comparisons were also used to further investigate the effects of hemisphere of presentation on phonological priming. A 2 (hemisphere of presentation: left versus right hemisphere) x 2 (prime-type: orthographically dissimilar homophones versus unrelated) within-participants ANOVA revealed that there was not an effect of hemisphere of presentation [F_1 (1, 43) = .92, $p > .05$, partial $\eta^2 = .02$] or prime-type [F_1 (1, 43) = 1.33, $p > .05$, partial $\eta^2 = .03$], and that no interaction between hemisphere of presentation and prime-type occurred [F_1 (1, 43) = .03, $p > .05$, partial $\eta^2 = .00$]. Thus, as Table 2 and Figure 2 indicate, according to the manner in which similar data was interpreted by Lavidor and Ellis (2003; i.e., subtracting the orthographically dissimilar homophone condition from the unrelated condition to yield the phonological processing effect), the reaction time data show no phonological priming in either hemisphere.

Accuracy Analyses

Two (hemisphere of presentation: right versus left hemisphere) x 3 (prime-type: orthographically similar homophones, orthographically dissimilar homophones, unrelated) within-participants ANOVAs were performed both for participants and items. Performance was more accurate for left hemisphere targets (Mean = 32% error) than for right hemisphere targets (Mean = 37% error) [F_1 (1, 43) = 4.32, $p < .05$, partial $\eta^2 = .09$; F_2 (1, 29) = 8.57, $p < .01$, partial $\eta^2 = .23$]. An effect of prime-type was obtained for participants [F_1 (2, 86) = 12.21, $p < .001$, partial $\eta^2 = .22$] and trended towards significance by items [F_2 (2, 58) = 3.16, p = .05, partial η^2 = .10], indicating that effective priming occurred. The interaction between hemisphere of presentation and prime-type was not significant for participants or items [F_1 (2, 86) = 2.65, p > .05, partial η^2 = .06; F_2 (2, 58) = 1.87, p > .05, partial η^2 = .06]. The data relevant to these analyses are summarized in Table 2. As hemisphere of presentation did not modulate priming in the accuracy data, the same planned comparisons that were conducted for the reaction time data were not performed; however, the main effect of prime-type was further probed.

Post-hoc comparisons were performed in order to further investigate the main effect of prime-type using two-tailed t-tests employing a Bonferroni correction for the number of comparisons made (α = .025). Regarding orthographic priming, participants responded more accurately to targets preceded by orthographically similar homophone primes (Mean = 30% error) than orthographically dissimilar homophone primes (Mean = 36% error) (p < .01). Given that hemisphere of presentation did not modulate priming in the accuracy data, this finding is viewed as being consistent with the reaction time data for the left hemisphere but not for the right hemisphere. Regarding phonological priming, participants responded with similar accuracy to targets preceded by orthographically dissimilar homophone primes (Mean = 36% error) and unrelated primes (Mean = 39% error) (p > .025). This finding is consistent with the reaction time data for both the left and right hemispheres.

Discussion of Results for Experiment 1

The findings of Lavidor and Ellis (2003) were not replicated. With regard to the left hemisphere, no phonological priming was obtained, but orthographic priming was found in both the reaction time and accuracy data. Just as with the left hemisphere, no right hemisphere phonological priming was obtained, but the results are somewhat ambiguous regarding orthographic priming. Orthographic priming was obtained in the accuracy data but not in the reaction time data; however, the lack of effect in the reaction time data weakens any claims made on the basis of the accuracy data, as reaction times are a finer grained and more sensitive dependent variable.

Given the results of Ferrand and Grainger (1996), the failure to replicate the results of Lavidor and Ellis (2003) may not be surprising; however, it is perplexing that no phonological priming was obtained. This contrasts with the results of other implicit experiments examining intrahemispheric phonological processing, and is especially perplexing given that the use of true nonwords as opposed to pseudohomophones was expected to increase the probability of observing phonological priming. Two explanations are posited. First, a different set of targets was used in each of the orthographically similar homophone, orthographically dissimilar homophone, and unrelated conditions. It is more usual in primed lexical decision tasks for targets to be rotated though each prime condition so that the effects of primes on target recognition can be directly compared. While those psycholinguistic variables to which word recognition is thought to be most sensitive (i.e., word frequency and word length) were carefully controlled, some variable(s) not controlled may have affected target recognition. As such, there is substantial ambiguity as to whether the results obtained can be attributed to the presence of the primes, either partially or totally.

The second explanation as to why no phonological priming was obtained is that the results were interpreted incorrectly. The assumption was that comparing the effect of orthographically similar homophone primes to orthographically dissimilar homophone primes on target recognition yields an effect dependent on orthographic processing, and comparing the effect of orthographically dissimilar homophone primes to unrelated primes on target recognition yields an effect dependent on phonological processing. Grainger and Ferrand (1994) suggest that this basic assumption is incorrect. They performed two relevant experiments. In the first experiment, they found that orthographically similar homophone primes facilitated target lexical decisions relative to unrelated primes (e.g., *real-REEL* vs. *arch-REEL*) and that orthographically similar non-homophone primes inhibited decisions relative to unrelated primes (e.g., *ride-RITE* vs. *arch-RITE*). From the second experiment, they obtained results similar to the current ones. They did not directly compare the orthographically dissimilar homophone and orthographically similar homophone prime conditions, but there was an approximate 27 ms advantage for targets when preceded by orthographically similar homophone primes, and they obtained no difference between orthographically dissimilar homophone and unrelated prime-target pairs. Grainger and Ferrand interpreted their results within their modified interactive activation framework.

Grainger and Ferrand (1994) introduced a modified version of the interactive activation framework introduced by McClelland and Rumelhart (1981) in which priming effects are dependent upon activation of lexical-level representations by primes (see Figure 3). Within the interactive activation framework proposed by Grainger and Ferrand, there are separate sublexical orthographic and phonological processing units and separate orthographic and phonological lexicons. There are excitatory connections between the sublexical units, between each of the sublexical units and their respective lexicons, and between the lexicons. These excitatory connections are bidrectional, which allow for both top-down and bottom-up processing. There are also connections between lexical entries within each lexicon that are inhibitory. Activation of an orthographic lexical entry from print is accomplished by mapping sublexical orthographic units of printed words (e.g., letters or graphemes) onto whole word orthographic lexical entries. Activation of phonological lexical entries is accomplished either through mapping whole word orthographic lexical entries directly onto whole word phonological entries in the phonological lexicon (i.e., addressed phonology), or by mapping sublexical orthographic units onto sublexical phonological units (e.g., phonemes) and then mapping the sublexical phonological units onto whole word phonological lexical entries (i.e., assembled phonology). Grainger and Ferrand hypothesized that lexical decisions can be made when activation in either the orthographic or phonological lexicons reaches a critical activation level[5]. Priming effects occur because processing of primes leaves lexical-level representations in a preactivated state when targets are presented. Generally, when a stimulus is a printed word, the orthographic representation is hypothesized to reach the critical activation threshold first because arrival of information at the phonological lexicon lags behind the arrival of information at the orthographic lexicon due to the extra processing involved.

With regard to Grainger and Ferrand's (1994) initial experiment, the inhibitory effect of the orthographically similar non-homophone primes is attributable to their own entries being strongly activated in the orthographic lexicon, initially inhibiting activation of the lexical representations of the targets. Lexical decisions to the targets are delayed

[5] It should be noted that Ferrand and Grainger (1996) also supply some experimental data suggesting that lexical decisions can be made based on the summed activation of the orthographic and phonological lexicons.

until activation of the lexical entries for the targets can overcome this initial inhibition. In contrast, the facilitation of targets preceded by orthographically similar homophone primes is attributable to the representations of the targets in the phonological lexicon reaching the critical activation threshold prior to the representations in the orthographic lexicon. The orthographic similarity between orthographically similar homophone primes and targets results in inhibition of activation in the orthographic lexicon, as described above. However, the phonological representations quickly reach the critical activation threshold because the orthographic representations of the primes and targets fighting for activation in the orthographic lexicon simultaneously activate the same representations in the phonological lexicon. As in their first experiment, in Grainger and Ferrand's second experiment the representations of both the orthographically similar and orthographically dissimilar homophone primes are theorized to have reached the critical activation threshold in the phonological lexicon first because the phonological representations of the primes and targets matched exactly. More facilitation for the orthographically similar homophone trials was obtained because activation of the orthographically dissimilar homophone targets in the phonological lexicon is slowed due to the contrasting grapheme representations activated at the level of the sublexical orthographic processing units. With regard to the comparison of the unrelated and orthographically dissimilar homophone prime-target conditions, a null effect was obtained because the phonological overlap between the orthographically dissimilar homophone primes and targets facilitates activation in the phonological lexicon but the orthographic mismatch inhibits activation due to the sublexical orthographic incompatibility.

Grainger and Ferrand's (1994) modified interactive activation model casts doubt on the assumptions under which both the current data and that of Lavidor and Ellis (2003) was interpreted. Thus, new tests of simple effects making the same comparisons as Grainger and Ferrand were conducted on the current data using t-tests employing a Bonferroni correction for the number of comparisons made. With regard to the reaction time data ($\alpha = .013$), targets presented to the left hemisphere were responded to faster by participants when preceded by orthographically similar homophone primes than when preceded by unrelated primes ($p < .001$), and there was no difference between the unrelated and orthographically dissimilar homophone prime-target pairs ($p > .013$). According to the logic of Granger and Ferrand, this is evidence that the left hemisphere has access to phonological representations, as the presence of homophony encourages lexical decision responses that are based on activation in the phonological lexicon, which is consistent with previous findings. For the right hemisphere, the reaction time data revealed no differences (all *p*s > .01). With regard to the accuracy data, because no interaction between hemisphere of presentation and prime-type was obtained in the original analysis, new tests of only the main effect of prime-type were conducted ($\alpha = .025$). Participants responded more accurately to the targets preceded by orthographically similar homophone primes than the unrelated primes ($p < .001$) and there was no difference between the unrelated and orthographically dissimilar homophone prime-target pairs ($p > .025$). According to the logic of Granger and Ferrand, this is evidence that both the left hemisphere and right hemisphere can process phonology. However, as stated above, that no evidence of phonological priming was obtained in the reaction time data weakens any claims that can be made on the basis of the accuracy data, as reaction times are generally viewed to be a finer grained and more sensitive dependent variable. The absence of orthographic processing effects is not surprising considering that the experimental paradigm, according to Grainger and Ferrand, does not allow an examination of whether the orthographic representation of a printed word is accessed.

Regardless of the manner in which the results of Experiment 1 are interpreted, whether in accordance with Lavidor and Ellis (2003) or Grainger and Ferrand (1994), only minimal, weak evidence of right hemisphere phonological processing was obtained. Three possible reasons for this exist. First, the original proposition of Lavidor and Ellis, that the presence of a mask for 500 ms between the offset of the primes and onset of the targets caused phonological information initially available to the right hemisphere to decay, still holds. Second, it may be that the differences obtained between prime conditions in Experiment 1 are attributable to the use of different targets in each prime condition. A third, and theoretically more interesting, possibility is offered by the model of Grainger and Ferrand.

Chapter III

A Timeline of Orthographic and Phonological Processing in the Left and Right Cerebral Hemispheres

I posit that only minimal evidence of right hemisphere phonological processing was obtained because the primed lexical decision methodology reflects lexical-level processing, whereas the experimental methodologies that have previously yielded evidence of implicit right hemisphere phonological processing reflect processing at the pre- or sublexical-level. This division among experimental tasks is most clear when comparing the backward masking and primed lexical decision tasks. With regard to the former, the mask is assumed to reinstate some of the decoded aspects of the target that the two share. There seems to be little debate that decoded aspects of the target that are reinstated are at the phonemic or sublexical-level (e.g., Brysbaert, 2001; Frost & Yogev, 2001; Halderman; Halderman & Chiarello). In contrast, there is not the same consensus for forward masked priming. Authors have referred to the effects observed in forward masking experiments as being sublexical (e.g., Brysbaert, 2001). However, this assumption may be made in error. As discussed previously, in the model of Grainger and Ferrand (1994) priming effects are dependent upon activation of lexical-level representations, a view shared by Forster (1998). As partial evidence, Forster cites findings of forward masked semantic priming effects and priming effects between noncognate words with equivalent meanings from two different languages with dissimilar scripts (e.g., priming of *cat* in English by cat written in Japanese Kanji-*neko*).

Accepting the premise that backward masking and primed lexical decision differentially reflect sublexical- and lexical-level processing, the data from both

Halderman (2006) and Experiment 1 enable construction of a tentative timeline of sublexical and lexical orthographic and phonological processing in the hemispheres. Beginning with the left hemisphere, the results of Halderman suggest sublexical processing of both orthography and phonology beginning early in the time course of processing (at 30 ms[6]). However, the results of Halderman suggest increased activation of sublexical phonological representations relative to orthographic representations later in processing (at 70 ms). The results of Experiment 1 suggest that phonological representations may be activated in parallel at the lexical level (by 50 ms). A parallel relationship between activation of phonological representations at the sublexical- and lexical-levels could be accounted for by a feedback mechanism between lexical and sublexical units similar to that featured in the model of Grainger and Ferrand (1994). However, further examination of the time course of lexical-level processing is required to fully flesh out a timeline. For example, it may be that activation of phonological representations, though largely in parallel, is somewhat delayed at the lexical-level relative to the sublexical-level. This would seem to be more logical and consistent with the model of Grainger and Ferrand. With regard to the window of time examined in Experiment 1, Lavidor and Ellis (2003) assumed that prime processing was halted at 50 ms by the masks. However, it is possible that the primes were processed for another 500 ms (the presentation duration of the mask intervening between the primes and targets in their experiment), as the masks were void of linguistic information that required

[6] Please note that reference is made to specific time points in processing only to ease the readers understanding of the timeline outlined. Rather than the strong assumption that it can be used to reveal the absolute time course for the computation of linguistic codes, it is assumed that SOA manipulations can help provide approximations of the time course of early word processing and provide evidence for strong claims about relative processing (Frost & Yogev, 2001). For a discussion, please see below.

processing resources to be diverted from the primes. Further examination of the time course of lexical-level processing is also required to fully flesh out a timeline because there is limited experimental data regarding left hemisphere lexical-level orthographic processing. It may be that the lexicon in the left hemisphere does not store orthographic representations, though this would seem counterintuitive given that Halderman evidenced sublexical orthographic processing in the left hemisphere. Alternatively, processing at the lexical-level in the left hemisphere may mirror processing at the sublexical-level as evidenced by Halderman. That is, orthographic representations may be activated in the lexicon early and experience sustained activation until later, though the activation levels of phonological representations become greater. This would be most consistent with the model of Grainger and Ferrand. It is also possible that phonological representations are activated first in the lexicon, with lexical-level orthographic representations being activated later, as in the resonance visual word recognition model of Van Orden & Goldinger (1994).

With regard to the right hemisphere, the results of Halderman (2006) suggest sublexical processing of both orthography and phonology beginning early in the time course of processing (at 20 ms). According to the results of Experiment 1, however, it seems more likely that only orthographic representations are activated at the lexical-level, as no evidence of right hemisphere phonological processing was obtained. That both orthography and phonology are processed at the sublexical-level but only orthographic representations are activated at the lexical-level would seem to be somewhat paradoxical. However, Smolka and Eviatar (2006) have suggested a mechanism by which this seeming paradox can be unraveled. Smolka and Eviatar manipulated diacritic markings in

Hebrew words such that any observed interference in word recognition (naming) could be attributed to a change in phonology, a change in orthography, or a figurative change (i.e., the diacritic marks were replaced with non-linguistic symbols). Only phonological interference was obtained for stimuli presented to the left hemisphere. In contrast, for stimuli presented to the right hemisphere, equivalent phonological and figurative interference was obtained, suggesting that the right hemisphere processes graphemes as visual signs that are not language specific. However, no orthographic interference was obtained, suggesting that graphemic units are stored according to phonological categories. This storage method for sublexical information may explain why phonological effects are observed for stimuli presented to the right hemisphere under experimental conditions reflecting sublexical processing, as well as why participants are better able to decide that two words do not rhyme when presented to the right hemisphere. The claim that only orthographic representations are activated at the lexical-level in the right hemisphere is supported by Lavidor and Ellis (2001), who observed facilitation effects that were limited to the right hemisphere for lexical decisions when targets had many orthographic neighbors. Orthographic neighbors are words that can be derived for a given target by changing one letter, and neighborhood density is the number of neighbors a given target possesses (Coltheart, Davelaar, Jonasson, & Besner, 1977). As such, this finding suggests that the lexicon in the right hemisphere is organized along dimensions related to the orthographic representations of words. As with the left hemisphere, however, further examination of the time course of lexical-level processing is also required to fully flesh out a timeline because there is limited experimental data regarding lexical-level orthographic processing.

Chapter IV

Forward Masked Orthographic and Phonological Priming

The aim of Experiments 2 and 3 is to partially test and extend the framework of print processing outlined by corroborating the findings of Experiment 1 and further examine the time course of processing at the lexical-level. In contrast to the primed lexical decision methodology used in Experiment 1, the <u>forward masked primed lexical decision</u> paradigm is used in Experiments 2 and 3 to examine lexical activation of phonological and orthographic representations. Since the early- to mid-eighties, the forward masked primed lexical decision task has become an increasingly popular method to study the processing of orthography and phonology during lexical access. The task is easily adapted to the visual half-field paradigm, and adhering to the methodology laid out in the central visual field literature provides the opportunity to interpret new data in the context of an experimental methodology with commonly accepted assumptions supported by a relatively long experimental history.

In a typical forward masked priming experiment, a mask (usually a row of hash marks) is initially presented for approximately 500 ms. This is followed by a 10-70 ms presentation of a prime that is followed immediately by the target. Generally, participants are asked to make a lexical decision, although some researchers have used alternative modes of response (e.g., naming). As was stated above, the time needed to make a lexical decision response is assumed to reflect the time needed for lexical access of a word target (or time required to confirm that a nonword target does not have a lexical entry) in addition to the time needed to plan and make a motor response. Phonologically related primes are generally pseudohomophones of the word targets (e.g., *tode-TOAD*) and are compared to nonword orthographic prime controls that are as orthographically similar to the word targets as the phonological primes (e.g., *tods-TOAD*) in order to parcel out the effects of orthographic relatedness from phonological relatedness. Phonological priming[7] (and, by inference, phonological processing) is said to have occurred if the phonological prime facilitates target recognition more so than the orthographic prime. Orthographically related primes are generally nonwords that are one letter different from the word target (e.g., *tood-TOAD*) and are compared to nonword primes that are unrelated to the target (e.g., *fieb-TOAD*). Orthographic priming[8] (and, by inference, orthographic processing) is said to have occurred if the orthographic prime facilitates target recognition more so than the unrelated prime. However, inferring that orthographic processing is responsible for orthographic priming is somewhat problematic in English. This is because orthographic primes have some degree of phonological overlap with their respective targets. For example, the orthographic prime *tood* shares two of three phonemes with the target *TOAD*. This overlap notwithstanding, it is assumed that any benefit produced by orthographic primes relative to unrelated primes can be attributed primarily to orthographic processing (Holyk & Pexman, 2004).

The assumption that orthographic priming and phonological priming reflect lexical-level orthographic and phonological processing, respectively, is consistent with the modified interactive activation model of Grainger and Ferrand (1994). Beginning with orthographic priming, presentation of a nonword prime (e.g., *jark*) activates the prime's neighborhood of entries in the orthographic lexicon (e.g., bark, lark, park, jerk).

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[7] When primes are pseudohomophones, another term commonly used in the literature to refer to phonological priming is pseudohomophone priming.
[8] When primes are orthographically related nonwords, another term commonly used in the literature to refer to orthographic priming is form priming.

Subsequently, upon presentation of a target (e.g., *JERK*), its neighborhood of orthographic representations (e.g., jerk, perk, berk) are also activated. The lexical entry of the target eventually becomes the most highly activated; however, its activation level will rise more quickly, and the critical threshold needed to make a lexical decision response will be reached faster, when the prime is orthographically related, because the target's representation is in a preactivated state when it is presented. It is important to note that nonword orthographic primes facilitate target recognition because they do not activate any one lexical entry too strongly (though see below for evidence that nonword orthographic primes that activate many orthographic neighbors also shared by their targets slow the activation of the lexical representations of the targets), in contrast to the effect of orthographically similar real word primes.

With regard to phonological priming, a prime (e.g., *jurk*) will initially activate a neighborhood of orthographically similar lexical entries in the orthographic lexicon (e.g., jerk, lurk, jury). Via input from the orthographic lexicon, these phonological representations will also become activated in the phonological lexicon. Subsequently, the target (e.g., *JERK*) will also activate a neighborhood of orthographically similar lexical entries in the orthographic lexicon and phonological lexicon (e.g., jerk, perk, berk). The lexical entry of the target eventually becomes the most highly activated in both the orthographic and phonological lexicons; however, its activation level will rise more quickly, and the critical threshold needed to make a lexical decision is reached faster, when the prime is phonologically and orthographically related relative to when a prime is only orthographically related. This is because the target's representation is in a preactivated state in the phonological lexicon when it is presented. The activation level of the lexical entry of the target reaches the critical threshold in the phonological lexicon more quickly because both the prime and target share the same phonological representations but different orthographic representations. The rise of activation in the orthographic lexicon is slowed relative to the rise in activation in the phonological lexicon because the input from the sublexical orthographic units is different for the prime and target.

Two more assumptions are important for understanding the results of forward masked priming experiments – that the effects are automatic and that stimulus onset asynchrony can reveal the absolute time course of the computation of linguistic codes in forward masked priming experiments, as was discussed in the context of Lavidor and Ellis' (2003) experimental methodology. Automaticity is assumed because the brief presentation of the prime between the forward mask and the target ensures that participants are not aware of the presence of the prime (Forster & Davis, 1984; Forster, Davis, Schoknect, & Carter, 1987). Under conditions fostering automatic processing, facilitative priming effects are thought to arise due to the automatic spread of activation through associative connections at the sublexical and lexical levels. In contrast, conditions in which controlled processing can occur are thought to allow participants to use the prime to explicitly generate lexical candidates for the subsequent target (for review see McNamara & Holbrook, 2003). With regard to the stimulus onset asynchrony assumption, Tzur and Frost (2007) recently demonstrated that the exposure duration of primes in combination with their luminance determine the magnitude of priming effects. This finding is in accordance with Bloch's law, which states that the overall energy of a stimulus perceived by the visual system is equal to the product of the exposure duration and luminance of that stimulus. This suggests that changes in priming effects at different stimulus onset asynchronies may have as much to do with the changes in the overall energy of the primes as with the time course of processing being examined. Given this finding, it may be more appropriate to assume that stimulus onset manipulations can help provide approximations of the time course of early word processing and provide evidence for strong claims about relative processing rather than the strong assumption that it can be used to reveal the absolute time course for the computation of linguistic codes (Frost & Yogev, 2001).

While there is common agreement and/or experimental data supporting the above assumptions, the forward masking task is not without its disadvantages. Chief among these are diverging results and failures to replicate. With regard to orthographic priming, Forster et al. (1987) found that orthographic primes were facilitatory only when prime-target pairs were drawn from a low-density neighborhood, and Forster (1987) obtained no orthographic priming regardless of the neighborhood density of the primes when targets were drawn from high-density neighborhoods. As such, Forster concluded that only the neighborhood density of targets affects orthographic priming; however, Forster did not manipulate the neighborhood density of orthographic primes for targets drawn from only low-density neighborhoods and the results of Hinton, Liversedge, and Underwood (1998) and Van Heuven, Dijkstra, Grainger, and Schriefers (2001) challenge the conclusion of Forster. Using a masked priming paradigm, Hinton et al. found that unambiguous primes (e.g., the partial prime *pa%h* only primes *PATH*) facilitate target recognition but that ambiguous primes (e.g., the partial prime *%ath* primes *MATH*, *BATH*, etc.) do not. Using Dutch stimuli, Van Heuven et al. obtained a larger orthographic priming effect for prime-target pairs that shared no orthographic neighbors versus primes and targets that shared multiple orthographic neighbors. Van Heuven et al. argue that the results of Hinton et al. (1987), as well as the results of Forster et al. (1987) and Forster (1987), can also be attributed to the effect of shared orthographic neighborhood size between prime and target. However, it must be noted that Forster (personal communication, November 20, 2008) has not been able to replicate the results of Van Heuven et al. using English stimuli. Additionally, the results of my own pilot data using English stimuli are mixed, as I replicated the results of Van Heuven in an initial experiment but did not in a subsequent attempt. Even so, the results from forward masked orthographic priming experiments seem relatively straightforward to interpret relative to the results of forward masked phonological priming experiments.

The first researchers to find evidence of forward masked phonological priming were Perfetti and Bell (1991). They obtained phonological priming only at stimulus onset asynchronies of 45 ms and longer, a finding replicated by Ferrand and Grainger (1992, 1993) using French stimuli and Brysbaert (2001) using Dutch stimuli. Lukatela, Frost, and Turvey (1998) and Lukatela and Turvey (2000), however, obtained phonological priming at stimulus onset asynchronies of 29 ms and 14 ms, respectively. This divergence of results is complicated even further by the fact that several researchers have failed to obtain a phonological priming effect regardless of stimulus onset asynchrony (Coltheart & Woolams as cited in Holyk & Pexman, 2004 and Rastle & Brysbaert, 2006; Davis, Castles, & Iakovidis, 1998; Forster & Mahoney as cited in Holyk & Pexman and Rastle & Brysbaert; Holyk & Pexman), leading some to question whether the phonological priming effect is real (e.g., Coltheart et al., 2001).

Several explanations of the variability in the results of forward masked phonological priming experiments have been offered, including the demonstration of Tzur and Frost (2007) that the exposure duration of primes in combination with their luminance modulates the size of identity priming effects. With regard to the experiments of Perfetti and Bell (1991), Ferrand and Grainger (1992, 1993), and Brysbaert (2001), if the luminous intensity of their stimuli was low, then it may be that they did not obtain phonological priming at the shorter stimulus onset asynchronies because the overall energy of their primes was not sufficient. However, while this may explain the failures to find a pseudohomophone effect at shorter stimulus onset asynchronies (i.e., less than 29 ms), this does not explain failures to do so at longer stimulus onset asynchronies, as Tzur and Frost found that luminous effects are discontinuous and are not a factor at longer stimulus onset asynchronies (i.e., 40 ms), such as that used by Davis, Castles, and Iakovidis (1998).

Another explanation for the variability in the results of forward masked phonological priming experiments was posited by Lukatela and Turvey (2000), who proposed that the variability has to do with the vowel complexity of the stimuli. Lukatela and Turvey obtained phonological priming for prime-target pairs that consisted of stimuli with simple vowel patterns (e.g., *KLIP-clip*) at a stimulus onset asynchrony of 14 ms but not for prime-target pairs that consisted of stimuli with complex vowel patterns (e.g., *BOTE-boat*). This finding was replicated by Holyk and Pexman (2004). While the source of this difference between prime-target pairs with simple and complex vowel patterns is not completely clear, the most reasonable explanation, according Lukatela and Turvey, is simply that it takes more time to process the phonology of words with complex vowels than words with simple vowels. This may partially explain the diverging results, as the stimuli of Perfetti and Bell (1991) consisted primarily of stimuli with complex vowel patterns and the stimuli of Lukatela et al. (1998) and Lukatela and Turvey had primarily simple vowel patterns. However, further study is needed to determine if the dichotomy between simple and complex vowels in phonological priming using English stimuli can be generalized to French and Dutch.

Holyk and Pexman (2004) attributed the variability in the results of forward masked phonological priming experiments to individual differences, whereas Rastle and Brysbaert (2006) attributed it to the relatively small effect size. Holyk and Pexman found that participants with either high phonological awareness or perceptual skill evidenced a greater phonological priming effect at a 15 ms stimulus onset asynchrony than participants with low phonological awareness or perceptual skill. Rastle and Brysbaert, however, criticized Holyk and Pexman's conclusion. Rastle and Brysbaert conducted a meta-analysis that showed phonological priming to be a small to medium effect. They concluded that the failures to obtain phonological priming were due to small sample sizes and obtained phonological priming using a sample considerably larger than that of any of the previously reviewed studies.

Frost, Ahissar, Gotesman, & Tayeb (2003) offer yet another explanation for the variability of findings. Taking advantage of the unique properties of Hebrew orthography, Frost et al. found that the advantage conferred by the homophonic one-letter-different primes on target recognition was greater when compared to two-phoneme one-letter-different primes than one-phoneme one-letter-different primes. They observed this pattern for stimulus onset asynchronies as brief as 20 ms and concluded that phonological priming effects are tenuous, especially at brief stimulus onset asynchronies, because phonological codes are initially impoverished, or coarse-grained, during the course of lexical access and that substantial phonological contrasts are required to obtain forward masked phonological priming effects.

While the forward masked priming task has many advantages, its major drawback lies in the fact that the literature is not consistent with regard to obtaining orthographic and phonological priming. Fortunately, control variables have been identified that may enable observation of orthographic and phonological priming, and this knowledge was used in the stimulus set development for the current study to optimize the experimental design: For orthographic priming both the orthographic neighborhood size of targets and the number of orthographic neighbors shared between primes and targets is limited; and for phonological priming, only primes and targets with simple vowel complexities are used and the sample collected is relatively large. Unfortunately, the population of words with simple vowel patterns for which both orthographic and phonological primes can be created that share zero orthographic neighbors is relatively small. Thus, rather than conduct one experiment examining both form and phonological priming, two experiments must be carried out, with the first examining orthographic priming and the second examining phonological priming. To maximize the chances of finding priming effects, the luminous intensity of the stimuli is maximized by keeping the testing room dark and maximizing the brightness of the monitor. Given that the absolute value of exposure duration is not of theoretical importance, luminance is not directly controlled. While this lack of luminance control may limit the generalizability of the findings from this study with respect to future forward masked priming experiments studying the impact of luminance, it will not impact the tests of the relative time course of processing (Tzur & Frost, 2007), which is the primary goal of this study.

Chapter V

Visual Half-Field Forward Masked Orthographic and Phonological Priming

The purpose of Experiments 2 and 3 is to examine the time course of lexical-level orthographic and phonological processing in the left and right hemispheres. The forward masked primed lexical decision task is ideal because it can easily be adapted to the visual half-field presentation, the assumptions underlying it are commonly accepted, control variables have been identified that better enable observation of priming, and it can be used to examine a broad time course of processing.

With regard to the latter, stimulus onset asynchrony was manipulated to allow examination of processing at 50 ms and 150 ms. A stimulus onset asynchrony of 50 ms was chosen because it is the temporal point around which the debate seems to center in the central visual field forward masked priming literature regarding whether phonological priming may be observed. A stimulus onset asynchrony of 150 ms was chosen because it is the maximum stimulus onset asynchrony that may be used in the forward masked priming paradigm to examine later processing downstream of 50 ms. One of the common assumptions about forward masked priming is that the processes underlying it are automatic rather than strategic because participants are unaware of the presence of the primes due to the short prime presentation durations. Obviously, participants are aware of primes that are present for 150 ms, which brings this assumption into question in the current experiment. However, according to the guidelines outlined by McNamara and Holbrook (2003), a stimulus onset asynchrony of 150 ms is sufficiently short to guard against strategic processing in priming experiments.

Making predictions for the outcome of Experiment 2 is difficult, as there is limited prior data regarding left and right hemisphere lexical-level orthographic processing on which to base predictions. Thus, Experiment 2 is somewhat exploratory. However, with regard to right hemisphere orthographic priming, the data of Lavidor and Ellis (2001) and Smolka and Eviatar (2006) do indicate that the right hemisphere is heavily dependent upon orthographic processing at both the sublexical and lexical-levels. The predictions for Experiment 3 are thus: (1) With regard to left hemisphere phonological priming, lexical-level phonological representations likely become more activated later in the time course of processing, delayed relative to the processing of phonology at the sublexical-level per Halderman's (2006) demonstration. This is consistent with the model of Grainger and Ferrand (1994). Thus, priming is expected in the longer 150 ms but not the shorter 50 ms stimulus onset asynchrony condition. (2) With regard to right hemisphere phonological priming, again, the data of Lavidor and Ellis and Smolka and Eviatar indicate that the right hemisphere is heavily dependent upon orthographic processing at both the sublexical and lexical levels. Thus, phonological priming is not expected in either stimulus onset asynchrony condition.

Experiment 2 Method:

Visual Half-Field Forward Masked Orthographic Priming

Participants

Participants were undergraduate students at the University of Windsor who participated for bonus course credit. Informed consent was obtained from all participants (see Appendix A for a copy of the informed consent form). Thirty of 150 participants had excessive error rates for the experimental trials (> 35% across all trials) and their data were removed from the final analysis. Of the 120 participants that were included in the final analysis, 14 were males and 106 were females. All participants were right-handed, as indicated by a score equal to or greater than 40 on the Edinburgh Handedness Inventory (Oldfield, 1971). All participants had normal or corrected-to-normal vision, no history of neurological trauma, and were native speakers of English (see Appendix E for a copy of the questionnaire used to collect demographic information, as well as the Edinburgh Handedness Inventory). Additionally, all participants were given a measure of reading fluency to assess competency (Fuchs, Fuchs, Hosp, & Jenkins, 2001). Participants were asked to read a passage aloud as quickly and as accurately as they could for one minute. Total number of words read and uncorrected errors were recorded. The passage chosen was "The Dragons Tears," which is a traditional folktale used in previous studies of reading fluency (Brown & Smiley, 1977; Fuchs, Fuchs, & Maxwell, 1988; Jenkins, Heliotis, Haynes, & Beck, 1986). It was decided *a priori* that participants whose number of words read fell 2.5 standard deviations from the mean for all participants were to be removed. In practice, all participants to whom these criteria applied were already removed because they met other excluding criteria.

Materials

Forty critical targets were each paired with two types of primes: (1) Nonword primes unrelated to their respective targets (e.g., *wilk-JERK*, *snoth-CLIFF*) and (2) Nonword orthographic primes that differ by one grapheme from their respective targets (e.g., *jark-JERK*, *cloff-CLIFF*). The orthographic prime for each of the critical targets was created by changing a vowel in the body of the respective critical target. The critical targets for which primes were created were limited by the constraints set out above. To review, in accordance with the findings of Forster et al. (1987) and Van Heuven et al. (2001), the critical targets were drawn from low-density neighborhoods and limited to those that could be paired with orthographic primes that shared zero orthographic neighbors. So that the psycholinguistic properties did not vary between Experiments 2 and 3 (examining phonological priming), the critical targets were also limited to those that could be paired with phonological primes that shared zero orthographic neighbors; and, following Lukatela and Turvey (2000) and Holyk and Pexman (2004), only words with simple vowel patterns were included as critical targets. The mean word frequency of the critical targets was 61.73 (Standard Deviation = 203.73) and the mean orthographic neighborhood size was 2.59 (Standard Deviation = 2.85). The word frequencies and neighborhood sizes of the targets were drawn from the WordMine2 database (Durda & Buchanan, 2006). All stimuli were four to six letters in length. Primes and targets were always the same length. All nonwords were orthographically legal and pronounceable. Appendix F contains a list of the critical prime-target pairs.

In addition to the critical targets, 40 nonword targets were created, each with an unrelated nonword prime (e.g., *jash-LERF*) and nonword orthographic prime (e.g., *lorf-LERF;* see Appendix G). Also, 80 filler targets, 40 words and 40 nonwords, were generated. Each of the filler targets was paired with an unrelated nonword prime (see Appendix H).

Design

In each of the two experiments, participants were asked to decide whether a letter-string (i.e., the target) displayed on the computer screen in their left visual field/right hemisphere or right visual field/left hemisphere was a real English word. Each of the targets was preceded by a laterally presented prime for which no response was required. In each of the two experiments, each participant saw each target item only once, but across the experiment all target items were presented to both visual fields/hemispheres paired with each of their respective primes. To accomplish this, four counter-balanced lists were created from the combinations of the two visual field/hemisphere conditions and two prime-type conditions for the critical targets and the nonword targets with unrelated nonword and nonword orthographic primes. An example is presented in Table 3 demonstrating the method by which the lists were counter-balanced to account for visual field/hemisphere of presentation and prime-type using the critical target *JERK*, its unrelated nonword prime *wilk,* and orthographic prime *jark*. The participants were assigned to the lists randomly. To eliminate any possibility of simple surface feature priming, all primes appeared in lowercase and all targets appeared in uppercase. For each of the critical targets and the nonword targets paired with unrelated nonword and orthographic primes, the primes were always presented in the same visual field/hemisphere as the targets.

In addition to visual field/hemisphere of presentation and prime-type, stimulus onset asynchrony was manipulated such that half of the participants were presented the primes for 50 ms and half were presented the primes for 150 ms. While a prime presentation duration of 50 ms is likely too fast to alert participants to the presence of primes, participants were able to identify primes when presented for 150 ms. To ensure that participants could not predict in which visual field/hemisphere the target items would be presented, 80 filler target items with unrelated nonword primes were created. Unlike the other prime-target pairs, the filler target items were presented in the visual field/hemisphere opposite to each of their respective primes. Just as with the other items, the filler target items were rotated such that across each of the two experiments they were seen in both visual fields/hemispheres. Thus, each participant saw a total of 160 targets, the 40 critical targets, the 40 nonword targets, and the 80 filler targets.

Apparatus and Procedure

A Dual Core Pentium D PC running Direct RT was used to present the stimuli and collect reaction time and accuracy data. Figure 4 is a timeline of events for Experiment 2. Each trial consisted of four events. Each trial began with the presentation of a fixation point (+) in the center of the computer screen for 500 ms. Immediately following the presentation of the fixation point, masks (#####) were presented simultaneously in both the left visual field/right hemisphere and right visual field/left hemisphere for 500 ms. Immediately following the presentation of the masks, the lowercase prime was presented in either the left visual field/right hemisphere or right visual field/left hemisphere for 50 ms or 150 ms with the mask present in the opposite visual field/hemisphere. The upper-case target was then presented to either the left visual field/right hemisphere or right visual field/left hemisphere for 180 ms with the mask present in the opposite visual field/hemisphere. Following the target, a blank screen was displayed until a response was made. The next trial began immediately after the response. The prime-target pair trials were presented in random order (including each the critical prime-target, nonword-nonword prime-target, and filler prime-target pairs). The stimuli were white and seen against a black background. The participants' heads were stabilized by a chin-rest located 152 cm from the monitor. This location ensured that the visual angle from the central fixation point to the innermost edge each word was at least 2.50°.

Limiting the presentation time of the target and manipulating the visual angle ensured that the stimuli were presented laterally and that the participants were not able to foveate toward the stimuli (Bourne, 2006).

Participants were asked to determine whether the letter-string presented entirely in uppercase letters was a word or nonword. Half of the participants responded to words by pressing the "N" key with the index finger of their right hands and to nonwords by pressing the "V" key with the index finger of their left hand. This response-key pairing was reversed for the other half of the participants. Participants were instructed to make their response as quickly and accurately as possible. Participants were not informed as to the presence of the primes. Upon debriefing, none of the participants who were presented the primes for 50 ms reported being aware of the presence of the primes, though some did report noticing the screen flicker between the presentation of the mask and the target. All of the participants who were presented the primes for 150 ms reported being able to identify at least some of the primes. The experimenter emphasized the importance of focusing on the fixation cross throughout the duration of trial. Each experimental session began with the presentation of a 50-item practice list. The construction of the practice list mirrored the construction of the experimental lists. The practice list was administered in two parts. After half of the practice trials were administered, participants were provided with feedback concerning accuracy. Throughout each of the experimental sessions, the luminous intensity of the stimuli was maximized by keeping the testing room dark and maximizing the brightness of the monitor.

Experiment 2 Results:

Visual Half-Field Forward Masked Orthographic Priming

Presentation and background effects

The two independent variables list and responding hand were analyzed to determine whether they had significant effects on performance. Using the dependent variable reaction time, mixed between-within-participants ANOVAs were conducted and revealed that these variables produced neither main effects nor interactions with the independent variables of interest, prime-type and hemisphere of presentation (all Fs < 3.00). Therefore, the data from all 120 participants performing above chance levels were collapsed into a single analysis.

Reaction Time Analyses

For each participant, reaction times for incorrect trials were removed (accounting for 18% of the data points). Also, reaction times greater than 4000 ms were considered outliers and removed (accounting for 0.5% of the data points). The identification and removal of outliers was done according to the suggestions made by Ulrich and Miller (1994).

Two (stimulus onset asynchrony: 50 ms versus 150 ms) x 2 (hemisphere of presentation: right versus left hemisphere) x 2 (prime-type: unrelated versus orthographic prime) mixed between-within-participants ANOVAs were performed both for participants and items. Stimulus onset asynchrony was a between-participants factor and hemisphere of presentation and prime-type were within-participants factors. Performance for left hemisphere targets (Mean = 817) was faster than for right hemisphere targets (Mean = 838 ms) for participants [F_1 (1, 118) = 4.02, $p < .05$, partial $\eta^2 = .03$], but not for items [F_2 (1, 78) = 1.91, $p > .05$, partial $\eta^2 = .02$]. Importantly, as is indicated in Figure 5, there was a main effect of prime-type indicating that participants responded faster to targets preceded by orthographic primes (Mean = 800) than unrelated primes (Mean = 851) [F_1 (1, 118) = 37.88, $p < .001$, partial $\eta^2 = .24$; F_2 (1, 78) = 27.42, $p < .001$, partial $\eta^2 = .26$]. The main effect of stimulus onset asynchrony [F_1 (1, 118) = .10, $p > .05$, partial $\eta^2 = .00$; F_2 (1, 78) = .08, $p > .05$, partial $\eta^2 = .00$], its two-way interactions with hemisphere of presentation [F_1 (1, 118) = .03, $p > .05$, partial $\eta^2 = .00$; F_2 (1, 78) = .36, $p > .05$, partial $\eta^2 = .01$] and prime-type [F_1 (1, 118) = .00, $p > .05$, partial $\eta^2 = .00$; F_2 (1, 78) = .02, $p > .05$, partial $\eta^2 = .00$], and the three-way interaction between stimulus onset asynchrony, hemisphere of presentation, and prime-type [F_1 (1, 118) = 1.19, $p > .05$, partial $\eta^2 = .01$; F_2 (1, 78) = 1.32, $p > .05$, partial $\eta^2 = .02$] did not reach significance. Thus, the orthographic priming effect was not modulated by stimulus onset asynchrony or hemisphere of presentation. The data relevant to these analyses are summarized in Table 4.

Accuracy Analyses

Two (stimulus onset asynchrony: 50 ms versus 150 ms) x 2 (hemisphere of presentation: right versus left hemisphere) x 2 (prime-type: unrelated versus orthographic prime) mixed between-within-participants ANOVAs were performed both for participants and items. Stimulus onset asynchrony was a between-participants factor and hemisphere of presentation and prime-type were within-participants factors. The accuracy data differed from the reaction time data in that only the two-way interaction between stimulus onset asynchrony and prime-type reached significance [F_1 (1, 118) = 7.32, $p < .01$, partial $\eta^2 = .06$; F_2 (1, 78) = 6.77, $p = .01$, partial $\eta^2 = .08$]. The main effects of stimulus onset asynchrony [F_1 (1, 118) = .78, $p > .05$, partial η^2 = .00; F_2 (1, 78) = 1.01, $p > .05$, partial η^2 = .01], hemisphere of presentation [F_1 (1, 118) = .77, $p > .05$, partial η^2 = .01; F_2 (1, 78) = 1.35, $p > .05$, partial η^2 = .02], and prime-type [F_1 (1, 118) = .01, $p > .05$, partial η^2 = .00; F_2 (1, 78) = .01, $p > .05$, partial η^2 = .00] did not reach significance. Also, neither the two-way interactions between stimulus onset asynchrony and hemisphere of presentation [F_1 (1, 118) = .14, $p > .05$, partial η^2 = .00; F_2 (1, 78) = .25, $p > .05$, partial η^2 = .00] and hemisphere of presentation and prime-type [F_1 (1, 118) = .18, $p > .05$, partial η^2 = .00; F_2 (1, 78) = .12, $p > .05$, partial η^2 = .00], nor the three way interaction [F_1 (1, 118) = .01, $p > .05$, partial η^2 = .00; F_2 (1, 78) = .01, $p > .05$, partial η^2 = .00] reached significance. The data relevant to these analyses are summarized in Table 4.

Post hoc comparisons using pairwise two-tailed *t*-tests employing a Bonferroni correction for the number of comparisons made were performed in order to further investigate the two-way interaction between stimulus onset asynchrony and prime-type (α = .008). These comparisons revealed that the source of the interaction was the fact that targets preceded by orthographic primes were responded to more accurately in the 150 ms stimulus onset asynchrony condition (Mean = 17% error) than in the 50 ms stimulus onset asynchrony condition (Mean = 23% error) by items ($p < .001$). No difference in accuracy was found between the targets preceded by the unrelated primes in the 150 ms stimulus onset asynchrony condition (Mean = 20% error) versus the 50 ms stimulus onset asynchrony condition (Mean = 20% error) in the items analysis, nor was there any difference in accuracy evidenced in the other pairwise comparisons in the items analysis or in any of the pairwise comparisons in the participants analysis (*p*s > .008). Thus, the presence of the orthographically related orthographic primes enhanced accuracy to targets at the longer 150 ms stimulus onset asynchrony relative to the shorter 50 ms condition.

Experiment 3 Method:
Visual Half-Field Forward Masked Phonological Priming

Participants

Thirty-six of 156 participants had excessive error rates for the experimental trials (> 35% across all trials) and their data were removed from the final analysis. Of the 120 participants that were included in the final analysis, 13 were males and 107 were females. Otherwise, the characteristics of the participants in Experiment 3 were the same as in Experiment 2.

Materials

Forty critical targets were each paired with two types of primes: (1) nonword orthographic primes that differ by one grapheme from their respective targets (e.g., *jark-JERK, cloff-CLIFF*) and (2) nonword phonological primes that are pseudohomophones of, and differ by one grapheme from, their respective targets (e.g., *jurk-JERK, kliff-CLIFF*). The critical targets and each of their respective orthographic primes were the same as those used in Experiment 2. The phonological prime for each of the critical targets was created either by changing the vowel in the body of the respective critical target or by changing a "*C*" at the head of the respective critical target to a "*K*." With regard to the C-K prime-target pairs, the critical targets and their respective unrelated primes (used in Experiment 2), orthographic primes, and phonological primes were drawn from the stimuli of Holyk and Pexman (2004). The psycholinguistic properties of the critical targets are the same as in Experiment 2. Appendix I contains a list of the critical prime-target pairs.

In addition to the critical targets, 40 nonword targets were each paired with nonword orthographic (e.g., *lorf-LERF*) and phonological primes (e.g., *lurf-LERF*). Also, 80 filler targets, 40 words and 40 nonwords, were each paired with an unrelated nonword prime. Again, the nonword targets and each of their respective orthographic and phonological primes, as well as the filler prime-target pairs, were the same as used in Experiment 2.

Design

The design was the same as in Experiment 2 except that the four counter-balanced lists were created from the combinations of the two visual field/hemisphere conditions and two prime-type conditions for the critical targets and the nonword targets with nonword orthographic and phonological primes. Again, an example is presented in Table 3 demonstrating the method by which the lists were counter-balanced to account for visual field/hemisphere of presentation and prime-type using the critical target *JERK* and its orthographic prime *jark* and phonological prime *jurk.*

Apparatus and Procedure

The apparatus and procedure was the same as in Experiment 2.

Experiment 3 Results:

Visual Half-Field Forward Masked Phonological Priming

Presentation and background effects

Just as in Experiment 2, the independent variables list and responding hand were analyzed to determine whether they had significant effects on performance. Using the dependent variable reaction time, mixed between-within-participants ANOVAs were conducted and revealed that these variables produced neither main effects nor interactions with the independent variables of interest, prime-type and hemisphere of presentation (all Fs < 3.00). Therefore, the data from all 120 participants performing above chance levels were collapsed into a single analysis.

Reaction Time Analyses

For each participant, reaction times for incorrect trials were removed (accounting for 18% of the data points). Also, reaction times greater than 4000 ms were considered outliers and removed (accounting for 0.5% of the data points). The identification and removal of outliers was done according to the suggestions made by Ulrich and Miller (1994).

Two (stimulus onset asynchrony: 50 ms versus 150 ms) x 2 (hemisphere of presentation: right versus left hemisphere) x 2 (prime-type: orthographic versus phonological prime) mixed between-within-participants ANOVAs were performed both for participants and items. Stimulus onset asynchrony was a between-participants factor and hemisphere of presentation and prime-type were within-participants factors. Neither the main effects of stimulus onset asynchrony [F_1 (1, 118) = 2.75, $p > .05$, partial η^2 = .02; F_2 (1, 78) = 2.81, $p > .05$, partial η^2 = .03], hemisphere of presentation [F_1 (1, 118) =

3.31, $p > .05$, partial $\eta^2 = .03$; $F_2(1, 78) = 1.54$, $p > .05$, partial $\eta^2 = .02$], and prime-type [$F_1(1, 118) = .10$, $p > .05$, partial $\eta^2 = .00$; $F_2(1, 78) = .14$, $p > .05$, partial $\eta^2 = .00$], nor the two-way interaction between stimulus onset asynchrony and hemisphere of presentation [$F_1(1, 118) = 3.59$, $p > .05$, partial $\eta^2 = .03$; $F_2(1, 78) = 3.70$, $p > .05$, partial $\eta^2 = .05$] reached significance for participants or items. However, two-way interactions were obtained between stimulus onset asynchrony and prime-type [$F_1(1, 118) = 10.23$, $p < .01$, partial $\eta^2 = .08$] and hemisphere of presentation and prime-type by participants [$F_1(1, 118) = 7.92$, $p < .01$, partial $\eta^2 = .06$], but not by items [$F_2(1, 78) = 3.40$, $p > .05$, partial $\eta^2 = .04$ and $F_2(1, 78) = 1.06$, $p > .05$, partial $\eta^2 = .01$, respectively). Also, importantly, a three-way interaction was obtained between stimulus onset asynchrony, hemisphere of presentation, and prime-type by participants [$F_1(1, 118) = 4.35$, $p < .05$, partial $\eta^2 = .04$], but not by items [$F_2(1, 78) = 1.21$, $p > .05$, partial $\eta^2 = .02$].

Planned comparisons were performed in order to further investigate the three-way interaction between stimulus onset asynchrony, hemisphere of presentation, and prime-type using two-tailed *t*-tests employing a Bonferroni correction for the number of comparisons made ($\alpha = .013$). As Figure 6 indicates, participants responded faster to targets preceded by phonological primes than orthographic primes only when the primes were presented to the left hemisphere for 150 ms ($p = .001$). No difference was obtained between targets preceded by orthographic primes and phonological primes when the primes were presented to the right hemisphere for 150 ms ($p > .013$). For the 50 ms stimulus onset asynchrony condition, regardless of hemisphere of presentation, no significant differences were obtained between targets preceded by orthographic primes and phonological primes (all *p*s > .013), though a trend was observed in which targets presented to the right hemisphere were responded to slower when preceded by phonological primes (p = .05). Thus, a phonological priming effect was obtained only for items presented to the left hemisphere at the longer 150 ms stimulus onset asynchrony. The data relevant to these analyses are summarized in Table 5.

Accuracy Analyses

Two (stimulus onset asynchrony: 50 ms, 150 ms) x 2 (hemisphere of presentation: right versus left hemisphere) x 2 (prime-type: orthographic versus phonological prime) mixed between-within-participants ANOVAs were performed both for participants and items. Stimulus onset asynchrony was a between-participants factor and hemisphere of presentation and prime-type were within-participants factors. Just as in Experiment 2, the accuracy data differed from the reaction time data. Performance was more accurate for left hemisphere targets (Mean = 19% error) than for right hemisphere targets (Mean = 22% error) [F_1 (1, 118) = 6.41, p = .01, partial η^2 = .05; F_2 (1, 78) = 10.74, p < .01, partial η^2 = .12]. Also, a main effect of stimulus onset asynchrony was obtained whereby performance was more accurate for targets preceded by primes in the 150 ms condition (Mean = 17% error) than the 50 ms condition (Mean = 23% error) [F_1 (1, 118) = 8.09, p < .01, partial η^2 = .06; F_2 (1, 78) = 4.76, p < .05, partial η^2 = .03]. However, the main effect of prime-type was not significant [F_1 (1, 118) = .15, p > .05, partial η^2 = .00; F_2 (1, 78) = .15, p > .05, partial η^2 = .00]. Additionally, neither the two-way interactions between stimulus onset asynchrony and hemisphere of presentation [F_1 (1, 118) = .00, p > .05, partial η^2 = .00; F_2 (1, 78) = .01, p > .05, partial η^2 = .00], stimulus onset asynchrony and prime-type [F_1 (1, 118) = .02, p > .05, partial η^2 = .01; F_2 (1, 78) = .01, p > .05, partial η^2 = .02], and hemisphere of presentation and prime-type [F_1 (1, 118) = .10,

$p > .05$, partial $\eta^2 = .00$; F_2 (1, 78) = .09, $p > .05$, partial $\eta^2 = .00$], nor the three way interaction [F_1 (1, 118) = .30, $p > .05$, partial $\eta^2 = .00$; F_2 (1, 78) = .28, $p > .05$, partial $\eta^2 = .00$] reached significance. The data relevant to these analyses are summarized in Table 5. The pattern of results obtained in the accuracy analyses for Experiment 3 is consistent with those obtained in Experiment 2. In addition to being related phonologically, the phonological primes are related to the targets orthographically. The fact that no interaction was obtained between prime-type and stimulus onset asynchrony in Experiment 3 would seem to indicate that the additional phonological similarity between phonological primes and targets did not enhance accuracy to targets beyond the effect of orthographic similarity observed in Experiment 2. Thus, the accuracy analyses for Experiments 2 and 3 indicate that the presence of orthographically related primes enhanced accuracy at the longer 150 ms stimulus onset asynchrony condition relative to the shorter 50 ms condition.

Discussion of Results for Experiments 2 and 3

The purpose of the current study was to examine the time course of activation of lexical-level orthographic and phonological representations of print in both the left hemisphere and right hemisphere. In Experiment 2, forward masked orthographic priming was obtained regardless of hemisphere of presentation and stimulus onset asynchrony, providing evidence that both hemispheres store lexical orthographic representations of printed words. Furthermore, the results of Experiment 2 show that lexical-level orthographic representations are activated early in the time course of processing in both hemispheres of the brain and that the activation is sustained until later stages of processing. In contrast, in Experiment 3 phonological priming was obtained only for stimuli presented to the left hemisphere and only in the 150 ms stimulus onset asynchrony condition. Thus, the results of Experiment 3 indicate that lexical phonological representations of printed words are activated only in the left hemisphere later in the time course of processing.

While interpretation of the reaction time data from Experiments 2 and 3 would seem to be relatively straightforward, no main effect of hemisphere of presentation was obtained in the reaction time data for Experiment 3. Enhanced task performance for stimuli presented to the left hemisphere relative to the right hemisphere is a common finding. For example, in Experiment 2, lexical decisions were faster and more accurate for critical targets presented to the left hemisphere. The same was also true for the accuracy data from Experiment 3. The hemisphere of presentation effect has been interpreted to reflect the left hemisphere's superior capability for the processing of print. As such, the absence of a main effect of hemisphere of presentation in Experiment 3 is worrisome because it may indicate poor experimental control regarding visual half-field presentation. Thus, it may be that discussion of hemispheric differences for phonological priming should be tempered. However, it has also been posited that enhanced task performance for stimuli presented to the left hemisphere is accounted for by non-hemispheric factors. For example, Hellige (1996) proposed that if there is a bias to scan visual space from left to right in English readers, then when participants are focused on a central fixation marker a word in the right visual field/left hemisphere has an advantage over a word in the left visual field/right hemisphere, as participants will initially scan to the right. Significantly, Young, Atchley, and Atchley (2005) found that the visual field/hemisphere of presentation effect was attenuated when a nonword placeholder was presented concurrently in the visual field opposite that of the targets. They hypothesized that their finding was a result of a reduction in the bias of their participants to shift attention rightward because of the presence of a stimulus in the left visual field. With regard to the current study, it thus seems reasonable to argue that the presence of the mask in the left visual field reduced the bias of participants to first scan rightward when targets were presented to the right visual field, thereby eliminating the main effect of visual field/hemisphere of presentation in Experiment 3. Regardless, Hellige notes that interactions between task variables and visual field/hemisphere of presentation have been far more critical for theoretical predictions than obtaining a main effect of visual field/hemisphere of presentation.

In contrast to the reaction time data, interpretation of the accuracy data from Experiments 2 and 3 is more difficult. The accuracy analyses for Experiments 2 and 3 indicate enhanced accuracy to critical targets when orthographically related primes were presented for 150 ms relative to when they were presented for 50 ms, regardless of phonological similarity. Concern that this effect is secondary to participants being alerted to the visual field/hemisphere of presentation of the critical targets because of increased awareness of the primes when presented for 150 ms is set aside by the fact that the same effect was not obtained for critical targets presented subsequent to unrelated primes. Rather, this pattern of results likely reflects increased processing of the orthographic representations of the primes in the 150 ms stimulus onset asynchrony condition. Increased processing of primes may result in greater refinement in orthographic codes activated at the lexical-level, which would likely ease target recognition. That no effect of phonological similarity was observed beyond that of orthographic similarity is not surprising, as accuracy is a relatively coarse grained measure and the effects of phonological primes on target recognition have been shown to be rather small and tenuous. It may be for the same reason that no priming effects were observed in the accuracy data. That is, the priming effects examined may have simply been too fine grained to be observed in the accuracy data.

Chapter VI

General Discussion

The purpose of Experiment 1 was to reconcile the findings of Lavidor and Ellis' (2003) second experiment with those experiments listed in Table 1 that evidenced right hemisphere phonological processing using implicit tasks. While interpretation of the results of Experiment 1 is made difficult due to poor experimental control of stimuli and the fact that the manner in which the results should be interpreted is ambiguous, interpreting the results within the context of the modified interactive activation model of Grainger and Ferrand (1994) gives way to a theoretically interesting hypothesis: Phonological priming, indicative of phonological processing, was obtained for stimuli presented to the left hemisphere and not the right hemisphere because primed lexical decision reflects lexical-level processing. In contrast, the experiments listed in Table 1 that revealed right hemisphere phonological processing using implicit tasks are hypothesized to mirror sublexical processes. Based upon this division among psycholinguistic tasks, a partial timeline of hemispheric processing was outlined.

Beginning with the left hemisphere, the results of Halderman (2006) suggest sublexical processing of both orthography and phonology beginning early in the time course of processing, with increased activation of sublexical phonological representations relative to orthographic representations later in processing. The results of Experiments 2 and 3 suggest that the pattern of processing at the lexical level mirrors that at the sublexical-level. Lexical-level orthographic representations are activated early in the time course of processing and sustained in terms of their level of activation until later in processing. However, later in processing lexical-level phonological representations are activated in addition to orthographic representations, confirming the findings from Experiment 1. This timeline of left hemisphere processing, presented in Figure 7, is fully consistent with the modified interactive activation model of Grainger and Ferrand (1994).

In contrast, right hemisphere processing is more dependent upon the orthographic characteristics of words at both the sublexical and lexical-levels. Halderman (2006) suggest sublexical processing of both orthography and phonology beginning early in the time course of processing (at 20 ms). According to the results of Experiment 1, however, it seems more likely that only orthographic representations are activated at the lexical-level, as no evidence of right hemisphere phonological processing was obtained. This interpretation of Experiment 1 was validated by Experiments 2 and 3, as the results suggest that lexical-level orthographic representations are activated early in the time course of processing and sustained in terms of their level of activation until later in processing. No evidence of access to lexical-level phonological representations was obtained. That both orthography and phonology are processed at the sublexical-level, but only orthographic representations are activated at the lexical-level would seem to be somewhat paradoxical. However, Smolka and Eviatar (2006) suggest that orthographic codes are stored in phonological categories. Smolka and Eviatar suggest that this storage mechanism is sufficient to subserve a compensatory right hemisphere strategy to process phonology when required. This timeline of right hemisphere processing is also presented in Figure 7.

Future Directions

In the current study, an underlying assumption was that priming effects being examined reflected the same cognitive processes regardless of the hemisphere in which they were obtained. However, it is possible that the same results could be obtained from both hemispheres, but that the processes by which the two hemispheres generate the same result is different. An example is provided when comparing the results of Experiment 2 to those of Chiarello (1985). Chiarello obtained phonological priming (i.e., more accurate lexical decisions to *JUICE-MOOSE* than *PINT-ROCK* prime-target pairs) only for prime-target pairs presented to the left hemisphere under conditions when the proportion of related prime-target pairs was low. This is consistent with the findings of the current study. However, orthographic priming (i.e., more accurate lexical decisions to *BEAK-BEAR* than *PINT-ROCK* prime-target pairs) was obtained only for prime-target pairs presented to the right hemisphere. While the stimuli used by Chiarello make interpretation of the findings difficult, as the targets across each prime-type condition were different (in a manner similar to Experiment 1), that real-word orthographic primes facilitated target recognition in the right hemisphere but not the left suggests that there is less inhibition of activation in the right hemisphere. Bilateral orthographic priming was obtained in Experiment 2, but nonword primes were expected to facilitate target recognition because nonwords would not activate any one lexical entry too strongly. This is in contrast to real word orthographic primes, which Grainger and Ferrand (1994) found to inhibit target recognition. That there would be less inhibition of activated orthographic representations in the right hemisphere is not surprising when considering data from visual half-field semantic priming experiments. It has been shown that the left hemisphere initially activates all meanings of a given word (e.g., for the word *BANK*, both money-bank and river-bank) but rapidly inhibits the activation of the subordinate (e.g., river-bank) meanings, whereas the right hemisphere sustains activation of both dominant and subordinate meanings (Beeman & Chiarello, 1998). Future studies should be aimed at investigating the patterns of activation and inhibition of orthographic and phonological representations in the hemispheres.

In addition to the current results and those of Chiarello (1985) and Halderman (2006), the account of left hemisphere and right hemisphere orthographic and phonological processing outlined above must also be able to reconcile with the results of Barry (1981), Chiarello et al. (1999), Lukatela et al. (1986), and Underwood et al. (1983), who evidenced right hemisphere phonological effects. A convergent rationalization for the results of Barry is relatively straightforward. Barry obtained a bilateral pseudohomophone effect. Though the pseudohomophone effect is assumed to arise because activation of lexical representations by pseudohomophones must be overcome in order to correctly judge them nonwords, it is assumed that pseudohomophones only activate lexical representations of real words via sublexical phonological recoding. It is more open to debate whether the results of Chiarello et al., Lukatela et al., and Underwood et al. are attributable to sublexical processing. The methodologies employed (i.e., examining the effects of phonologically related distracters on target recognition and phonological ambiguity on target recognition) to study hemispheric processing of phonology are relatively novel. Thus, there is little empirical data to support any claim and further study is needed.

In addition to further examination of tasks that have been used to examine hemispheric processing of phonology, future studies should be aimed at studying the effects of gender on the lateralization of the neuroanatomical correlates of phonological processing. Several studies have shown an increased bilaterality of language areas in women (e.g., Pugh et al., 1996; Shaywitz, et al., 1995). More specifically regarding phonological processing, Coney (2002) and Crossman and Polich (1988) evidenced greater left hemisphere ability to make rhyme judgments in males but no difference in the ability of the hemispheres to make rhyme judgments in females. This pattern has also been reflected in a more recent neuroimaging study examining gender differences for rhyme judgment (Clements et al., 2006), though diverging results have been obtained as well (Chiarello et al., 2009; Sommer, Aleman, Bouma, & Kahn, 2004). The participants of the experiments included in this dissertation consisted of a high proportion of women due to the demographic characteristics of undergraduate students participating in the psychology research pool at the University of Windsor. If it had been possible to include a higher proportion of men, the pattern of obtained priming effects may have changed and gender differences may have been found.

Conclusion

Three experiments were conducted in order to investigate whether the right cerebral hemisphere is able to process the phonology of single printed words with an overall aim of generating an understanding of the role of each of the cerebral hemispheres in the processing of the phonology and orthography of a printed word. It was found that lexical-level phonological representations are activated only in the left hemisphere and only later in the time course of processing. In contrast, it was found that lexical-level orthographic representations are activated bilaterally early in the time course of processing and that their levels of activation are sustained. Taking into account both the current findings and those of previous experiments, a framework of hemispheric processing of print is proposed in which left hemisphere processing resembles that of the modified interactive activation model of Grainger and Ferrand (1994), whereas right hemisphere processing is more dependent upon orthography at the sublexical and lexical levels, though graphemes as the sublexical level are stored in phonological categories. This framework is consistent with Chiarello's (2003) view that the left hemisphere rapidly contacts more abstract phonological levels of language encoding, whereas the right hemisphere is more dependent on the visual surface characteristics of language encoding when processing print.

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Appendix A

University of Windsor

CONSENT TO PARTICIPATE IN RESEARCH

Title of Study: Response Time Variability in a Visual Half-Field Lexical Decision Task.

You are asked to participate in a research study conducted by Chris Domen, Psychology Doctoral Candidate, under the supervision of Dr. Lori Buchanan from the Department of Psychology at the University of Windsor. Your participation will contribute to the Ph.D. dissertation for Chris Domen.

If you have any questions or concerns about the research, please feel to contact Lori Buchanan at (519) 235-3000, ext. 2246

PURPOSE OF THE STUDY

This study is designed to investigate the cognitive process underlying the recognition of visually presented words and nonwords.

PROCEDURES

If you volunteer to participate in this study, we would ask you to do the following things:

You will first be asked to provide demographic information pertinent to the current study. Then, you will be asked to make decisions as to whether strings of letters presented on a computer screen are real words or nonwords. For each word or nonword presented, you will be asked to indicate your response by pressing one of two designated computer keys. One of the keys is to be pressed if a word is presented, while the other is to be pressed if a nonword is presented. You will be asked to make your decisions as quickly and accurately as possible. You will be given the opportunity to do a number of practice trials until you feel comfortable with your task. You will be provided with a more detailed set of instructions by the experimenter.

The entire experiment should take about 30 minutes. This study will take place in room 62 in Chrysler Hall South

POTENTIAL RISKS AND DISCOMFORTS

There are no foreseeable risks associated with this study.

POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

Your participation in this study will help us learn more about how people process information about words and nonwords and about methods we can use to investigate linguistic processing in laboratory settings. In general, this information will help us learn more about the cognitive processes underlying language processing.

PAYMENT FOR PARTICIPATION

In accordance with the policy of the psychology participant pool, participants will receive .5 bonus points per 1/2 hour of participation.

CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission.

In order to ensure participant confidentiallity, consent forms and the demographic questionaires will be identified by participant number only, and consent forms and demographic questionaires will be stored in locked file cabinets.

PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may also refuse to answer any questions you don't want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so.

FEEDBACK OF THE RESULTS OF THIS STUDY TO THE SUBJECTS

Research findings will be available to participants.

Web address: www.uwindsor.ca/reb
Date when results are available: Results will be made available upon project completion anticipated as 9/2009.

SUBSEQUENT USE OF DATA

This data will be used in subsequent studies.

RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. If you have questions regarding your rights as a research subject, contact: Research Ethics Coordinator, University of Windsor, Windsor, Ontario N9B 3P4; Telephone: 519-253-3000, ext. 3948; e-mail: ethics@uwindsor.ca

SIGNATURE OF RESEARCH SUBJECT/LEGAL REPRESENTATIVE

I understand the information provided for the study Response Time Variability in a Visual Half-Field Lexical Decision Task as described herein. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

____
Name of Subject

____ __________________
Signature of Subject Date

SIGNATURE OF INVESTIGATOR

These are the terms under which I will conduct research.

____ __________________
Signature of Investigator Date

Revised February 2008

Appendix B

Participnat ID # ____________________School Year:____________________________

Gender: M F Age________________ Date of Birth (Month/Year):___________

Please answer each of the following questions:

What is your native language?

Do you speak any language, other than English, fluently? Y N

Do you have a learning disability? Y N

If yes, does this learning disability affect any of the following:

Reading? Y N **Writing?** Y N **Math?** Y N

Do you have dyslexia? Y N

Have you ever been diagnosed with a speech or learning disorder? Y N

Have you ever received speech, language, or reading therapy? Y N

If yes, did this therapy focus only on a single speech sound, such as a lisp or difficulty producing "r"? Y N

Does anyone in your immediate family have any of the above language difficulties? Y N

Do you have ADD/ADHD? Y N

Do you have normal (or corrected to normal) vision? Y N

Are you color blind? Y N

Which hand do you use to hold the pencil when you write? Right Left Both

Which hand do you use to hold the scissors when you cut paper? Right Left Both

Which hand do you use to throw a baseball? Right Left Both

Which hand do you use when you brush your teeth? Right Left Both

Do you have anyone in your immediate family who is left-handed? Y N

Have you ever had a head trauma resulting in loss of consciousness? Y N

Appendix C

Experiment 1 Critical Prime-Target Pairs and Mean Item Reaction Time (in ms) for Correct Lexical Decisions as a Function of Hemisphere of Presentation (n = 22)

Target	Prime	Left Hemisphere	Right Hemisphere
	Unrelated Prime-Target Pairs		
CASK	sand	635	534
FLUTE	mind	584	900
FLOP	room	666	615
MUG	cop	545	603
PIER	hand	618	600
BROOM	store	553	645
LANE	dark	633	630
LUCK	rave	541	590
LEAF	said	551	582
BARN	disk	633	781
BAZAAR	please	873	716
EMBARK	switch	746	638
LUTE	teen	588	652
MOTH	full	677	691
RENT	view	746	760
ENTRY	ginger	621	616
GOOSE	power	562	653
SKIT	head	749	563

RIB	dry	532	564
PRY	star	685	627
LAMB	knot	588	600
HYMN	time	593	667
RASH	pail	641	530
CAMPING	carve	633	562
PAWN	clue	615	563
DRUM	cast	692	647
FROG	drag	534	662
GLARE	night	736	631
GLORY	brain	682	659
GOLFER	print	690	674

<u>Orthographically Dissimilar Homophonic Prime-Target Pairs</u>

LUTE	loot	707	785
CLAWS	clause	555	585
MITE	might	642	569
DOE	dough	491	589
PAWS	pause	549	609
BRAKE	break	660	599
ROWS	rose	484	671
LOAN	lone	534	472
HAIL	hale	635	645

TAIL	tale	587	552
SERIAL	cereal	604	766
SELLER	cellar	604	703
HARE	hair	724	747
LYNX	links	659	824
FLEW	flu	578	571
SUITE	sweet	592	637
WEIGH	way	497	782
VANE	vein	578	828
NUN	none	681	654
AXE	acts	658	678
CITE	sight	636	598
HYMN	him	966	719
DAZE	days	544	622
SEALING	ceiling	582	650
FLEX	flecks	548	640
BLEW	blue	895	591
SLAY	sleigh	551	523
MEDAL	meddle	624	580
DRAFT	draught	621	563
KERNEL	colonel	599	676

<u>Orthographically Similar Homophonic Prime-Target Pairs</u>

SURF	serf	521	599
CREAK	creek	584	746
VISE	vice	549	765
FIR	fur	548	599
TICK	tic	574	569
BARON	barren	601	941
MEAT	meet	541	578
SELL	cell	508	551
PEAR	pair	573	622
TIED	tide	512	537
QUARTS	quartz	615	695
CHILLY	chili	616	930
LEAK	leek	588	595
SEEL	seal	575	675
WEAK	week	539	508
WASTE	waist	548	681
PEDAL	peddle	629	580
BEET	beat	640	612
TOW	toe	580	577
TEE	tea	647	688
MIST	missed	542	499
STEAK	stake	630	626
STAIR	stare	656	658

MOURNING	morning	680	662
FOWL	foul	508	510
BITE	byte	616	606
BAWL	ball	527	711
MINER	minor	667	676
GROWN	groan	514	714
HOARSE	horse	714	710

Appendix D

Unrelated Word-Nonword Prime-Target Pairs for Experiment 1

Target	Prime
ABEW	pots
ABID	laws
BLOP	drum
BORF	eyes
CERN	bees
CORF	nail
DALS	flap
DIAT	ape
EAFT	boot
FIRD	late
FLID	guns
GRUT	pigs
GUTE	door
JIKE	arms
JOGE	lump
JORK	rush
KIGE	blot
KOFE	lawn
LIPE	link
LUDE	laws

NILA	ship
NOND	fame
PONC	hand
RAME	mold
RIGE	wash
TIST	rule
VAIF	cans
WAMP	king
WHEA	away
ARSOG	break
ATHID	tight
BOMMA	layer
CRIPE	fresh
DIGMA	shirt
DIRMS	nails
DRIPE	place
DROOM	under
DUCAC	north
ENJOK	fleet
FATAR	broad
FLOUP	argue
FUMIS	march
LEITY	bears

LEORY	marsh
LIVOS	armor
MECRO	tiles
NRONE	extra
PAPAT	atlas
RORST	baker
SCART	large
SNOFF	brave
TOTIM	watch
WAZEN	argue
ASSOSS	defeat
BASTEL	needle
BLAWES	writer
BOSGED	dancer
CASUCK	bruise
CEBELS	loving
CERING	manner
DATOVE	sneeze
DEBABS	pimple
DEMOKE	puzzle
DERIXE	boring
DOULER	nephew
DRARED	mammal

EMBERN	middle
EPUITY	afraid
FABMIC	drawer
FLICYS	mellow
GRUSTS	abduct
LINGED	animal
MANKER	drugs
MEMING	yours
OUTINY	brush
PADDLU	beauty
PASACE	wrong
PISTRO	fries
RORELY	laugh
ROUGEL	devil
SAWERS	lonely
SCIUNS	maggot
SKAZER	bubble
TERROB	peanut
TINGID	system
ZEETHE	forget
AZEROID	pyramid
BIBBIES	algebra
BONNISY	lasting

CANCORD	anatomy

Appendix E

Participant ID # ____________________School Year:______________________________

Gender: M F Age________________ Date of Birth (Month/Year):___________

Please answer each of the following questions:

What is your native language?

Do you speak any language, other than English, fluently? Y N

Have you ever been diagnosed with a learning disability? Y N

If yes, does this learning disability affect any of the following:

Reading? Y N **Writing?** Y N **Math?** Y N

Have you ever received speech, language, or reading therapy? Y N

If yes, did this therapy focus only on a single speech sound, such as a lisp or difficulty producing "r"? Y N

Have you ever been diagnosed with ADD/ADHD? Y N

Do you have normal (or corrected to normal) vision? Y N

Have you ever had a head trauma resulting in loss of consciousness (> 15 minutes)? Y N

Please indicate your preferences in the use of hands in the following activities by putting + in the appropriate column. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, put ++. If in any case you are really indifferent put + in both columns. Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets.

	Left	Right
Writing		
Drawing		
Throwing		
Scissors		
Toothbrush		
Knife (without fork)		
Spoon		
Broom (upper hand)		
Striking Match (match)		
Opening box (lid)		
Which foot do you prefer to kick with?		
Which eye do use when using only one?		

Appendix F

Experiment 2 Critical Prime-Target Pairs and Mean Item Reaction Time (in ms) for Correct Lexical Decisions as a Function of Stimulus Onset Asynchrony (SOA) and Hemisphere of Presentation (n = 60)

Target	Prime (Unrelated, Orthographic)	50 ms SOA		150 ms SOA	
		Left Hemisphere	Right Hemisphere	Left Hemisphere	Right Hemisphere
JERK					
	wilk	637	753	780	951
	jark	627	716	710	794
HYMN					
	covt	812	865	876	800
	homn	846	829	744	813
TERM					
	rald	872	891	729	787
	tarm	838	809	861	791
FERN					
	rolp	737	1031	830	923
	farn	823	747	792	962
BLURT					
	certh	826	896	945	909

	blart	749	839	796	1017
CLERK					
	scawl	738	847	767	753
	clork	713	767	723	794
SMIRK					
	frold	928	924	896	858
	smark	977	846	793	816
THIRD					
	smeck	824	807	723	849
	thard	770	796	814	670
CRUMB					
	thasp	962	902	873	951
	crimb	870	707	756	855
CLUTCH					
	twints	870	903	806	757
	cletch	806	929	751	957
SKIRT					
	trand	883	746	680	1047
	skart	705	758	740	765
HERS					
	loff	825	945	1122	896
	hars	889	697	778	876
SLURS					

	thism	979	804	872	1030
	slars	1114	992	948	958
WORTH					
	grold	701	831	838	860
	warth	748	798	871	724
VERB					
	dilt	824	795	740	890
	varb	731	709	821	707
STERN					
	gromt	929	973	749	914
	storn	707	1000	816	841
THIRST					
	nenchs	668	823	811	810
	tharst	692	760	650	833
CRISP					
	flerd	694	794	769	802
	crasp	809	708	668	694
CLIFF					
	snoth	796	847	831	882
	cloff	664	820	728	744
CLASP					
	flird	824	828	798	794
	clusp	705	999	722	818

BLUR					
	sarv	816	840	774	990
	blar	1049	867	832	732
WOLF					
	fett	739	682	778	710
	walf	727	724	680	719
TURF					
	lann	789	866	774	955
	tarf	819	763	826	792
TURD					
	bofs	838	1030	840	906
	tord	1073	998	1331	793
CHIRP					
	parst	792	885	767	906
	charp	868	818	830	787
KIND					
	lirt	882	748	773	765
	kund	755	757	714	704
CLEFT					
	darms	884	1049	877	983
	claft	956	979	896	858
CLUB					
	snox	845	904	799	777

	cleb	835	714	755	868
CROWD					
	sarth	744	780	674	806
	krawd	806	788	753	728
SLURP					
	perst	1002	993	1000	861
	slarp	846	788	857	809
HERB					
	talp	887	795	896	793
	harb	784	710	684	724
FOLD					
	crot	870	716	806	831
	fald	795	767	647	706
CHURN					
	skuts	923	929	1006	957
	charn	982	936	783	1205
SPERM					
	golst	878	940	852	721
	sparm	807	732	741	713
FLIRT					
	skalz	846	834	986	778
	flart	796	874	683	694
FIRST					

	brind	758	985	842	854
	farst	715	698	720	803
CLIMB					
	wherp	797	744	855	740
	clomb	759	693	687	797
CUSP					
	mord	1098	919	1062	1022
	casp	1027	847	1002	1067
CRUD					
	derg	1485	1157	1177	896
	krid	907	919	979	995
PERM					
	hawt	778	1029	990	803
	porm	735	783	871	815

Appendix G

Nonword Targets, Unrelated Nonword Primes, Nonword Orthographic Primes, and Nonword Phonological Primes for Experiments 2 and 3

Target	Unrelated Nonword Prime	Orthographic Nonword Prime	Phonological Nonword Prime
LERF	jash	lorf	lurf
LURT	crad	lart	lert
CURK	sech	cark	kurk
LERM	zumb	lorm	lurm
CUZZ	derd	cazz	kuzz
ZERT	slef	zort	zurt
GLURT	clewm	glart	glert
CROTH	srest	cryth	kroth
CHURT	narmb	chort	chert
CRUMP	darch	cromp	krump
HURP	slad	horp	herp
LERS	moch	lars	lurs
NURT	yifs	nort	nert
GURF	zolk	garf	gerf
CORM	belk	carm	korm
BLURS	snash	blors	blers
SLURT	macts	slart	slert
JERSH	srath	jarsh	jursh

MURTS	cetch	marts	merts
CORCH	marst	carch	korch
HERK	zamb	hork	hurk
CACK	mont	cuck	kack
BYMN	jish	bumn	bimn
MERN	gelf	marn	murn
CORB	luzz	cerb	korb
HERCH	snosk	horch	hurch
CLUNT	sroth	clant	klunt
ZURMB	north	zormb	zermb
SERKS	thelst	sorks	surks
CRITH	morck	crath	krith
FLUR	zelk	flar	fler
COTH	nurm	cuth	koth
BERM	kled	borm	burm
SERM	nabt	sarm	surm
MERD	shob	mard	murd
BYNCH	slusk	bonch	binch
CRAST	kreth	crost	krast
CHURM	nurmb	chorm	cherm
ZERNS	dorth	zarns	zurns
DERMB	klisp	darmb	durmb

Appendix H

Filler Targets and Unrelated Nonword Primes for Experiments 2 and 3

Word Target		Nonword Target	
Target	Prime	Target	Prime
PIMP	neft	ZLEN	kisk
RIFT	lelk	NONG	bist
PLUM	bock	PIRF	brel
LUNG	brip	RAWK	camt
FLING	blent	RUDD	chur
SNIFF	brast	SATH	crat
TRUNK	cheth	SHAS	dast
WHACK	cleng	SLAF	drot
FROWN	dreck	SURD	fard
CLASH	dwerf	VRID	fent
DWELL	flink	YERD	guck
CHUNK	groft	ZAST	jibt
CHOMP	kleng	SIRSH	barth
PLUMP	litch	SHORD	blant
DRANK	shich	SLIND	brank
CHANT	shomp	SLUCK	zerth
BLESS	slock	SUMPS	glaps
GRUNT	thamb	SPART	gwing
WALTZ	thomp	TRANT	kwamp

KNELT	wilsh	WRASS	plink
POND	hamk	ZOLD	kuds
HUSH	lomp	ZUNK	lalt
MESS	bant	PERN	brab
LUST	Bith	RARL	brep
SWAP	Bolm	RISH	chib
CALF	Frew	SARN	colk
CRAFT	bolch	SCOY	dard
PITCH	chall	SILD	dorp
BUNCH	clack	SOLL	falb
BLAST	creff	TUTH	feck
GRIND	droft	WELS	filg
HATCH	flawn	YIMP	gulk
PRINT	gress	ZACT	keld
SWORN	lanks	SATCH	bempt
WITCH	shant	SILTH	blick
PLUMB	sholl	SLOCH	braps
TRUMP	skalk	SOTCH	cheft
BLOWN	stant	SUNCH	glung
SWELL	Thirp	TERCH	gwiss
BURNT	wherf	WRAWL	prock

Appendix I

Experiment 3 Critical Prime-Target Pairs and Item Reaction Time (in ms) for Correct Lexical Decisions as a Function of Stimulus Onset Asynchrony and Hemisphere of Presentation (n = 60)

Target	Prime (Orthographic, Phonological)	50 ms SOA		150 ms SOA	
		Left Hemisphere	Right Hemisphere	Left Hemisphere	Right Hemisphere
JERK					
	jark	718	937	683	1013
	jurk	765	758	668	703
HYMN					
	homn	1083	948	742	1077
	himn	1070	912	1007	842
TERM					
	tarm	848	946	919	824
	turm	849	845	865	781
FERN					
	farn	965	910	714	803
	firn	891	878	850	723
BLURT					
	blart	799	878	845	927

	blert	943	830	792	805
CLERK					
	clork	765	781	717	866
	klerk	747	881	696	717
SMIRK					
	smark	954	810	857	957
	smirk	921	890	833	740
THIRD					
	thard	790	769	707	851
	thurd	1075	841	670	687
CRUMB					
	crimb	1109	745	725	1033
	krumb	926	916	675	804
CLUTCH					
	cletch	905	869	778	974
	klutch	789	776	731	959
SKIRT					
	skart	839	717	755	751
	skert	850	748	694	883
HERS					
	hars	894	865	1088	834
	hurs	1043	849	975	884
SLURS					

	slars	1094	1205	1057	834
	slers	1030	917	939	1111
WORTH					
	warth	806	821	843	698
	werth	856	737	686	786
VERB					
	varb	773	765	695	764
	virb	929	871	741	822
STERN					
	storn	1070	908	962	907
	stirn	887	1392	829	1018
THIRST					
	tharst	803	723	747	704
	thurst	762	827	783	789
CRISP					
	crasp	766	747	805	697
	krisp	907	759	823	1040
CLIFF					
	cloff	798	807	1052	676
	kliff	875	778	764	819
CLASP					
	clusp	714	815	740	693
	klasp	874	1037	844	1105

BLUR					
	blar	995	1008	1036	883
	bler	843	1293	742	775
WOLF					
	walf	865	835	643	723
	wulf	729	966	618	715
TURF					
	tarf	827	1135	1080	789
	terf	960	991	638	844
TURD					
	tord	951	1278	1086	1025
	terd	890	878	720	991
CHIRP					
	charp	875	1086	1152	824
	cherp	904	855	824	751
KIND					
	kund	750	836	852	719
	kynd	773	827	698	850
CLEFT					
	claft	1077	1067	961	954
	kleft	929	1187	871	1001
CLUB					
	cleb	874	788	786	790

	klub	935	1056	770	721
CROWD					
	krawd	719	772	812	806
	krowd	730	901	625	721
SLURP					
	slarp	884	889	1246	825
	slerp	937	928	835	757
HERB					
	harb	725	752	807	793
	hurb	753	1176	870	847
FOLD					
	fald	777	952	715	676
	fuld	894	882	919	916
CHURN					
	charn	805	988	1084	942
	chern	868	958	942	837
SPERM					
	sparm	979	911	665	892
	spurm	820	796	779	733
FLIRT					
	flart	813	880	838	678
	flert	835	903	874	664
FIRST					

	farst	796	852	728	623
	furst	785	776	690	714
CLIMB					
	clomb	726	861	674	713
	klimb	788	823	754	726
CUSP					
	casp	871	1216	797	1082
	kusp	924	1098	1405	957
CRUD					
	krid	815	1115	1261	882
	krud	1054	1126	1126	1095
PERM					
	porm	900	1020	1224	890
	purm	924	1022	1107	810

Table 1

Findings from explicit and implicit visual half-field experiments investigating right hemisphere access to phonological representations.

Study	Participants		Method		Evidenced LH Access to Phonological Representations			Evidenced RH Access to Phonological Representations		
	Commisurotomy Patients	*Neurologically Intact Participants*	*Explicit*	*Implicit*	*Yes*	*No*	*Inconclusive*	*Yes*	*No*	*Inconclusive*
Baynes et al. (1995) Exp. 2	x		x		x				x	
Sidtis et al. (1981)	x		x		x				x	
Zaidel & Peters (1981) Exp. 2	x		x		x				x	
Zaidel & Peters (1981) Exp. 3	x		x		x				x	
Zaidel & Peters (1981) Exp. 4	x		x		x				x	
Zaidel & Peters (1981) Exp. 5	x		x		x				x	
Banich & Karol (1992) Exp. 1		x	x		x					x
Coney (2002) Exp. 1		x	x		x					x
Coney (2002) Exp. 2		x	x		x				x	
Crossman & Polich (1988)		x	x		x					x
Hunter & Liederman (1991)		x	x		x					x
Rayman & Zaidel (1991)		x	x		x					x
Sasanuma et al. (1980)		x	x		x				x	
Barry (1981)		x		x	x			x		
Chiarello (1985) Exp. 4-5		x		x	x				x	
Chiarello et al. (1999) Exp. 2		x		x	x			x		
Halderman & Chiarello (2005)		x		x	x				x	
Halderman (2006)		x		x	x			x		
Lavidor & Ellis (2003) Exp. 2		x		x	x				x	
Lukatela et al. (1986)		x		x	x			x		
Underwood et al. (1983)		x		x	x			x		

Table 2

Experiment 1 mean reaction times (RT; in ms) for correct lexical decisions and percentage of lexical decision errors (% error; standard deviations in parentheses) as a function of hemisphere of presentation and prime-type (n = 44).

Prime Type	Left Hemisphere		Right Hemisphere	
	RT	% error	RT	% error
Orthographically Similar Homophone Prime	586 (138)	27 (44)	645 (167)	33 (47)
Orthographically Dissimilar Homophone Prime	628 (136)	34 (48)	640 (157)	36 (48)
Unrelated Control Prime	637 (155)	34 (48)	653 (151)	44 (50)

Table 3

An example of the method of list construction for Experiments 2 (orthographic priming) and 3 (phonological priming) counter-balancing visual field/hemisphere of presentation and prime-type using the critical target *JERK* and its yoked nonword prime *wilk*, orthographic prime *jark*, and phonological prime *jurk*.

Experiment	List	Visual Field/Hemisphere of Presentation	Prime	Target
Experiment 2:				
Forward Masked	1	Right Visual Field/Left Hemisphere	Wilk	JERK
Orthographic	2	Right Visual Field/Left Hemisphere	Jark	JERK
Priming	3	Left Visual Field/Right Hemisphere	Wilk	JERK
	4	Left Visual Field/Right Hemisphere	Jark	JERK
Experiment 3:				JERK
Forward Masked	1	Right Visual Field/Left Hemisphere	Jark	JERK
Phonological	2	Right Visual Field/Left Hemisphere	Jurk	JERK
Priming	3	Left Visual Field/Right Hemisphere	Jark	JERK
	4	Left Visual Field/Right Hemisphere	Jurk	JERK

Table 4

Experiment 2 mean reaction times (RT; in ms) for correct lexical decisions and percentage of lexical decision errors (% error; standard deviations in parentheses) as a function of stimulus onset asynchrony (SOA), hemisphere of presentation, and prime-type (n = 60).

	Prime Type	Unrelated Prime	Orthographic Prime	Orthographic Priming Effect
50 ms SOA				
Left Hemisphere	RT	836 (127)	803 (137)	33
	% error	19 (19)	23 (18)	-4
Right Hemisphere	RT	877 (156)	807 (130)	70
	% error	21 (15)	23 (18)	-2
150 ms SOA				
Left Hemisphere	RT	840 (157)	789 (127)	51
	% error	19 (16)	17 (16)	2
Right Hemisphere	RT	860 (164)	807 (147)	53
	% error	22 (16)	18 (17)	4

Table 5

Experiment 3 mean reaction times (RT; in ms) for correct lexical decisions and percentage of lexical decision errors (standard deviations in parentheses) as a function of stimulus onset asynchrony (SOA), hemisphere of presentation, and prime-type (n = 60).

	Prime Type	Orthographic Prime	Phonological Prime	Phonological Priming Effect
50 ms SOA				
Left Hemisphere	RT	852 (181)	878 (169)	-26
	% error	21 (17)	22 (18)	-1
Right Hemisphere	RT	887 (193)	925 (229)	-38
	% error	24 (17)	27 (19)	-3
150 ms SOA				
Left Hemisphere	RT	868 (221)	800 (180)	68
	% error	16 (15)	15 (14)	1
Right Hemisphere	RT	826 (180)	841 (187)	-15
	% error	20 (13)	19 (16)	1

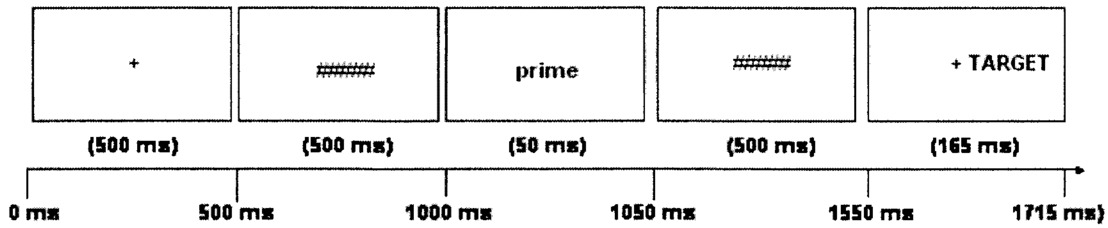

Figure 1. A timeline of events during a trial in Experiment 1 (for targets presented to the right visual field/left hemisphere).

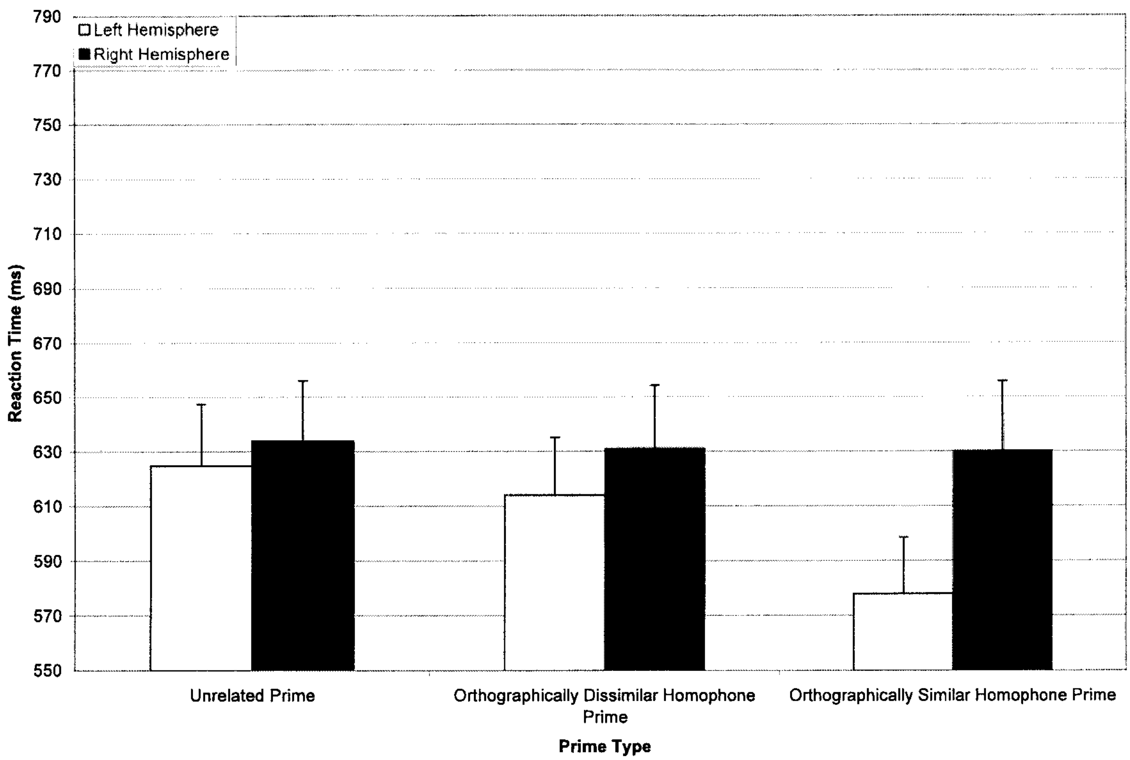

Figure 2. Mean reaction times (in ms) for correct lexical decisions as a function of hemisphere of presentation and prime-type (Experiment 1).

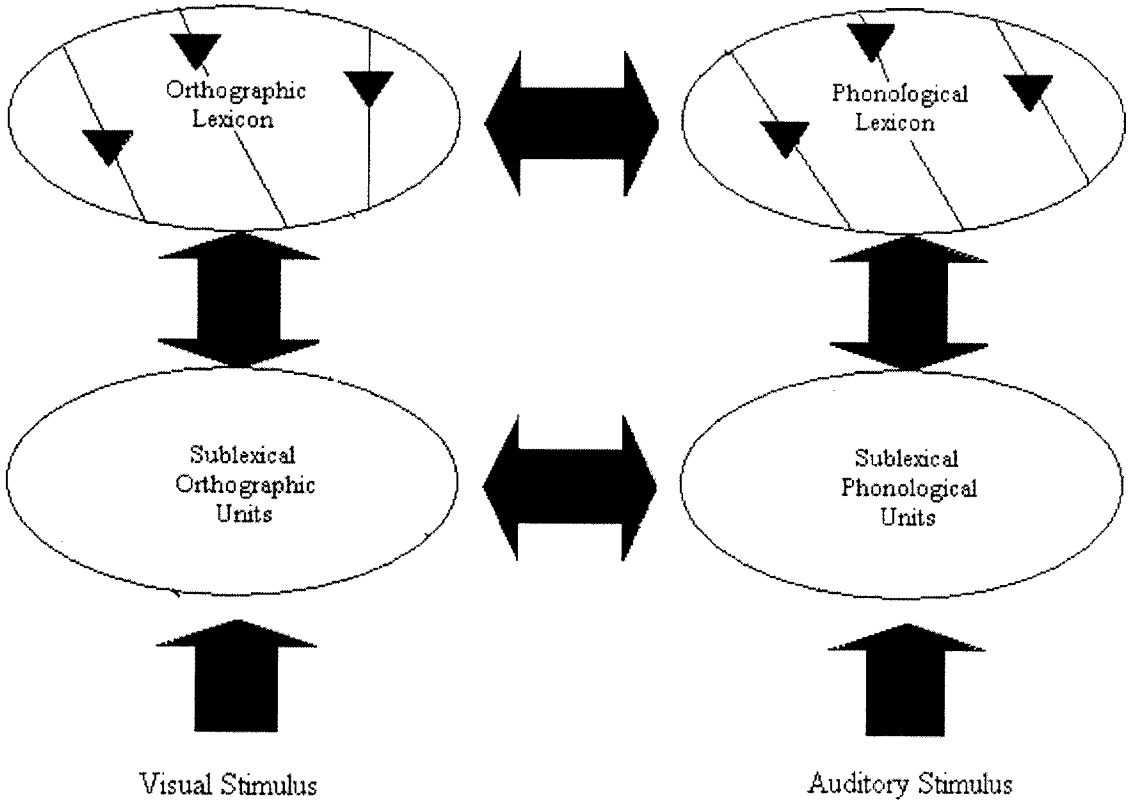

Figure 3. The dual-lexicon interactive activation model of Grainger and Ferrand (1994) in which the sublexical orthographic units activated by visual input and the sublexical phonological units activated by an auditory input mutually facilitate each other and send activation to their respective orthographic and phonological lexicons. These lexicons contain mutually inhibitory within-lexicon connections (as denoted by the triangles) and excitatory between-lexicon connections (as denoted by the arrows).

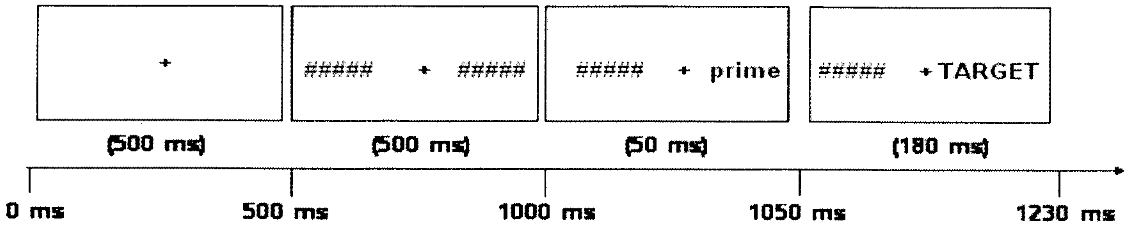

Figure 4. A timeline of events during a trial in Experiments 2 and 3 (for targets presented to the right visual field/left hemisphere in the 50 ms SOA condition).

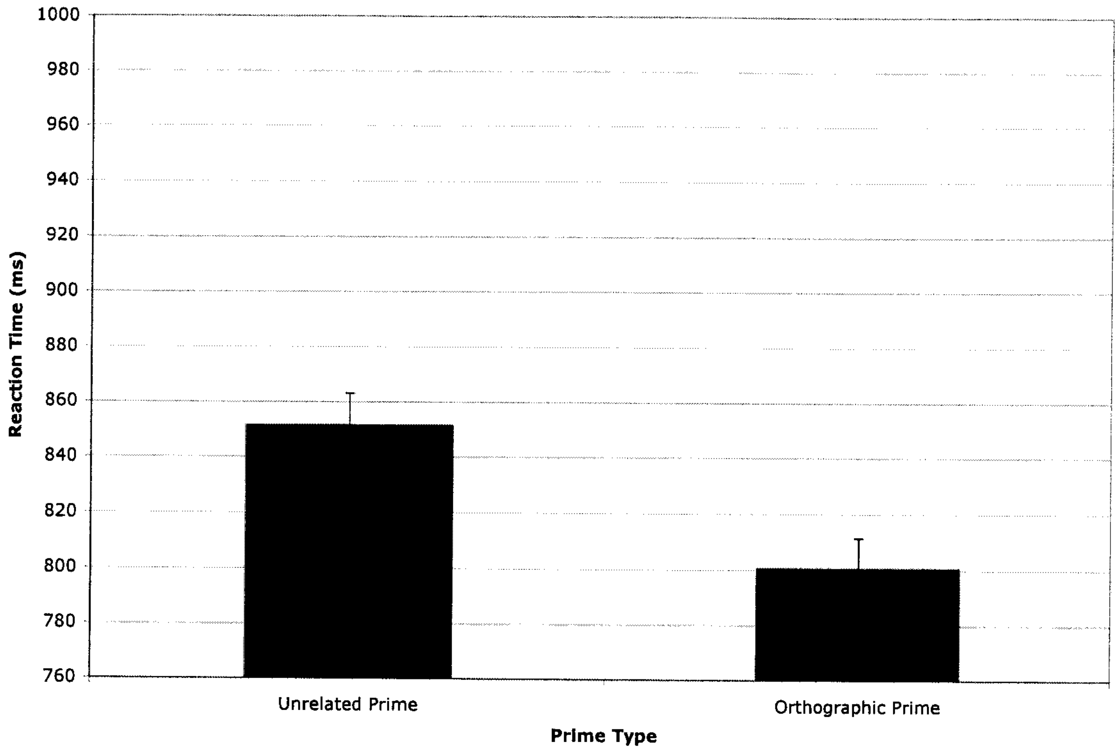

Figure 5. Mean reaction times (in ms) for correct lexical decisions as a function of prime-type collapsed across hemisphere of presentation and stimulus onset asynchrony (Experiment 2).

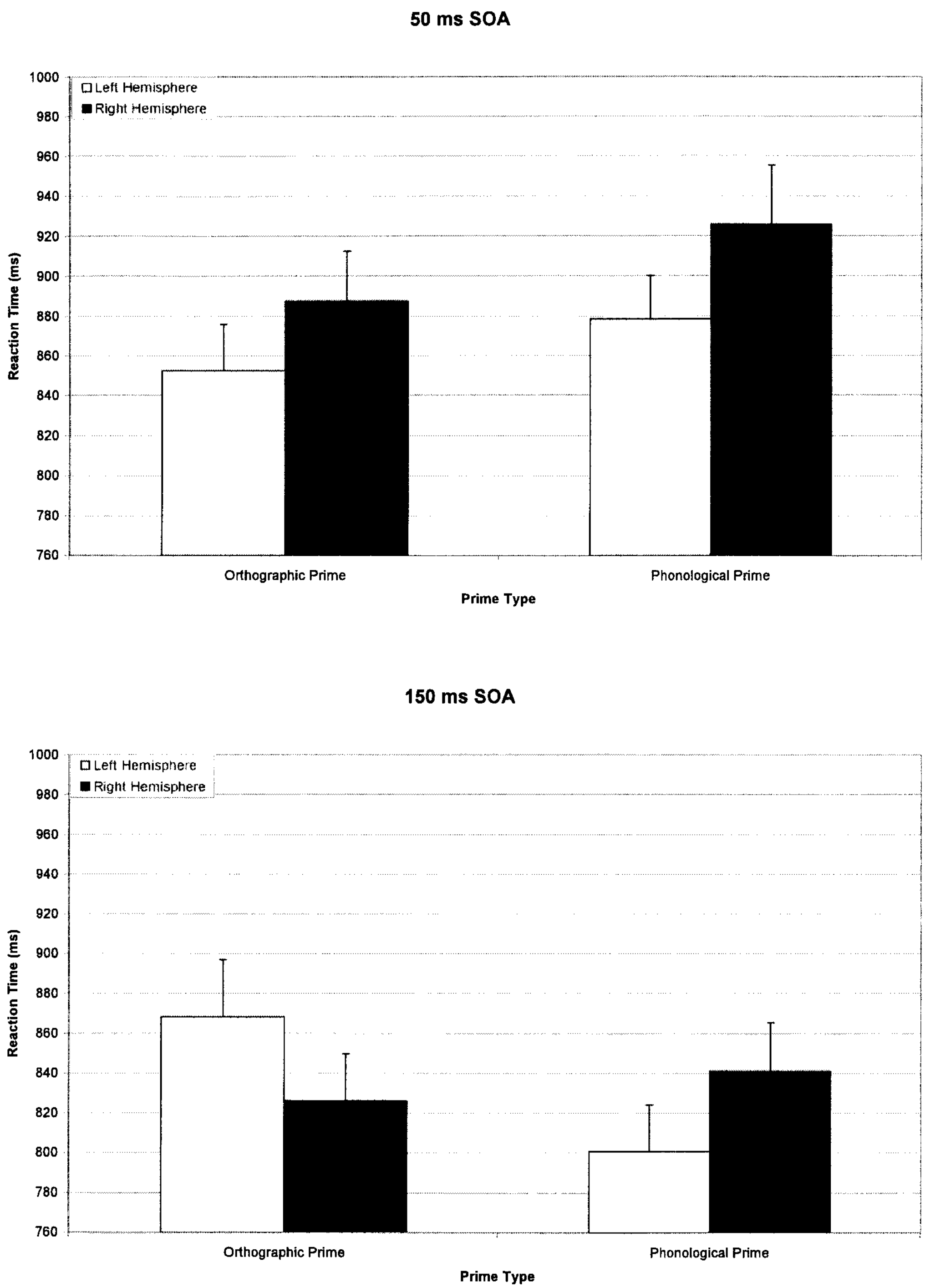

Figure 6. Mean reaction times (in ms) for correct lexical decisions as a function of stimulus onset asynchrony, hemisphere of presentation, and prime-type (Experiment 3).

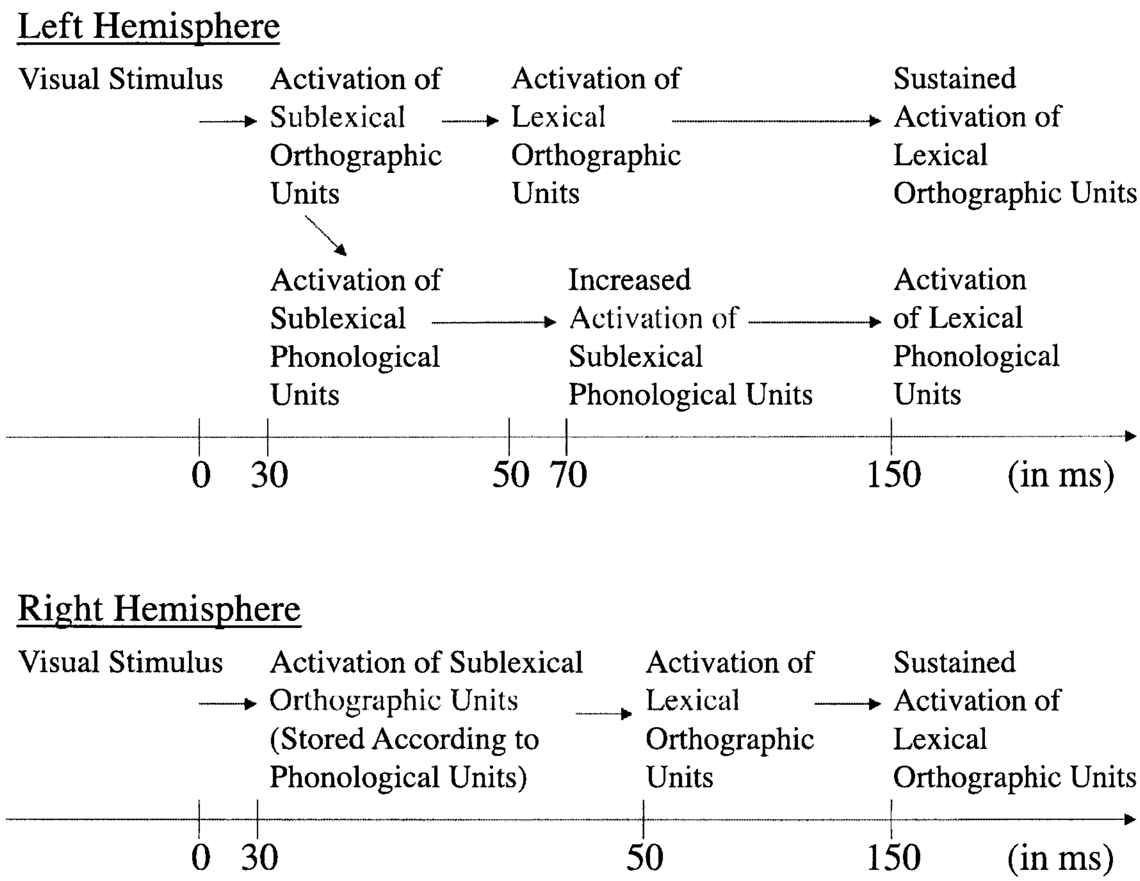

Figure 7. A timeline of sublexical and lexical orthographic and phonological processing of single printed words in the left and right cerebral hemispheres.[9]

[9] Please note that reference is made to specific time points in processing only to ease the readers understanding of the timeline outlined. Rather than the strong assumption that it can be used to reveal the absolute time course for the computation of linguistic codes, it is assumed that SOA manipulations can help provide approximations of the time course of early word processing and provide evidence for strong claims about relative processing (Frost & Yogev, 2001).

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