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Hemisphere differences in conscious and unconscious word reading☆

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Abstract

Hemisphere differences in word reading were examined using explicit and implicit processing measures. In an *inclusion task*, which indexes both conscious (explicit) and unconscious (implicit) word reading processes, participants were briefly presented with a word in either the right or the left visual field and were asked to use this word to complete a three-letter word stem. In an *exclusion task*, which estimates unconscious word reading, participants completed the word stem with any word other than the prime word. Experiment 1 showed that words presented to either visual field were processed in very similar ways in both tasks, with the exception that words in the right visual field (left hemisphere) were more readily accessible for conscious report. Experiment 2 indicated that unconsciously processed words are shared between the hemispheres, as similar results were obtained when either the same or the opposite visual field received the word stem. Experiment 3 demonstrated that this sharing between hemispheres is cortically mediated by testing a split-brain patient. These results suggest that the left hemisphere advantage for word reading holds only for explicit measures; unconscious word reading is much more balanced between the hemispheres.

Keywords: Hemisphere differences; Perception without awareness; Word reading; Explicit processing; Implicit processing; Conscious awareness; Unconscious priming; Masking

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1. Introduction

Many cognitive tasks are performed differently when the relevant information is presented only to the left or the right visual field (Hellige, 1993; Ivry & Robertson, 1998; Springer & Deutsch, 1998). Word reading is one of the most strongly lateralized, showing a left hemisphere advantage. Healthy normal readers identify words presented to the right visual field (left hemisphere) more rapidly and accurately than words presented to the left visual field (right hemisphere) (Hellige, 1993; Iacoboni & Zaidel, 1996; Jung-Beeman & Chiarello, 1998; Pirozzolo, 1977; Zaidel, 1983). Patients with unilateral lesions have more severe reading impairments when damage is to the left hemisphere (Hellige, 1993; Springer & Deutsch, 1998). Finally, after surgical disconnection of the cerebral hemispheres, split-brain participants are better at reading words presented to the left hemisphere (e.g., Gazzaniga, 1970, 1983; Sperry, 1968; Zaidel, 1983).

This pattern of laterality is less clear when indirect measurements of reading are taken. Studies of repetition priming, in which participants first judge the pleasantness of a word before they complete a three-letter word stem, show equal (and sometimes stronger) priming effects for word stems flashed to the left versus the right visual field (Marsolek, Kosslyn, & Squire, 1992). In patients with pure alexia (the inability to read) acquired as a consequence of left hemisphere damage, there is still evidence of implicit word reading abilities (Coslett & Saffran, 1989; Schacter, Rapscak, Rubens, Tharan, & Laguna, 1990). Importantly, these patients are completely unaware of their achievements and claim that they cannot identify anything beyond single letters. This suggests that the right hemisphere is capable of reading at an unconscious level (Coslett & Saffran, 1989).

The strong laterality in explicit reading tasks, coupled with the weak laterality in some implicit reading tasks, suggests that the left hemisphere may not be advantaged for all aspects of word reading. Instead, it may only be advantaged when conscious access to a word is required. This is a provocative hypothesis that has not yet been properly tested. In existing studies involving healthy subjects, there are many procedural differences between studies of explicit reports and implicit influences that complicate the comparison. For example, in studies of explicit reading, the word is typically presented briefly to the left or right side of fixation and the participant is asked to name it. In studies of implicit reading, a word is typically presented to the center of gaze for an extended duration and then the participants are asked to complete a "word-stem" (the first two or three letters of a word) that is presented briefly to the left or right of fixation with the first word that comes to mind. The explicit tasks thus require the reading of a word that has been presented to a single hemisphere, whereas the implicit tasks involve reading two words: the first word presented to both hemispheres by way of a central presentation, and the second (partial) word presented to only one hemisphere by way of peripheral presentation (see Kroll, Rocha, Yonelinas, & Baynes, 2001; Kroll et al., 2003; Yonelinas et al., 2001; for additional implicit priming methods).

To further complicate matters, these procedural differences have measurable consequences. For instance, the typical left hemisphere advantage in explicit tasks is diminished when a word is first presented centrally and then participants are asked to complete a word stem presented peripherally with the same word (Marsolek et al., 1992). Priming tasks also yield different results, depending on whether participants respond to the prime words or not. A left hemisphere advantage is more likely when participants must name the prime words than if they are presented in the absence of any response demands (Burgund & Marsolek, 1997, Experiment 1; Koivisto, 1995, 1996; see Kroll et al., 2001, 2003; Yonelinas et al., 2001, for additional examples).

This investigation examined visual field differences in explicit and implicit word reading tasks without confounding procedural differences in stimulus presentation and acquisition. To do this, we presented participants with the same displays in each task and varied only the response that they were asked to make. The procedure was a split-field version of the perception without awareness paradigm (Merikle, Joordens, & Stolz, 1995; Visser & Merikle, 1999). Observers are given a word stem to complete (e.g., "find an English word that begins with the three letters, BOT...") in one of two task sets. In the *inclusion task*, participants are told to complete the word stem with the word that has recently been flashed and backward masked (e.g., BOTANY). Thus, to the best of their ability, observers deliberately and intentionally use the information that they have recently experienced to perform the task. In the *exclusion task*, observers are told to complete the word stem with any word other than the one that was recently experienced (e.g., BOTTLE). Performance is indexed in this task by the failure of the observer to comply with instructions. It is assumed that this failure occurs when the prime word was used unintentionally and without awareness (see Jacoby, 1998).

These two tasks were assessed with three critically different durations of the prime word. Idealized results are shown in Fig. 1. In a control condition (zero duration), no prime word is presented and so inclusion accuracy rate and exclusion failure rate should agree in providing an estimate of how frequently observers chose to complete the word stem with words from the unseen list of primes. Under brief exposure of the prime, both inclusion accuracy and exclusion failures should increase, reflecting the extent to which some word processing is possible. Finally, under long prime word durations, inclusion accuracy increases again because of the additional information that the participant has available in their recent conscious experience. However, with long prime word durations, exclusion failures should decrease, because the prime word has become visible and so the instructions to complete the stem with a non-prime word can be adhered to. Unconscious word reading is quantified in this procedure by the extent to which the rate of exclusion failures in the brief exposure condition exceeds that in the baseline condition. As a check on task compliance, exclusion failures in the long exposure condition should be reduced relative to the brief exposure because it is assumed that longer exposures increase the likelihood that the prime is read consciously.

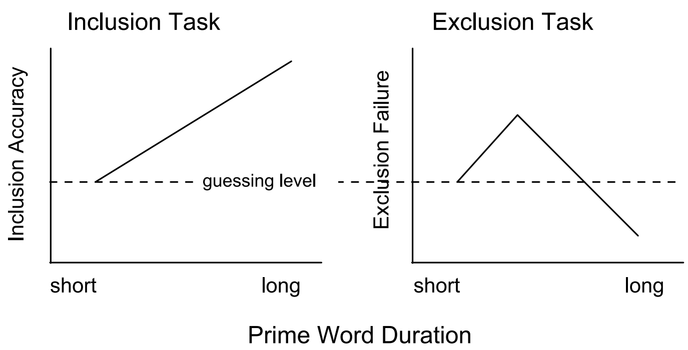

Fig. 1. Idealized results for the two tasks in the perception without awareness paradigm.

2. Experiment 1: Hemisphere differences in conscious access to words

Three modifications were made to the standard perception without awareness paradigm in order to implement it using a split-field display. First, because prime words were presented in the parafovea of either the right or the left visual field, we chose a large font size that permitted high accuracy in both fields when the words were presented unmasked for an extended period (e.g., 500 ms).

Second, because spatial uncertainty is inherent in a split-field presentation, we were concerned about combining this divided attention manipulation with masking, as both the distribution of spatial attention and masking operate to decrease conscious awareness (Debner & Jacoby, 1994; Forster, 1998; Merikle & Joordens, 1997; Mulligan, 1998; Wolters & Prinsen, 1997). We therefore tested some participants with a mask and others without a mask. Testing with a mask in split-field presentations has the added advantage of permitting the measurement of any hemispheric differences in processing speed, if it is assumed that processing of the word is halted when the mask appears, but that it continues when no mask is presented.

Third, we wanted to ensure that participants did not move their eyes during the sequence of trial events. While we were confident that systematic eye movements were not possible during the duration of the brief prime (i.e., 70 ms), which yielded the data most critical to our questions, there was no such guarantee for the long prime duration (i.e., 500 ms) or for the extended period of the word stem presentation. To discourage eye movements, the experimenter faced the participants from behind the display screen and reminded them about the fixation instructions whenever she detected an eye movement. Although this is a crude means of ensuring fixation, it should be noted that the occurrence of any eye movements would only serve to weaken any hemispheric differences that existed. This makes the present study a conservative one for detecting visual field/hemispheric differences.

2.1. Method

2.1.1. Participants

Forty-three university students (24 female) with corrected-to-normal visual acuity volunteered to participate for extra-course credit or $5. All but one participant reported herself as right-handed. The one left-handed subject performed similarly to the remaining subjects, consistent with reports that most left-handers have similar patterns of language dominance as right-handers (e.g., Lezak, 1995).

2.1.2. Stimuli

A pool of 300 low frequency words was chosen as primes (mean frequency = 4.13 per million, standard deviation = 4.93, Kucera & Francis, 1967). All words were 5–7 letters in length and were chosen so that a minimum of 3 other words could be constructed from the first three letters (e.g., BOT = botany, bottle, bottom, bother, botch, etc.). Words were randomly divided into three lists. The exposure duration of each of these lists (0, 70, or 500 ms) was counterbalanced across participants. Displays were presented on a 17-in. Hewlett–Packard monitor, with screen resolution set to 640×480 pixels and 16 colors, using MEL software (Schneider, 1990). Text was displayed in *Roman Sim* font. Participants sat 60 cm away from the screen.

Prime words were presented in a horizontal orientation to either the right or left of a fixation cross of 20×24 pixels. For each word, the letter nearest to fixation was always at a distance of 2.5° with the longest words extending 8.9° from fixation. In the masking conditions, the mask that followed the word consisted of a random letter string of 8 lowercase letters and appeared in the same location as the prime word. Word stems were presented in a horizontal orientation to either the right or left of fixation, they were printed in the same font, and the nearest letter appeared 2.5° from fixation.

2.1.3. Procedure

Participants were randomly divided into eight groups that differed in instruction set (inclusion, exclusion), visual field of word stem (left, right), and masking of the prime word (no mask, mask). The *inclusion* instructions asked participants to complete the word stem with the briefly presented prime word to the best of their ability. The *exclusion* instructions asked participants to complete the word stem with *any word other than* the briefly presented prime word. For both instruction sets, participants were told to complete the word stem with any word that began with the same three letters when no word was presented (0 ms duration). All participants were told that the prime words would be presented equally often and randomly to the left or right of fixation. Each participant was also informed of the side on which each word stem would appear, which remained the same throughout the experiment. Participants were asked to keep their eyes fixated on the central fixation marker at all times.

Participants were tested on 300 trials. Instructions were first read from the screen by the participant and then they were reiterated by the experimenter. The participant initiated each trial by saying "ready", which prompted the experimenter to start the trial with a key press. For every trial, the prime word was preceded by a 500 ms fixation marker and was followed by a 500 ms mask or blank screen, after which the word stem immediately followed and remained in view until the participant verbally responded with word. The experimenter then typed this word into the computer. When participants reported a word that was out of bounds (e.g. "perceive" for PRE...) or included fewer than 5 letters (e.g., prep) or more than 7 (e.g., preceptor), participants were asked to generate another word. Because trials were self-paced and participants were encouraged to take short breaks between trials, the time needed to complete all trials ranged from 45 to 120 min.

2.2. Results

2.2.1. Inclusion task

The mean percentage of word stems completed correctly (report of the prime word) is shown in the left-hand panel of Fig. 2. Three results are readily apparent. There was an increase in inclusion accuracy with increasing exposure duration, a left hemisphere advantage for word-identification, and a decrease in prime word reading accuracy with masking.

These observations were supported by an analysis of variance (ANOVA) examining Prime Duration (0, 70, and 500 ms), Prime Hemisphere (Right, Left), Stem Hemisphere (Right, Left), Masking (None, Mask), and Word List (A, B, C). Neither stem hemisphere nor word list were significant (all ps $> .10$), so these factors were not included in subsequent analyses.

The analysis showed that prime word inclusion accuracy increased with prime duration, $F(2, 20) = 268.77$, $p < .001$, and that primes presented to the left hemisphere were identified more

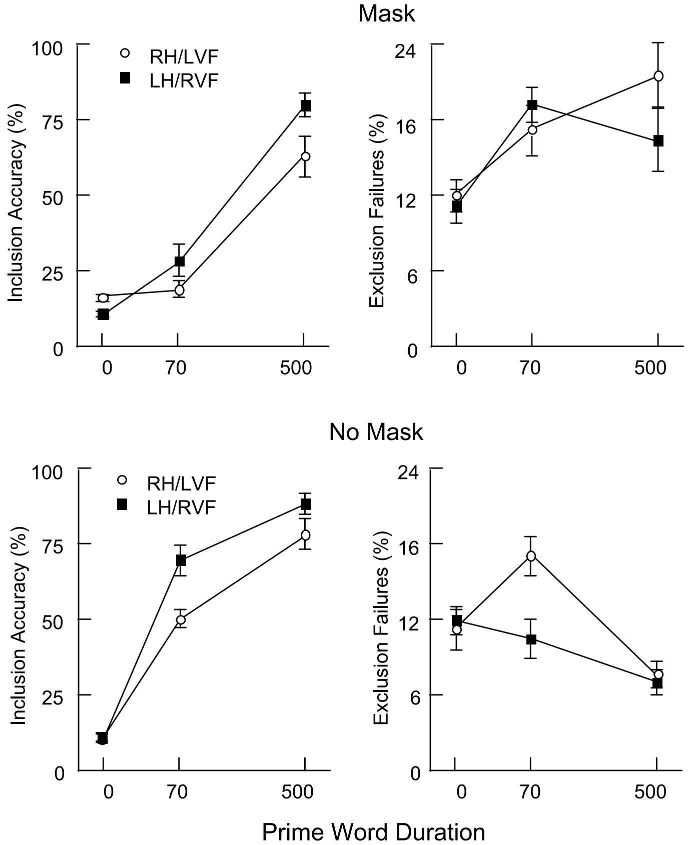

Fig. 2. Results in Experiment 1 for Mask and No Mask Conditions. Mean percentage correct in the inclusion task (left panel). Mean errors in the exclusion task (right panel). LH, left hemisphere; RH, right hemisphere; LVF, left visual field, and RVF, right visual field. Error bars are ±1 SE.

accurately than primes presented to the right hemisphere, $F(1,20) = 24.56$, $p < .001$. As expected, this hemisphere difference only occurred when a word was actually presented, resulting in an interaction of Prime Hemisphere × Prime Duration, $F(2,40) = 12.078$, $p = .001$. Specifically, left hemisphere accuracy was higher than right hemisphere accuracy at 70 ms, $F(1,40) = 28.52$, $p < .001$, and 500 ms, $F(1,40) = 25.04$, $p < .001$, but not at a duration of 0 ms, $F(1,40) < 1$.

Finally, primes were identified with less accuracy when they were masked than when they were not masked, $F(1,20) = 21.93$, $p < .001$, but only for one duration, $F(2,40) = 24.123$, $p < .001$. Specifically, the masking effect was significant for the 70 ms duration, $t(20) = 7.79$, $p < .001$, but not for the 0 or 500 ms durations ($p > .05$).

2.2.2. Exclusion task

Mean percentage errors in excluding the prime word from the stem-completion task is shown in Fig. 2 (right panel). As in the inclusion task, words presented to the left hemisphere were more likely to become consciously available to the participants than prime words presented to the right hemisphere. This was seen in fewer exclusion errors for the left hemisphere. However, this only occurred in two conditions: the 500 ms duration in the Mask condition and the 70 ms durations in the No Mask condition.

The ANOVA for the exclusion task revealed a significant three-way interaction of Masking, Prime Duration, and Prime Hemisphere, $F(2,18) = 4.39$, $p < .03$, in addition to a significant main effect of Mask, $F(1,9) = 9.00$, $p < .02$. To follow up on the three-way interaction, we examined the two masking conditions separately.

Exclusion errors in the Mask condition yielded a marginally significant interaction of Duration $\times$ Prime Hemisphere, $F(2,22) = 3.13$, $p < .06$. There were no significant hemispheric differences at 0 or 70 ms, both Fs < 1, but in the 500 ms duration the right hemisphere showed a higher rate of exclusion errors than the left hemisphere, $F(1,22) = 6.40$, $p < .02$.

Exclusion errors in the No Mask condition also revealed a significant interaction between Duration $\times$ Prime Hemisphere, $F(2,16) = 5.62$, $p < .02$, but of a very different pattern than in the mask condition. There was a greater percentage of exclusion errors for primes presented to the right than left hemisphere only for the 70 ms duration, $F(1,16) = 8.22$, $p < .02$. Hemispheric differences for 0 and 500 ms durations were not significant ($p > .05$).

2.3. Discussion

The results showed that whereas explicit word reading is strongly lateralized, as has been reported previously, the same left hemisphere advantage is not evident when unconscious reading is measured. Rather, errors in the exclusion task showed that the right hemisphere yields as much, and in some conditions even more evidence of unconscious word reading. But we think caution is warranted in interpreting the greater number of exclusion errors made for words presented to the right hemisphere too strongly. Rather than interpreting this as evidence of a greater degree of unconscious processing, we think it is consistent with the idea that words presented to the left hemisphere gain access to conscious awareness more readily. That is, the smaller number of exclusion errors made for left hemisphere words in the Mask-500 ms condition, and the smaller number of exclusion errors made for left hemisphere words in the No Mask-70 ms, likely reflect the ability of words presented to the left hemisphere to emerge more rapidly and accurately into awareness. In any case, the results from the exclusion task reveal a high degree of unconscious reading for words presented to the right hemisphere; the same hemisphere that is considered ‘disadvantaged’ in studies of explicit reading.

An interesting and unexpected implication of Experiment 1 concerns the high degree of unconscious reading that was observed when the long duration primes were masked (Mask-500 ms). Although participants had little trouble excluding primes of this duration in either hemisphere when no mask was presented, masking at these prime durations increased the exclusion failure rate dramatically for words in the right hemisphere. In comparison with previous studies of masked priming, which have presented words with spatial certainty at fixation and have not obtained these high failure rates (Debner & Jacoby, 1994; Merikle et al., 1995; Visser & Merikle, 1999), these results indicate that either the division of attention across space and/or the parafoveal presentation of words makes the period of vulnerability to backward masking that much longer. An important component of this vulnerability to masking is an increase in unconscious priming (Enns & Di Lollo, 2000; Merikle & Joordens, 1997). The low exclusion failure rates for 500 ms in the no mask condition indicate that this result is specific to masking, and not just reflective of participants' inability to follow directions under these display conditions.

3. Experiment 2: Unconsciously read words are shared between hemispheres

Experiment 1 showed clearly that words presented to the right hemisphere are capable of inducing unconscious reading. This raises the question of whether these influences are exclusive to the hemisphere receiving the word, or whether the results are shared between the hemispheres. It has been proposed that the unconscious influences of prime words are limited to the hemisphere receiving the prime and that only consciously mediated words transfer between the hemispheres (Collins, 1999). This view would suggest that in our Experiment 1, unconscious reading of words by the right hemisphere occurred only when that hemisphere also received the word stem. An alternative view is that the verbal word stem completion required in the exclusion task makes the hemisphere receiving the word stem less important, given that the left hemisphere is required to make the verbal response in this task (e.g., Hellige, 1993; Ivry & Robertson, 1998; Springer & Deutsch, 1998).

It was not possible to decide between these alternatives in Experiment 1 because eye movements were not controlled in word stem reading. Stems stayed in view until the participant responded and so eye movements to them were inevitable, even though they were not made to the briefly flashed prime word. In Experiment 2, the word stem was also presented briefly, allowing for a strong test of whether a prime word presented to one hemisphere can prime the completion of a word stem presented to the opposite hemisphere.

3.1. Method

3.1.1. Participants

Eight right-handed university students (6 female) with normal or corrected-to-normal visual acuity participated for course credit or cash ($5/h).

3.1.2. Stimuli and procedure

All participants were given exclusion task instructions. With the exception of word stem duration set at 200 ms, and the stem presented randomly and equally often to the left and right visual fields, the method was identical to the no mask exclusion condition of Experiment 1.

3.2. Results

Mean exclusion errors are shown in Fig. 3. This shows that the same pattern of results was obtained here as in the No Mask exclusion task in Experiment 1. The important finding was that there was no difference in the results depending on which hemisphere received the prime word and the stem. The same pattern was observed for both within and between hemisphere conditions.

This observation was supported by repeated-measures ANOVA including the factors of Prime Hemisphere (left or right), Prime Duration (0, 70, and 500), and Transfer (transfer, or no transfer). The interaction of Prime Hemisphere × Duration, $F(2,14) = 3.63$, $p < .05$, revealed

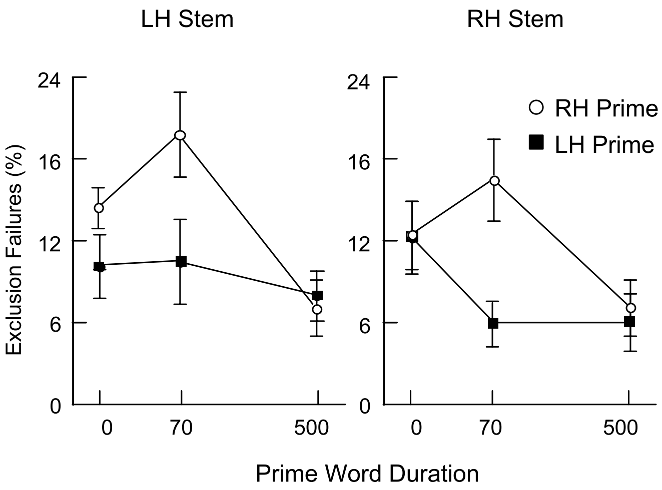

Fig. 3. Results in Experiment 2. Mean errors in the exclusion task separated by hemisphere of prime word and hemisphere of word stem. LH, left hemisphere and RH, right hemisphere. Error bars are ±1 SE.

that more exclusion failures were obtained when the prime was presented to the right hemisphere at 70 ms, $F(1,7) = 10.07$, $p < .01$; but not at 0 ms, $F(1,7) < 1$, or 500 ms, $F(1,7) < 1$.

In addition, the three-way interaction of Prime Hemisphere × Prime Duration × Transfer approached significance, $F(2,14) = 3.32$, $p < .07$, indicating that more exclusion errors were made for right hemisphere primes at 70 ms that were followed by left hemisphere word stems, $F(1,14) = 4.70$, $p < .05$. For the left hemisphere primes, more exclusion errors were obtained when the word stem was also presented to the left hemisphere, $F(1,14) = 5.25$, $p < .04$. However, the level of exclusion errors never exceeded baseline values, making the interaction difficult to interpret. No other effects were significant.

3.3. Discussion

These results indicate that a prime word presented to one hemisphere can prime the completion of a word stem presented to either hemisphere. There was no hint that the unconscious influence of a prime word was limited to the hemisphere receiving the prime (Collins, 1999). If anything, the trend in the data was for greater unconscious reading by the right hemisphere when the subsequent word stem was in the left hemisphere, but this effect was not statistically significant. A conservative interpretation of these data is that unconscious reading of words presented to the right hemisphere was equally available to be used for further processing in both hemispheres.

4. Experiment 3: Word reading by disconnected hemispheres

Experiment 2 indicated that unconsciously read words are shared between the hemispheres in the intact brain of healthy adults. In Experiment 3, we explored whether cortical or subcortical pathways mediate this transfer of information by testing a split-brain participant.

In the literature on cognition in split-brain individuals, the questions of 'what' and 'how much' information is transferred between the hemispheres is controversial. Some studies suggest that very little can be transferred (e.g., Gazzaniga, 1970; Kingstone & Gazzaniga, 1995), whereas others report that much can (e.g., Sergent, 1990). While we cannot resolve all the issues in the present study, it is worth considering whether these differences are linked to the use of explicit versus implicit measures. A study by Cronin-Golomb, Gabrieli, and Keane (1996) suggests that it is. These authors presented split-brain participants with words either in the left or right visual field, prior to a word stem-completion task that was either explicit (as in our inclusion task) or implicit (complete the stem with *any word* that comes to mind).

Cronin-Golomb et al. (1996) reported that implicit priming transferred between the hemispheres in split-brain individuals, but the evidence was far from straightforward. In one participant, prime words shown to the left hemisphere influenced word stems shown to the right hemisphere, whereas in the other participant priming was in the reverse direction. Neither showed symmetrical transfer of priming. Even more puzzling was that one participant demonstrated asymmetrical transfer in the explicit task, but in a direction opposite to their implicit priming effects. It is possible that the limited number of trials tested in the study underlies these unstable patterns.

We revisited this issue by testing a well-studied split-brain patient in both an explicit (inclusion task) and an implicit (exclusion task) measure, as in our Experiment 1.

4.1. Method

Commissurotomy patient JW participated in the study. JW was a 44-year-old right-handed male at the time of testing who suffered from intractable epilepsy for 7 years before his corpus callosum was sectioned surgically in 1979. The completeness of this procedure was verified in Gazzaniga, Holtzman, Deck, and Lee (1985). Both his hemispheres comprehend English in spoken and written form, although speech production is lateralized to his left hemisphere (see Gazzaniga, Nass, Reeves, & Roberts, 1984, for a detailed description of JW).

JW was tested using the same methods as Experiment 1, with two important exceptions. First, although prime words were presented to both of his hemispheres, the word stem was always presented to his left hemisphere, because only that hemisphere has normal speech reporting functions. JW is generally unable to report seeing any visual stimuli presented to his left visual field. Second, we tested only the masked condition, in which participants with intact brains showed unconscious reading of words presented to both hemispheres.

JW was tested on 150 trials in each of the tasks, in order to exhaust our pool of 300 words. He was tested in the exclusion task first in order to examine unconscious reading without the contamination that might occur if he was first asked to report the prime words directly, as in the inclusion task.

4.2. Results

JW's results are shown in Fig. 4 for both tasks. The pattern of correct responses in the inclusion task indicated that he was consciously aware of prime words only when they were presented to the left hemisphere. The pattern of errors in the exclusion task indicated that he was influenced in a

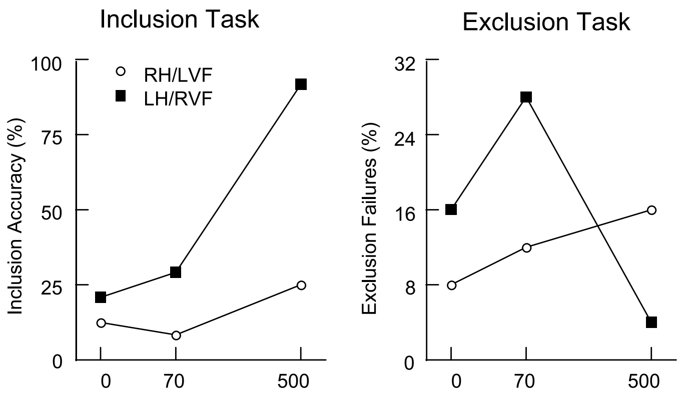

Fig. 4. Results in Experiment 3 for JW in the Mask condition. Mean percentage correct in the inclusion task (left panel). Mean exclusion errors in the exclusion task (right panel). LH, left hemisphere; RH, right hemisphere; LVF, left visual field; and RVF, right visual field. Error bars are ±1 SE.

very similar way as intact participants by the briefly presented prime words, but again only for words presented to the left hemisphere. That is, there was no evidence in either task that words presented and comprehensible by the right hemisphere of JW were accessible to his left hemisphere.

The data from each task were analyzed using the response in each trial as the basic datum. ANOVA for the inclusion task revealed a significant interaction between Prime Hemisphere and Prime Duration, $F(2, 144) = 6.42$, $p < .03$, indicating that left hemisphere primes were included with greater accuracy than right hemisphere primes in both the 70 ms condition, $F(1, 144) = 3.46$, $p < .06$, and the 500 ms condition, $F(1, 144) = 31.15$, $p < .001$. There was no difference in the baseline condition (0 ms), $F(1, 144) < 1, p > 1$. A left hemisphere advantage was obtained overall, as seen in the main effect of Prime Hemisphere, $F(1, 144) = 22.34$, $p < .001$; and in the increase in accuracy with increased Prime Duration for the left hemisphere, $F(1, 144) = 23.40$, $p < .001$.

Exclusion errors revealed that words presented to the left hemisphere resulted in more exclusion errors than those presented to the right hemisphere at the 70 ms duration, $t(144) = 1.64$, $p < .06$ (one-tailed). A similar number of exclusion errors occurred at the other time durations, 0 ms, $t(144) < 1$; 500 ms, $t(144) = 1.23$. The interaction between Prime Hemisphere and Prime Duration approached significance, $F(1, 144) = 2.18$, $p < .12$.

4.3. Discussion

Although it is well known that JW's right hemisphere can process the words used in the present study (Gazzaniga et al., 1984), the results demonstrate that his left hemisphere was isolated from their meaning for explicit report (inclusion task) and unconscious reading (exclusion task). These results dovetail with a series of recent demonstrations that word meaning cannot be transferred between the disconnected hemispheres either consciously or unconsciously (Kingstone & Gazzaniga, 1995; Miller & Kingstone, in press; Seymour, Reuter-Lorenz, & Gazzaniga, 1994). Thus, we can conclude with confidence that the transfer of word meaning observed with intact individuals in the previous experiment was mediated cortically via the corpus callosum.

5. General discussion

This study began by asking whether the left hemisphere advantage for word reading applies equally well to explicit and implicit measures of word processing. To make this comparison as similar as possible for both measures, we presented participants in Experiment 1 with the same split-field word displays in two tasks: an inclusion task that indexed the combined effects of unconscious and conscious reading processes, and an exclusion task that indexed only unconscious processes.

The results for the inclusion task were very clear. In keeping with many previous studies, we observed a strong left hemisphere advantage for explicit word reading in both masked prime and unmasked prime conditions. The results for the exclusion task were equally clear, although their full interpretation involved several steps. First, errors in the exclusion task indicated that the right hemisphere yielded strong evidence of unconscious reading of the prime words. This indicates that words presented to this hemisphere are processed even though they may not be consciously accessible. Second, exclusion errors for words presented to the right hemisphere were even greater in some conditions (i.e., Mask-500 ms, No Mask-70 ms) than exclusion errors for words presented to the left hemisphere. But we are not willing to interpret this finding in support of an "advantage" for unconscious processing of words presented to the right hemisphere. Instead, we propose that this finding indicates that words presented to the left hemisphere gain access to conscious awareness more readily.

The hypothesis that the left and right hemispheres differ primarily in the speed with which words are brought to consciousness is supported by re-plotting the exclusion failure data from Experiment 1, as shown in Fig. 5. In this graph, an attempt has been made to order the conditions

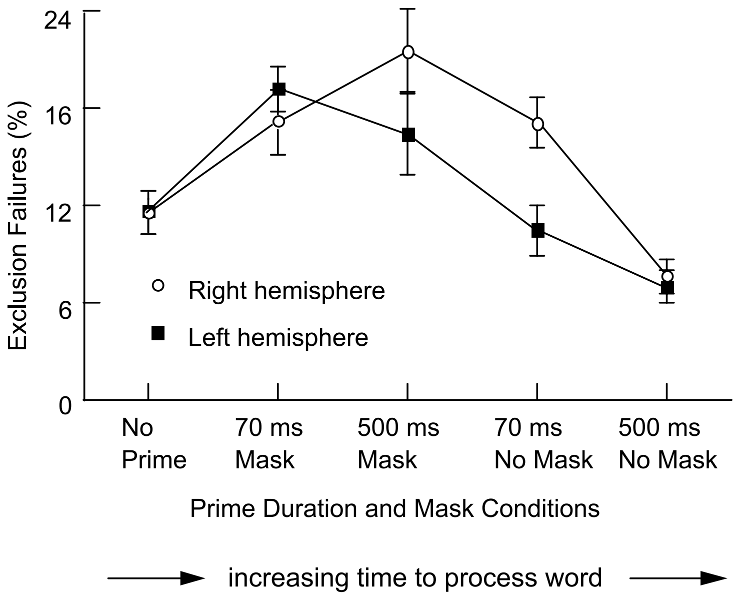

Fig. 5. Mean errors in the exclusion task in Experiment 1, with the conditions ordered approximately with regard to the amount of time that is made available for the prime words to be processed.

with respect to the time that is made available for the prime words to be processed. Admittedly, the specific ordering of two of them (i.e, 500 ms-Mask and the 70 ms-No Mask condition) is somewhat arbitrary, as it is unknown how masks and exposure duration interact under these conditions, but, even as a first approximation, the graph is instructive. It shows that exclusion failures rise, peak, and fall to similar levels in the two hemispheres, but that the left hemisphere do so in a shorter time period than does the right hemisphere.

This shorter period of inaccessibility to consciousness for words presented to the left hemisphere means there is less opportunity to unconsciously influence word stem completion. This is because participants are instructed to select words in the stem-completion task *other than* those they have detected in the prime. When they become aware of the prime words presented to left hemisphere, they are less likely to use them to complete the word stem. Therefore, from the exclusion task we can conclude that the right hemisphere shows as much evidence of reading words unconsciously as does the left hemisphere. Thus the 'classic' left hemisphere advantage in word reading is likely only an advantage of conscious access to words presented to that hemisphere.

We next asked whether the unconscious reading of words presented to either hemisphere had an equal influence on the completion of word stems presented to the same or opposite hemisphere. The results in Experiment 2 were again very clear. Although unconscious reading was ostensibly stronger for words presented to the right hemisphere (replicating Experiment 1), the influence of these words on a stem-completion task was equal for word stems presented briefly to either hemisphere. There was no evidence that the within hemisphere influence was stronger than the between hemisphere influence, as has been suggested previously (Collins, 1999).

Finally, we asked whether it was possible for words presented to the right hemisphere to unconsciously influence the completion of word stems presented to the left hemisphere, in an individual who has had his hemispheres surgically disconnected. Transfer of word meaning between the hemispheres under these conditions would imply a subcortical route. The results in Experiment 3 were clear in showing no evidence of such subcortical transfer. This implies that the hemisphere transfer of meaning we observed for healthy participants in Experiment 2 was occurring through cortical pathways.

Taken together, the picture that emerges from these findings is, first, that the two hemispheres may have more similarity in their word reading processes than has been previously acknowledged. Second, the two hemispheres appear to share their results more symmetrically via cortical communication than has previously been thought. Finally, the present findings point to the possibility that one realm in which the hemispheres are likely to differ from one another is in the efficiency with which they are able to make these results available for conscious awareness and report. We offer this as a tentative proposal that emerges from the present experiments, but one that will require additional research in order to fully accepted or modified further.

One important question that follows from this proposal is whether the greater efficiency with which words presented to the left hemisphere become conscious is due to the specifically faster and more accurate *word processing* of the left hemisphere, or whether it is due to the generally more efficient way in which *all visual stimuli* processed by left hemisphere reach conscious awareness. Support for a more general left hemisphere advantage in visual awareness can be found in studies showing that stimuli presented to the right visual field are less vulnerable to backward visual masking (Aharonovich, 1997; Nicholls & Cooper, 1991), and in studies showing a smaller cost incurred by invalid spatial cues in the right visual field (Mondor & Bryden, 1992; Nicholls &

Wood, 1998). This issue clearly deserves a more careful and systematic analysis than has been given it to date.

In summary, this study has shown that the unconscious reading of words occurs for words presented to both the left and right hemispheres and that the results of these processes are shared between the hemispheres, provided that the corpus callosum is intact. It also strongly suggests that the well-known left hemisphere advantage in explicit word reading tasks may reflect either a specific advantage for words, or a general advantage for all visual stimuli, in the efficiency with which the results of processing can gain access to conscious awareness.

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