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Evidence for Right Hemisphere Phonology in a Backward Masking Task

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Abstract

The extent to which orthographic and phonological processes are available during the initial moments of word recognition within each hemisphere is under specified, particularly for the right hemisphere. Few studies have investigated whether each hemisphere uses orthography and phonology under constraints that restrict the viewing time of words and reduce overt phonological demands. The current study used backward masking in the divided visual field paradigm to explore hemisphere differences in the availability of orthographic and phonological word recognition processes. A 20 ms and 60 ms SOA were used to track the time course of how these processes develop during pre-lexical moments of word recognition. Nonword masks varied in similarity to the target words such that there were four types: orthographically and phonologically similar, orthographically but not phonologically similar, phonologically but not orthographically similar and unrelated. The results showed the left hemisphere has access to both orthography and phonology early in the word recognition process. With more time to process the stimulus, the left hemisphere is able to use phonology which benefits word recognition to a larger extent than orthography. The right hemisphere also demonstrates access to both orthography and phonology in the initial moments of word recognition, however, orthographic similarity improves word recognition to a greater extent than phonological similarity.

Keywords

Phonology; Orthography; Laterality; Word Recognition; Backward Masking; Visual Field; Right Hemisphere; Left Hemisphere

Research on the right hemisphere's reading and language abilities has established the right hemisphere as a processing system that is distinct and separate from the left. It does not simply echo the processes of the left hemisphere. The early work with commissurotomy patients revealed its extensive comprehension of auditory language, restricted reading ability and with only few exceptions, lack of speech (Zaidel, 1998). With time, the collection of behavioral studies using the divided visual field technique with normal participants revealed finer differences in how each hemisphere processes linguistic information. For example, the right hemisphere has been shown to preserve lower-level visual characteristics of words (i.e. case) or letter identities during visual word recognition whereas the left hemisphere extracts more abstract and lexically-based representations very quickly (see Chiarello, 2003 for a

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review). Similarly, the right hemisphere seems to maintain the more distantly related meanings of words compared to the left hemisphere which quickly selects the most appropriate meaning for the context and discards superfluous meanings (see Chiarello, 2003 for a review). These differences in semantic processes have been demonstrated across categorically related words, ambiguous words and their various meanings and even in cases where sentence contexts have served as primes.

While the role of the right hemisphere has been fairly well specified in behavioral semantic tasks, its role during initial moments of word recognition remains under specified. It seems evident that the cerebral hemispheres access orthography and phonology to different degrees, however, the extent to which each hemisphere uses these types of information is vague in the literature. Studies using tasks such as rhyme judgment (e.g. participants indicate whether two words rhyme or do not rhyme) find a left hemisphere advantage for detecting when two words rhyme, suggesting left hemisphere specialization for phonological processes (Crossman & Polich, 1988; Khateb et al., 2000). An interesting finding in these studies shadows the simple conclusions one could draw from these results. The right hemisphere can detect non-rhyming trials more accurately than the left hemisphere. This result has been replicated in a visual match task (e.g. participants indicate whether two words look similar or not) (Crossman & Polich, 1988) and a semantic category match task (e.g. participants indicate whether two words are in the same category or not) (Khateb et al., 2000), suggesting a decision-making bias across the hemispheres that is independent of the type of similarity being judged. Thus, tasks that require explicit judgment may not be the best paradigm to measure the pre-lexical availability of phonological or orthographic processes within a hemisphere as they could be overshadowed by differences between the hemispheres that arise later during the decision making stage of these tasks.

When tasks do not require explicit phonological decisions like rhyme judgment, right hemisphere sensitivity to phonological characteristics of the stimulus is observed (Barry, 1981; Lukatela, Carello, Savic & Turvey, 1986; Chiarello, Hasbrooke & Maxfield, 1999; Smolka & Eviatar, 2006). Chiarello et al. (1999) showed that in a naming task, phonologically similar distractors facilitated naming performance of target words equivalently in both visual fields. Barry (1981) found a significant pseudohomophone effect in a lexical decision task (i.e. worse rejection performance for nonwords that are phonologically identical to real words compared to those that are not) in both visual fields. Lukatela et al. (1986) showed that when words were phonologically ambiguous (i.e. could have more than one phonological representation) in Serbo-Croatian, lexical decisions in both visual fields were worse compared to unambiguous words. More recently, Smolka and Eviatar (2006) showed that when Hebrew words were pointed incorrectly to distort phonological representations, this created interference distortion in a naming task in both visual fields. These results demonstrate that the right hemisphere must possess some level of phonological processing ability, otherwise, these effects would be absent in left visual field performance.

While these studies have gotten us closer to understanding the right hemisphere's capabilities during reading, the time course of the availability of phonology is still unknown. Because the studies mentioned above did not restrict viewing time or manipulate stimulus onset asynchronies (SOAs), it is still unknown whether the right hemisphere has direct access to phonology and computes it on its own, or if sound information is provided to the right hemisphere via callosal relay after it is computed by the left (Zaidel, Clarke & Suyenobu, 1990). By combining short stimulus durations and visual masking, the time a reader has to process stimuli can be restricted to a period of decoding that is more likely to reflect the earliest availability of orthography and phonology in each hemisphere.

Few studies have combined short duration and visual masking with the divided visual field paradigm. Lavidor and Ellis (2003) used a masked priming paradigm in which the primes varied in orthographic and phonological similarity to the target word. Their results revealed orthographic and phonological priming in the left hemisphere, but only orthographic priming in the right hemisphere. In fact, there was greater orthographic priming in the right hemisphere compared to the left suggesting the possibility for superior orthographic processing in the right hemisphere. These findings suggest that during initial word processing, phonology is not the primary pre-lexical process in the right hemisphere.

Varying SOAs in behavioral priming tasks can provide information on how orthographic and phonological processes unfold over time in a way similar to the time course differences seen in the semantic literature (see Chiarello, 2003 & Chiarello, 1998 for a review). Halderman & Chiarello (2005) used lateralized backward masking with SOAs of 30ms and 50ms to track the time course of orthographic and phonological processes in each visual field. Nonword masks were orthographically and phonologically similar, orthographically similar with little phonological similarity or unrelated to the target word. Participants selected the target word in a two-alternative forced choice decision. The results showed that orthography and phonology were available early in the left hemisphere and that when phonological similarity was present, word identification was better than just orthographic similarity alone. Conversely, there was no evidence that phonology affected word identification in the right hemisphere. However, orthographic similarity alone improved target identification more in the right hemisphere compared to the left suggesting enhanced pre-lexical orthographic processing in the right hemisphere.

Across these behavioral studies, it appears that phonological processing is a dominant feature of left hemisphere reading from the earliest moments of word recognition and onward. Conversely, initial reading processes in the right hemisphere seem to be governed by orthographic processes. While the right hemisphere has shown sensitivity to phonological characteristics of print, this has not been demonstrated pre-lexically. There were a few limitations to previous studies that leave this question unanswered. First, Halderman and Chiarello (2005) did not reveal any interactions with SOA which was treated as a between subject variable. Individual differences in visual masking may have weakened the possibility of finding time course differences in this study. Second, neither Lavidor & Ellis (2003) nor Halderman & Chiarello (2005) had a condition in which phonology was the sole source of similarity. Therefore, the current study used a lateralized backward masking paradigm similar to the one reported in Halderman and Chiarello (2005). Here, the target and nonword masks were presented for either 20 ms each or 60 ms each, with SOA as a within subject variable. In addition, the current study includes four types of target/mask similarity: orthographically and phonologically similar (O+P+), orthographically similar with little phonological similarity (O+P-), phonologically similar with little orthographic similarity (O-P+) and unrelated (O-P-). Including a condition where phonology is the main source of similarity (O-P+) provides a more stringent test of the right hemisphere's ability to access phonological information about print. If target identification is faster or more accurate with phonological similarity alone (O-P+) relative to the unrelated condition (O-P-), this would be evidence that some ability to process phonology exists in the right hemisphere. If the right hemisphere is not capable of processing phonology, the condition where phonology is the only source of similarity (O-P+) should be equivalent to the unrelated condition (O-P-).

Results

A 2 (SOA; 20ms and 60 ms) X 4 (Mask Type; O+P+, O+P-, O-P+, and O-P-) X 2 (Visual Field) repeated measures ANOVA was conducted with percent correct and the logged

reaction time of correct trials as the dependent variables. Reaction times of less than 350 ms (indicating spurious responses) and those that exceeded the subjects' conditional means ± 2.5 standard deviations were deleted which amounted to .01% of the total correct trials. Reaction times were then log transformed because they were not normally distributed. The Greenhouse-Geisser correction was applied to p-values on F-tests with more than two levels.

Percent Correct

For percent correct (see Table 1), there was a main effect of SOA ($F(1, 46) = 29.32, p < .001, \eta_p^2 = .389$). A main effect of visual field showed responses were more accurate to RVF presentations than LVF presentations ($F(1, 46) = 81.02, p < .001, \eta_p^2 = .638$). There was also a significant main effect of Mask Type ($F(3, 138) = 151.19, p < .001, \epsilon = .934, \eta_p^2 = .767$). Responses were most accurate for the O+P+ and O+P- conditions which were both more accurate than the O-P- condition. Responses in the O-P- were less accurate compared to all other mask type conditions.

The only significant interaction for percent correct was the SOA X Mask Type interaction ($F(3, 138) = 8.96, \text{MSE} = 103.4, p < .001, \epsilon = .924, \eta_p^2 = .163$). In order to interpret this interaction, the effect of SOA was examined for each mask type condition separately. The 60 ms SOA was significantly more accurate than the 20 ms SOA for the O+P+ ($t(46) = -4.73, p < .001$), O+P- ($t(46) = -5.24, p < .001$), and the O-P+ conditions ($t(46) = -5.60, p < .001$). However, there was no difference between the 60 ms SOA and the 20 ms SOA for the O-P- condition. Therefore, accuracy was higher when participants had more time to process the target and mask when similarity was present. When no similarity was present between the target and mask, extra time did not improve accuracy.

Reaction Time

For reaction time (see Table 2), there was a main effect of visual field ($F(1, 46) = 5.81, p < .05, \eta_p^2 = .112$) such that reaction times were faster to RVF presentations. There was also a main effect of mask type ($F(3, 138) = 100.16, p(\text{GG}) < .001, \epsilon = .641, \eta_p^2 = .685$). Reaction times were fastest to the O+P+ and O+P- conditions which were both faster compared to the O-P+ condition. Reaction times to the O-P- condition were slower compared to all other mask type conditions. There was a significant SOA X Mask Type interaction ($F(3, 138) = 6.13, p < .005, \epsilon = .767, \eta_p^2 = .118$). The three-way interaction, SOA X Visual Field X Mask Type was also significant ($F(3, 138) = 2.87, p < .05, \epsilon = .870, \eta_p^2 = .059$) (see Figure 1). In order to determine the nature of this three-way interaction, planned, pairwise comparisons were conducted. These planned comparisons tested the effects of orthographic and phonological similarity on target identification. The following subsections highlight the significant effects determined by these planned tests.

Effect of phonological similarity holding orthographic similarity constant—To examine this effect, the O+P+ and O+P- conditions were directly contrasted. For LVF presentations, in the 20 ms and 60 ms SOAs, the O+P+ condition was statistically equal to the O+P- condition. For RVF presentations, the pattern of results was quite different. The O+P+ condition was significantly slower than the O+P- in the 20 ms SOA ($t(46) = 2.05, p < .05$). However, in the 60 ms SOA, the O+P+ condition was significantly faster than the O+P- condition ($t(46) = -2.88, p < .01$). When orthographic similarity was present between the target and nonword mask, the RH was not benefited by additional phonological similarity, regardless of SOA. Masks with both orthographic and phonological similarity initially slowed down recognition in the LH. However, with slightly more time to view the stimulus, additional phonological similarity lead to faster recognition, even when orthographic similarity was present.

Effect of orthographic similarity holding phonological similarity constant—To examine this effect, the O+P+ and O–P+ conditions were directly contrasted. For LVF presentations, the O+P+ condition was significantly faster than the O–P+ condition in the 20 ms SOA ($t(46) = -3.28, p < .005$) and in the 60 ms SOA ($t(46) = -2.58, p < .05$). RVF presentations showed a different pattern. For presentations to the RVF, the O+P+ condition was statistically equal to the O–P+ condition in the 20 ms SOA. However, in the 60 ms SOA, the O+P+ condition was significantly faster than the O–P+ condition ($t(46) = -5.99, p < .001$). For this contrast, the results showed that even when phonological similarity was present, orthographic similarity lead to faster target identification for the RH in both SOAs. However, the benefit of orthographic similarity when phonological similarity was present did not appear until the 60 ms SOA for the LH.

Effect of orthographic similarity alone—To examine this effect, the O+P– and O–P– conditions were directly contrasted. For LVF presentations, in the 20 ms and 60 ms SOAs, the O+P– condition was significantly faster than the O–P– condition ($t(46) = -6.96, p < .001, t(46) = -8.90, p < .001$, respectively). The same pattern was found for the RVF. In the 20 ms SOA, the O+P– condition was significantly faster than the O–P– condition ($t(46) = -7.84, p < .001$) and also in the 60 ms SOA (290 ms) ($t(46) = -8.47, p < .001$). Therefore, at both SOAs and for both hemispheres, when orthographic similarity was the only information shared between the target and nonword mask, target identification was faster relative to the unrelated condition.

Effect of phonological similarity alone—To examine this effect, the O–P+ and O–P– conditions were directly contrasted. For LVF presentations, the O–P+ condition was significantly faster than the O–P– condition in the 20 ms SOA ($t(46) = -4.34, p < .001$) and in the 60 ms SOA ($t(46) = -7.26, p < .001$). The same pattern of results was seen for the RVF. In the 20 ms SOA, the O–P+ condition was significantly faster than the O–P– condition ($t(46) = -6.47, p < .001$), and in the 60 ms SOA ($t(46) = -6.83, p < .001$). These comparisons showed that in both SOAs and in both hemispheres, when phonological similarity was the only information shared between the target and nonword mask, target identification was faster relative to the unrelated condition.

Discussion

These results support previous findings that the left hemisphere has access to both orthography and phonology very early during word recognition (Halderman & Chiarello, 2005; Lavidor & Ellis, 2003). With 20 ms of presentation, the left hemisphere had access to both sources of information with no clear advantage of orthographic or phonological similarity on subsequent target identification. Interestingly, the left hemisphere did not demonstrate faster identification when both sources of similarity were present (O+P+) compared to when there was only one source of similarity (O+P– or O–P+). However, with 60 ms of presentation, phonological similarity facilitated word identification to a greater extent than orthographic similarity. Thus, the data presented here for the RVF/left hemisphere seems to capture the time course of a phonological representation developing over several milliseconds. In the shortest SOA, the left hemisphere had access to phonology, but with 40 ms of additional viewing time, word identification in conditions with phonological similarity was faster.

The data shows that the right hemisphere also gains access to phonology very early. If the right hemisphere was not capable of processing the phonology of words, the O–P+ condition should have been equivalent to the unrelated condition. Finding evidence for phonological processes in the right hemisphere this early during word recognition, suggesting it as direct access to some phonological aspects of words. This is very novel

finding, however evidence for phonological processes in the right hemisphere is not unprecedented. Previous studies have shown that when the experimental task does not require explicit phonological decisions, the right hemisphere performs similarly to the left hemisphere (Barry, 1981; Lukatela, Carello, Savic & Turvey, 1986; Chiarello, Hasbrooke & Maxfield, 1999; Smolka & Eviatar, 2006).

While the data shows right hemisphere access to phonology, it seems that word recognition is benefited to a greater degree by orthography relative to phonology. At both SOAs, as long as orthographic similarity was present, extra phonological information did not lead to faster word identification. This suggests that even with more time, the right hemisphere does not use the phonological representations of words when orthographic similarity is present. These results are similar to previous work that has shown a greater role for orthography in right hemisphere word recognition (Halderman & Chiarello, 2005; Lavidor & Ellis, 2003). The experiment reported here did not show enhanced orthographic processes in the right hemisphere relative to the left hemisphere as in previous studies using similar paradigms (Halderman & Chiarello, 2005; Lavidor & Ellis, 2003). The reported experiment used a shorter SOA than the previous experiments. Previous work has shown that orthographic and phonological processes develop rapidly in the first few hundred milliseconds of word recognition, leaving open the possibility that the shorter SOA used here (20 ms) sampled an earlier window of word recognition where orthographic processes in the right hemisphere had not yet reached their peak.

It has long been thought that the left hemisphere was solely capable of processing the phonology of printed words because speech production mechanisms are predominately lateralized to the left hemisphere (Zaidel, 1985). This view was driven by evidence from commissurotomy patients. In a review of behavioral data from several patients, it was found that the patients who possessed rhyming abilities of printed words in their right hemispheres also had right hemisphere speech production capabilities (Baynes & Eliassen, 1998). While it is likely that the right hemisphere in a majority of people cannot make use of phonological speech production codes, this does not preclude the possibility that the right hemisphere uses phonological representations from speech perception. Recent functional imaging of speech perception has revealed bilateral patterns of activation for phonological characteristics of spoken word recognition (Hickok & Poeppel, 2007). This evidence for a parallel system for speech recognition may explain why deficits in speech recognition are rarely seen after unilateral injury. While both hemispheres appear to be active during speech perception and recognition, it does seem that the left hemisphere alone coordinates brain areas involved in speech perception with those that are important for speech production (Hickok & Poeppel, 2007). This suggests that the left hemisphere is able to draw on information about production codes while the right hemisphere is not which may explain why greater phonological decoding of printed words is seen in the left hemisphere. The perceptual codes available in the right hemisphere may only provide minimal information. In order to produce a full phonological representation of a printed word, speech production codes may be necessary.

Federmeier (2007) recently proposed a framework that claims a primary difference between the hemispheres lies in the connectivity of the perceptual and production systems in the left hemisphere which is absent in the right. This connectivity in the left hemisphere allows for stronger feedback connections, allowing for a more top-down process which can exert a stronger influence on new information entering the language system. Thus, the left hemisphere is able to process language in a more expectancy driven manner whereas the right hemisphere tends to show a “bottom-up” or “feed-forward” process. Federmeier (2007) mostly draws from experiments on higher-level language processes (i.e. semantics and syntax) than the level of processing here, but these results may provide further evidence that

connections to production mechanisms give the left hemisphere an advantage over the right. In this case, the left hemisphere has enhanced phonological processing capabilities due to its unique connectivity.

The presented experiment provides evidence that both hemispheres gain access to orthography and phonology very early during visual word recognition. Phonology develops very quickly and allows for better word recognition in the left hemisphere. Orthography seems to aid word recognition to a greater extent in the right hemisphere, however, a minimal level of phonological processing is also available.

Methods

Participants

48 participants (24 females) were recruited for this experiment through the introductory psychology classes' subject pool. One participant was excluded from the analyses because they were run on the wrong list. All participants were native English speakers, right-handed, and had normal or corrected-to-normal vision. Handedness was measured by a five-item preference questionnaire (Bryden, 1982) with a range of +1.00 (extreme right-handedness) to -1.00 (extreme left-handedness). A score of +.30 was required for participation, and the mean handedness preference score was +.91.

Materials

The stimuli were 320 target words, presented in lowercase, in 20 point Helvetica font, and 3–7 letters in length. Target words were preceded by a row of uppercase Xs that was the same length as the target. Target words were masked by a nonword that was orthographically and phonologically related (O+P+), orthographically but not phonologically related (O+P-), phonologically but not orthographically related (O-P+), or completely unrelated (O-P-). All nonword masks were also 3–7 letters in length. The lowercase targets subtended 0.38° – 0.53° of vertical visual angle and 0.80° – 2.15° of horizontal visual angle. The nonword masks and pattern masks (e.g. XXXX) subtended $.53^{\circ}$ of vertical visual angle and 1.24° – 3.24° of horizontal visual angle.

In the O+P+ condition, the nonwords were pseudohomophones of the target words (e.g. crew – CRUE) and shared several letters. In the O+P- condition, orthographic similarity was identical to that in the O+P+ condition. Letters that were not orthographically similar in the O+P+ condition were changed such that the shared phonology in the O+P- condition was as different as possible (e.g. crew - CRAE). Nonwords in the O-P+ condition were also pseudohomophones of the target words, however, there was very limited shared orthography (e.g. crew - KROO). Finally, in the O-P- condition, there was no shared phonology or orthography between the target and nonword (e.g. crew – FAMS). The target and nonword masks shared the same first letter 86.3% of the time in the O+P+ condition, 86.7% in the O+P- condition, 67.8% in the O-P+ condition and 0% of the time in the O-P- condition. All nonword masks were backward masked by a row of Xs in uppercase and were the same length as the nonword mask (e.g. XXXX).

The target and distractor words for the two-alternative forced choice response were matched for frequency and differed by only one letter (e.g. crew – grew) (Kucera & Francis, 1967; Coltheart, 1981; Wilson, 1988). The letter change between the targets and distractors occurred equally across the first and second half of the words.

Each participant saw 320 trials; half in the 20 ms. SOA was blocked. Half the participants received the 20ms SOA first. Target words were fully counterbalanced so that each word was seen in every condition.

Apparatus and procedure

Participants sat 60 cm in front of a computer screen with G4 Macintosh computers equipped with Psyscope (Cohen, MacWhinney, Flatt & Provost, 1993). Stimuli were displayed in black on a white screen. Participants were given 48 practice trials before starting the experiment.

Each trial began with a fixation cross in the middle of the screen for 300ms prior to the onset of the stimuli. It remained on the screen throughout the trial and terminated 100 ms after the stimuli were presented. Next, a series of stimuli was presented to either the left or right visual field. All stimuli were presented to maintain a consistent 1.62° eccentricity. This distance from fixation exceeds the extent of the foveal region (approximately 1 degree of visual angle), ensuring the stimuli were initially presented to the contralateral hemisphere (Stone, Leicester & Sherman, 1973; Bunt, Minckler & Johanson, 1977). Each component of the series (forward pattern mask, target in lowercase, nonword mask in uppercase, backward pattern mask) lasted 20 or 60 ms according to the SOA condition (see Figure 2) with a 0 ms ISI between each component. The presentation of the stimuli was so brief that fixations to the target word were not possible because targets and nonword masks terminated by 60 ms and 180 ms for the 20 and 60 ms SOAs, respectively. After the fixation point disappeared there was a 300 ms ISI before the two-alternative forced choice items were presented. These words were presented in lowercase, in the middle of the screen, one above the other, for 4000 ms or until a participant made their response. If a response was not made within 4000 ms, the trial was recorded as a Time Out and dropped from the analysis. Responses were made on the zero and period key on a Macintosh numeric keypad with the index and middle fingers of the right hand. Response mapping was counterbalanced across participants. The next trial began 2000 ms after the end of the previous trial.

Highlights

- Hemisphere differences were examined using lateralized backward masking
- Masks varied in orthographic and phonological similarity to the target
- The left hemisphere showed very early access to both orthography and phonology
- Recognition in the right hemisphere was benefited more by orthographic similarity
- However, at the shortest SOA, the right hemisphere did have access to phonology

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Laura K. Halderman is no longer at the University of California, Riverside.

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References

- Barry C. Hemispheric asymmetry in lexical access and phonological encoding. *Neuropsychologia*. 1981; 19:473–478. [PubMed: 7266842]

- Baynes, K.; Eliassen, J. The visual Lexicon: Its access and organization in commissurotomy patients. In: Beeman, M.; Chiarello, C., editors. Right hemisphere language comprehension: Perspectives from Cognitive Neuroscience. Mahwah, NJ: Lawrence Erlbaum Associates; 1998. p. 79-104.
- Bryden, MP. Laterality: Functional asymmetry in the intact brain. New York: Academic Press; 1982.
- Bunt AH, Minckler DS, Johanson GW. Demonstration of bilateral projection of the central retina of the monkey with horseradish peroxidase neuroography. *Journal of Comparative Neurology*. 1977; 171:619–630. [PubMed: 401836]
- Chiarello, C. On codes of meaning and the meaning of codes: Semantic access and retrieval within and between hemispheres. In: Beeman, M.; Chiarello, C., editors. Right hemisphere language comprehension: Perspectives from Cognitive Neuroscience. Mahwah, NJ: Lawrence Erlbaum Associates; 1998. p. 141-160.
- Chiarello, C. Parallel systems for processing language: Hemispheric complementarity in the normal brain. In: Banich, MT.; Mack, M., editors. Mind, Brain and Language: Multidisciplinary Perspectives. Mahwah, NJ: Lawrence Erlbaum Associates; 2003. p. 229-247.
- Chiarello C, Hasbrooke R, Maxfield L. Orthographic and phonological facilitation from unattended words: Evidence for bilateral processing. *Laterality*. 1999; 4:97–125. [PubMed: 15513108]
- Cohen J, MacWhinney B, Flatt M, Provost J. PsyScope: An interactive graphic system for designing and controlling experiments in the psychology laboratory using Macintosh computers. *Behavior Research Methods, Instruments & Computers*. 1993; 25:257–271.
- Coltheart M. The MRC psycholinguistic database. *Quarterly Journal of Experimental Psychology*. 1981; 33A:497–505.
- Crossman DL, Polich J. Hemispheric differences for orthographic and phonological processing. *Brain and Language*. 1988; 35:301–312. [PubMed: 3208075]
- Federmeier KD. Thinking ahead: The role and roots of prediction in language comprehension. *Psychophysiology*. 2007; 44:491–505. [PubMed: 17521377]
- Halderman LK, Chiarello C. Cerebral asymmetries in early orthographic and phonological reading processes: Evidence from backward masking. *Brain and Language*. 2005; 95:342–352. [PubMed: 16246741]
- Hickok G, Poeppel D. The cortical organization of speech. *Nature Reviews*. 2007; 8:393–402.
- Khateb A, Pegna A, Michel C, Custodi MC, Landis T, Annoni JM. Semantic category and rhyming processing in the left and right cerebral hemisphere. *Laterality*. 2000; 5:35–53. [PubMed: 15513129]
- Kucera; Francis, W. Computational Analysis of Present-Day American English. Providence: Brown University Press; 1967.
- Lavidor M, Ellis AW. Orthographic and phonological priming in the two cerebral hemispheres. *Laterality: Asymmetries of Body, Brain & Cognition*. 2003; 8:201–223.
- Lukatela G, Carello C, Savic M, Turvey MT. Hemispheric asymmetries in phonological processing. *Neuropsychologia*. 1986; 24:341–350. [PubMed: 3736816]
- Smolka E, Eviatar Z. Phonological and orthographic visual word recognition in the two cerebral hemispheres: Evidence from Hebrew. *Cognitive Neuropsychology*. 2006; 23:972–989. [PubMed: 21049362]
- Stone J, Leicester J, Sherman SM. The naso-temporal division of the monkey's retina. *Journal of Comparative Neurology*. 1973; 150:333–346. [PubMed: 4198545]
- Wilson M. The MRC psycholinguistic database: Machine readable dictionary, version 2. *Behavioural Research Methods, Instruments and Computers*. 1988; 20:6–11.
- Zaidel, E. Language in the right hemisphere. In: Benson, DF.; Zaidel, E., editors. The Dual Brain: Hemispheric Specialization in Humans. New York: The Guilford Press; 1985. p. 205-231.
- Zaidel, E. Language in the right hemisphere following callosal disconnection. In: Stemmer, B.; Whitaker, H., editors. Handbook of Neurolinguistics. San Diego, CA: Academic Press; 1998. p. 369-383.
- Zaidel, E.; Clarke, JM.; Suyenobu, B. Hemispheric independence: A paradigm case for cognitive neuroscience. In: Scheibel, AB.; Weebler, AF., editors. Neurobiology of Higher Cognitive Functions. New York: Guilford Press; 1990. p. 297-355.

Figure 1.

Log reaction times for the nonword mask conditions (O+P+: orthographically and phonologically related, O+P-: orthographically but not phonologically related, O-P+: phonologically but not orthographically related, O-P-: unrelated) across visual fields and SOAs.

Figure 2.
Example of a trial from the 20 ms SOA using the O-P+ (phonology only) mask condition.

Table 1

Percent correct means and standard deviations

20 ms SOA	O+P+	O+P-	O-P+	O-P-
LVF	71.6 (10.9)	73.3 (11.0)	63.2 (11.4)	55.3 (11.4)
RVF	78.2 (10.8)	76.8 (11.8)	71.7 (10.2)	61.8 (13.3)
60 ms SOA				
LVF	80.0 (12.2)	79.5 (11.4)	75.1 (11.8)	54.0 (13.6)
RVF	85.4 (10.6)	83.6 (8.2)	79.6 (10.4)	62.4 (13.4)

Table 2

Log transformed reaction time means and standard deviations.

20 ms SOA	O+P+	O+P-	O-P+	O-P-
LVF	6.86 (.26)	6.87 (.27)	6.91 (.24)	7.03 (.31)
RVF	6.87 (.27)	6.85 (.26)	6.89 (.26)	7.00 (.26)
60 ms SOA				
LVF	6.86 (.23)	6.87 (.24)	6.90 (.25)	7.08 (.29)
RVF	6.79 (.25)	6.84 (.25)	6.89 (.25)	7.05 (.29)