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Sentence and Word Outline Shape as Co-primes for Target Words Presented to the Two Visual Hemifields

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A lexical decision experiment tested visual field stimulation of word targets after priming the central visual field by the target word outline shape and/or an incomplete sentence. In general, RT was shorter and accuracy better for target words presented to the RVF. Responses were quicker and more accurate to target words presented to either visual hemifield after priming by either a congruent incomplete sentence or a congruent word outline shape (WOS). However, the joint effect of WOS and an incomplete sentence as co-primes was different when the succeeding word target appeared in the RVF than when it appeared in the LVF. While a congruent WOS and incomplete sentence acting as co-primes reduced RT to LVF targets orthogonally, the two variables operated interactively as co-primes on target words presented to the RVF.

Key Words: lexical decision; word outline shape; sentence priming; cerebral asymmetries; visual hemifields.

The role of the two hemispheres in accessing words from the lexicon when primed by linguistic or nonlinguistic stimuli has been the focus of interest in the last two decades (for reviews, see Chiarello, 1991, 1998; Faust, 1998). The present paper reports an experiment using the lexical decision task combined with visual hemifield stimulation after priming the central visual field by the target word outline shape and a congruent incomplete sentence. Both word outline shape (WOS) and incomplete sentences have been shown to affect word recognition, but their roles may be quite different.

WOS is an important variable in processing familiar words (Haber & Haber, 1981a, b; Haber, Haber, & Furlin, 1983; Healy & Cunningham, 1992;

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Moravcsik & Healy, 1998). When an envelope is drawn around the outline of a word, different words have characteristic shapes and lengths, as a result of the ascending, descending, and box-like letters (Walker, 1987). Some researchers have suggested that participants tolerate misspellings involving missing letters as long as the WOS is maintained (Healy, Volbrecht, & Nye, 1983). With a very high level of expectancy or redundancy, the outline shape of a word along may even reduce the alternative choices to one particular word, without any of the letters being identified (Haber et al., 1983). Some authors, however, have claimed that skilled readers ignore word shape when recognizing a word (Paap, Newsome, & Noel, 1984) or question the extent to which orthographic information plays a role in foveal and parafoveal vision (for reviews, see Balota & Rayner, 1991; Bruhl & Inhoff, 1995).

Several authors over the past two decades have advanced the hypothesis that word outline shape, together with other cues, such as sentence contexts, can serve to enhance word recognition during reading (e.g., Haber et al., 1983; Healy & Cunningham, 1992). Several researchers speculated that the word shape cue would operate effectively only within context (Paap et al., 1984). Walker (1987) also argued that although WOS by itself is rarely sufficient to uniquely identify a word, its potential may be enhanced considerably when it is combined with knowledge of other contextual cues, as happens in real life reading situations. It is, therefore, important to consider the contribution of WOS to word recognition in conjunction with other linguistic cues, such as the semantic and syntactic information contained in priming sentences (Healy & Cunningham, 1992).

Sentence context was first demonstrated to facilitate the recognition of target words in a lexical decision task by Shuberth and Eimas (1977; for review, see Harley, 1995). A priming sentence can be effective even though there is no semantic relationship between the words in the sentence and the target word (Harley, 1995). Incomplete sentences, with a high level of constraint, can serve as very potent cues in the recognition of target words (e.g., Schwanenflugel & Shoben, 1985). Responses can be speeded up if the target word is a highly predictable continuation of the sentence and provides a clear unambiguous ending (Harley, 1995).

Recent research on linguistic processing, using the lexical decision task and hemifield stimulation, has shown that the two cerebral hemispheres are differentially sensitive to priming by incomplete sentences. While priming by single words seems to be effective for target words presented to either visual field (Chiarello, 1991, 1998), sentence priming is much more effective for target words presented to the right visual field (left hemisphere; RVF, LH) than for word targets presented to the left visual field (right hemisphere; LVF, RH) (see, e.g., Faust, Babkoff, & Kravetz, 1995; Faust & Kravetz, 1998). The results have been interpreted as showing that the two hemispheres utilize the information contained in the priming sentences in a different manner. While the LH is able to process the message level information of the sentence and use it for target word recognition, the RH is only able to utilize the semantic relations between the single words appearing in the sentence and the target word. Consequently, sentence priming effects are much more pronounced with RVF stimulation (for review, see Faust, 1998).

Although, as noted, differential hemispheric use of sentence context for target word recognition has been empirically shown, no direct evidence has been reported on differential processing of WOS by the two hemispheres. WOS, by definition, is a visuo-spatial stimulus and, therefore, may be processed more as a ''shape'' than a ''word.'' This may involve more RH- than LH- effective mechanisms. However, the priming component of the WOS which also involves its meaning and learned association may also weigh its processing more toward that of a linguistic stimulus. It is therefore not a trivial question as to whether word shape is processed differently by the two hemispheres, when used as a prime to aid in the detection or recognition of words (for discussion, see, e.g., Marsolek, Kosslyn, & Squire, 1992). Glaser and Vandemark (1983) compared aphasic patients and normal participants on the matching of words to their envelope shape. They reported that the performance of the aphasics was very similar to that of the normals and concluded that word shape processing could be performed by an intact RH.

The purpose of the present experiment was to test differential hemispheric processing of word outline shape on the discrimination of target words in a lexical decision paradigm. As noted, there is evidence that WOS reduces recognition time. However, there is some controversy as to whether WOS only operates together with other contextual cues or can operate independently (e.g., Walker, 1987). The design of the present experiment, therefore, included a condition in which word shape was used as a single prime (following a neutral sentence) as well as a condition in which the word shape was used cojointly with a congruent, high constraint, sentence as part of a multiple prime. In the latter case, both sentence and word shape served as joint primes to the succeeding target stimulus. In all cases, the primes were presented to the central visual field and the target stimuli were randomly presented either to the RVF or LVF.

METHOD

Participants

Forty-one Bar-Ilan University students (21 females), aged 21–30, participated in the experiment. All participants were native Hebrew speakers and yielded a laterality quotient of at least +80 on the Edinburgh Inventory, indicating right-handedness (Oldfield, 1971). All had normal or corrected to normal vision. Each participant received the equivalent of $6.00 in Israeli currency for his/her participation. Two participants were not included in the final analyses because their level of accuracy in all conditions was extremely low (~60%), more than two standard deviations below the average level of accuracy. Thus, the final results are based on 39 participants.

Stimuli

The stimulus pool consisted of both target and priming stimuli, all in Hebrew. Hebrew has 22 mid-word letters and 5 terminal-word letters. Of the 27, six letters extend vertically when printed, either above or below the midline. A seventh letter is shorter than all of the others. Thus, word outline shape can, theoretically, serve as a significant prime for Hebrew words. The target stimuli were 150 four- to five-letter words and 150 nonwords. The nonwords were constructed by changing one letter of the target word and were all orthographically possible and pronounceable. Priming stimuli consisted of two types of sentences and WOSs: (a) congruent to the target stimuli and (b) neutral. There were, thus, four priming conditions: (1) neutral priming sentence and neutral WOS, (2) congruent priming sentence and neutral WOS, (3) neutral priming sentence and congruent WOS, and (4) congruent priming sentence and congruent WOS.

Priming sentences. There were 150 different incomplete congruent sentences of 4–5 words each. The target stimuli completed the congruent sentences, rationally. The cloze procedure (see, e.g., Faust & Kravetz, 1998; Schwanenflugel & Shoben, 1985) was used to determine prime-target congruency. Twenty five judges, who did not participate in the experiment, were asked to complete 200 incomplete sentences with three reasonable endings. A word that was chosen by at least 80% of the judges as a completion to the sentence was defined as a target congruent to that sentence. At the end of this procedure, 150 sentences were chosen. For the neutral condition the following sentence was used: ‘‘The next word is. . . .’’

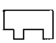
Priming word shapes. Word outline shapes were the envelopes drawn around the outline of the Hebrew target words. There were 150 priming WOSs which were presented after either the congruent sentence or the neutral sentence, prior to the presentation of the target word or nonword. ‘‘xxx’’ was used as the neutral WOS which preceded each target word and nonword and served as a baseline priming condition. It is difficult to find an appropriate ‘‘control’’ for WOS comparable to the neutral sentence used as a control for the congruent sentence because any shape can represent a possible target. We, therefore, chose to use ‘‘xxx’’ as a neutral control for WOS rather than a noncongruent shape such as three boxes. The latter would not be ‘‘neutral’’ but rather misleading since it could well reflect another Hebrew word composed of letters which do not extend beyond the midline. In fact, the results of a pilot study indicated that participants were misled by the use of such a word outline shape.

An experiment consisted of 300 trials. Each participant was exposed to the same target word and nonword only *once.* Each of the four combinations of sentence and WOS was presented to each participant 75 times, followed by a word or nonword target to the RVF or LVF. For example, if the target word was ‘‘circus’’ and the corresponding target nonword was ‘‘cincus’’ then the following four prime-target combinations appeared for the target word and, again, for the target nonword:

Congruent sentence/congruent word shape/word—‘‘The clown amused the crowd in the’’/word shape/*circus.*

Congruent sentence/neutral word shape/word—‘‘The clown amused the crowd in the’’ /xxx/*circus*

Neutral sentence/congruent word shape/word—‘‘The next word is’’/word shape/ *circus*

Neutral sentence/neutral word shape/word—‘‘The next word is’’ /xxx/ *circus* The Hebrew word for ‘‘circus’’ is ‘‘קרקס’’ and thus the word shape used for the above sentence is .

Procedure

There were 2400 experimental permutations [150 priming sentences × type of priming sentence (congruent/neutral) × type of WOS (congruent/neutral) × visual field (right/left)

× lexicality (word/nonword)]. Each participant completed one experimental session, during which he/she was exposed to all experimental conditions. As noted above, to reduce repetition, each of the targets was rotated over priming sentences and visual fields and across participants, such that a given target stimulus was seen only once by each participant. Eight lists, each containing 300 target stimuli, were needed to completely rotate items over experimental conditions in the full experimental design. The lists were constructed so that the exposure of participants to a companion target word or nonword previously encountered during the experiment could only occur, by design, after 150 trials. If the participant received ''cincus'' as a nonword target, the target word ''circus'' would not appear for another 150 trials. For each list, all sets of experimental conditions were counterbalanced. Each participant was exposed to one list only. Thus, cell means (WOS × priming sentence × lexicality × visual field) were based on 18–19 trials per condition per participant. Stimulus presentation and responses were controlled and recorded by a PC Elite 486 computer.

The incomplete priming sentences were presented to the central visual field in their entirety, followed by the WOS, also centrally presented. The inner edge of the target stimulus was presented 2° to the right or to the left of a centrally presented ''+''. Targets subtended, on the average, 1.90° of horizontal visual angle (0.7° vertical) at a viewing distance of 60 cm. Participants viewed the screen with their right eye only (left eye covered, see Babkoff & Faust, 1988) while resting their head on a chin rest.

The participant placed his/her right index finger on the middle key of the computer mouse and waited for a focusing signal (300 ms) which appeared on the center of the screen and indicated the onset of a trial. Immediately following the disappearance of the focusing signal, the prime sentence appeared for 1000 ms. Next, the focusing signal reappeared for 200 ms, followed by the second prime, the word shape, which appeared for 400 ms. Then, the focusing signal reappeared and remained on the screen for 440 ms, until the end of the target stimulus presentation, to ensure full fixation. Three hundred milliseconds after the appearance of the focusing signal, the target stimulus was presented randomly to the RVF or LVF for 140 ms. The participant was instructed at the beginning of the session to focus on the central ''+'' and not to move his/her eye while it was present.

Participants were asked to indicate as rapidly and accurately as possible whether the target stimulus was a word or a nonword by lifting and moving the right index finger from the middle mouse key to the right or left mouse keys. Assignment of the keys to word/nonword responses was counterbalanced over participants. The next trial began when a response was made or, in the case of no response, after 5 s from target onset. The session began with a practice list, consisting of 40 priming sentences, word shapes, and target stimuli not used in the experimental lists.

RESULTS

Three-way analyses of variance with visual field (right/left), type of priming sentence (congruent/neutral), and WOS (congruent/neutral) were performed on accuracy and correct reaction times (RTs) for the target words. Only responses whose RTs ranged between 200 and 1600 ms (95% of all of the responses)[1] were included in the analyses.

Mean RT to target words presented to the RVF and LVF following congru-

[1] Responses less than 200 ms after stimulus onset were considered ''anticipations.'' RTs longer than 1600 ms are not representative of the distributions as they are more than 2 SDs longer than mean RT to any of the experimental conditions.

TABLE 1
Mean RT (ms) and SD for Target Words Presented to the RVF and LVF Following Congruent and Neutral Incomplete Sentences and Congruent or Neutral Word Outline Shapes

	Right visual field		Left visual field	
	Congruent word outline shape	Neutral word outline shape	Congruent word outline shape	Neutral word outline shape
Congruent sentence	722 (124)	741 (120)	747 (107)	796 (106)
Neutral sentence	804 (123)	870 (135)	825 (110)	861 (124)

ent and neutral priming sentences and WOSs is shown in Table 1. Several main effects and one first-order interaction were significant. In general, responses were quicker and more accurate to RVF (793 ms, 88.1%) than to LVF (815 ms, 83.2%) targets. This difference was statistically significant for RT [$F(1, 38) = 7.92$, $p < .01$], and marginally significant for accuracy [$F(1, 38) = 3.4$, $p < .07$]. Responses were also quicker and more accurate to target words following a congruent priming sentence (760 ms, 90.9%) than those following a neutral sentence (849 ms, 82.1%) [$F(1, 38) = 24.7$, $p < .001$ and $F(1, 38) = 34.1$, $p < .001$ for RT and accuracy, respectively]. The main effect of type of WOS was also significant for both RT [$F(1, 38) = 55.3$, $p < .001$] and accuracy [$F(1, 38) = 30.6$, $p < .001$]. Responses were quicker and more accurate to target words following a congruent WOS (781 ms, 89.6%) than a neutral WOS (827 ms, 83.6%).

The interaction between visual field and type of priming sentence was significant for RT [$F(1, 38) = 5.6$, $p < .05$]. Post hoc analyses revealed that participants responded more quickly to RVF than to LVF presented targets when they followed a congruent priming sentence (40 ms, Duncan test, $p < .05$). However, there was no difference in RT between RVF and LVF presented target words when they followed a neutral priming sentence (14 ms, NS).

RT was not significantly correlated either with accuracy or with d' ($r = -.06$, NS).

If the main hypothesis of the present study is valid, a statistically significant three-way interaction among visual field, type of priming sentence, and WOS would be expected. This interaction was obtained for RT [$F(1, 38) = 7.04$, $p < .02$]. In the following analysis of the three-way interaction, we estimate the improvement in response speed (reduction in RT) under the various priming conditions by comparing RT under each of the conditions with RT to targets when preceded by a neutral WOS and a neutral sentence. The reduction in RT to RVF and LVF targets under the various congruent priming conditions is shown in Fig. 1. When a target word was presented to the RVF after priming by a congruent WOS and incomplete sentence, RT

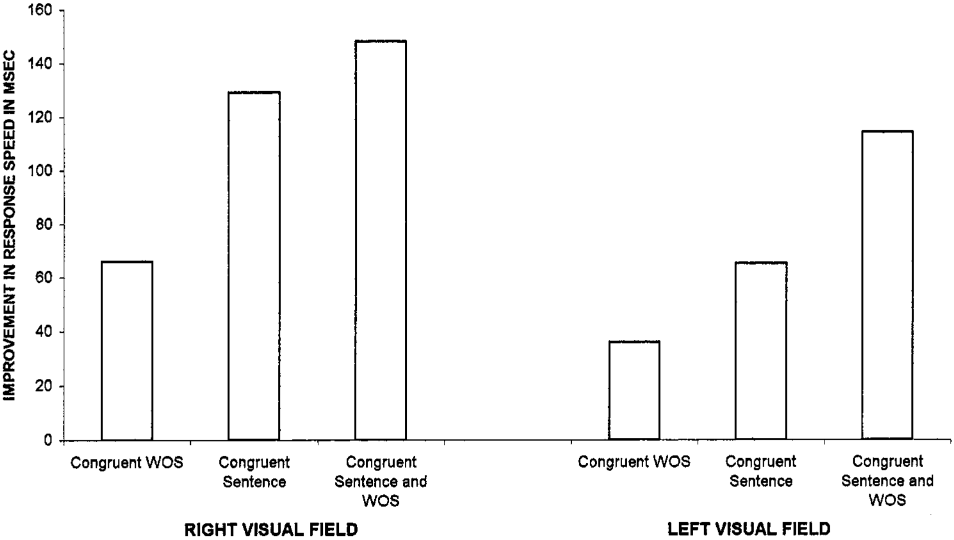


FIG. 1. Improvement in response speed (in ms) with priming by congruent WOS and neutral or congruent sentence. Data for right and left visual fields (RVF, LVF) are shown separately.

was decreased by 148 ms relative to the RT to a RVF target after a neutral sentence prime and a neutral WOS. For the comparable LVF presentation by a target word, the decrease in RT was 114 ms [Fig. 1, Table 2, ($t(39) = 2.04$, $p < .048$)]. Post hoc analyses revealed that participants responded more quickly to a RVF target following a congruent WOS than following a neutral WOS, whether preceded by a congruent or a neutral priming sentence (Duncan, $p < .05$). However, the effect of a congruent WOS in improving response speed (i.e., in reducing RT) to a RVF target word was significantly less when a congruent sentence was the co-prime than when a neutral sen-

TABLE 2

Improvement in Speed of Response for Target Words Presented to the RVF and LVF Preceded by Congruent Word Outline Shape and Congruent Sentence Relative to Targets Preceded by Neutral Word Outline Shape and Neutral Sentence

		RVF	LVF
Facilitation in ms of word outline shape and sentence as co-primes		148	114
Percentage improvement in response speed	Word outline shape prime	45%	32%
	Sentence prime	89%	56%
	Word outline shape and sentence as co-primes	100%	100%

tence was the co-prime (Fig. 1 and Table 1; 18 ms versus 66 ms, respectively, $t(38) = 10.17$, $p < .01$). For LVF word targets, responses were quicker and more accurate following a congruent WOS than following a neutral WOS (Duncan, $p < .05$). The effect of a congruent WOS in reducing RT to LVF targets was the same whether a congruent or neutral sentence was the co-prime (Fig. 1 and Table 1; 50 ms versus 37 ms, respectively, $t(38) = 1.4$, NS).

In order to examine the pattern of processing target words when preceded by WOS and priming sentences, RT was analyzed by regression analysis for RVF and LVF targets separately. For RVF target words, both priming sentence and WOS had a significant impact on RT ($\beta = -.3674$, $t = -14.981$, $p < .001$; and $\beta = -.1378$, $t = -5.709$, $p < .001$). In addition, there was a significant interaction between type of priming sentence and WOS ($\beta = -.0734$, $t = -3.148$, $p < .02$). Similarly, for LVF target words, both priming sentence and WOS impacted significantly on RT ($\beta = -.2654$, $t = -11.201$, $p < .001$; and $\beta = -.1445$, $t = -5.732$, $p < .001$). However, for LVF targets, the interaction was not significant ($\beta = -.0023$, $t = -.101$, NS). Also, note that the effect of a priming sentence on RVF targets is greater than on LVF targets ($\beta = -.3674$ vs $\beta = -.2654$), but the effect of WOS on targets in either visual hemifield is very similar.

DISCUSSION

All of the main effects were significant and support the findings reported in the literature. RT was shorter and accuracy better to word targets presented to the RVF-LH than to the LVF-RH. RT was shorter and accuracy better to target words presented after a congruent incomplete sentence as compared to a neutral sentence and after a congruent word outline shape as compared to a neutral WOS. RVF superiority was more pronounced when the target words followed a congruent sentence than a neutral sentence (Faust, 1998; Faust & Kravetz, 1998). The effect of WOS is very similar whether the succeeding target appears in either the RVF or the LVF. However, the effect of a congruent sentence prime is greater when the succeeding target appears in the RVF than in the LVF.

These findings support the argument that the LH is superior to the RH in processing the linguistic information contained in priming sentences. The results also indicate that both hemispheres can process the information available in a congruent WOS to aid as a cue in a lexical decision. However, further examination of the results suggests that although both hemispheres are capable of utilizing WOS, they may not operate by the same mechanisms. The joint effect of congruent WOS and a congruent, high constraining sentence as co-primes is different when the succeeding target word is presented to the RVF than when it is presented to the LVF, as shown by the significant three-way interaction.

To explain the three-way interaction, we will assume that the comparable reductions in RT reflect the maximum possible improvement in speed of performance when each of the two hemispheres is primed by a congruent sentence and WOS. Table 2 presents the findings in terms of improvement in response speed under the different experimental conditions. In an absolute sense, the improvement in response speed found when both an incomplete sentence and a WOS served as co-primes was always greater when the succeeding target was presented to the RVF (148 ms vs 114 ms). In addition, the improvement in response speed found when either WOS or an incomplete sentence alone served as a prime was also greater when the succeeding target was presented to the RVF. However, there was a difference in the effect size. When a RVF-presented target was preceded by a congruent WOS there was a 45% improvement in response speed as compared to a 32% improvement in RT to an LVF-presented word target. When preceded by a congruent sentence, however, the improvement in response speed for RVF-presented targets was 89%; whereas the improvement for LVF-presented targets was only 56%. Assuming, as we did above, that the maximum improvement found when a target was preceded both by an incomplete sentence and by WOS as co-primes represents the limitation of the word processing available in each of the two hemispheres, or the ‘‘ceiling’’ in improvement, we argue that there is more room for improvement left for LVF-presented word targets when preceded by a congruent sentence prime than there is for comparable RVF-presented targets. In other words, since the LH is much superior in utilizing the sentence level information, there is less room left for improvement when the outline shape also precedes the target word. Thus, in the presence of a congruent priming sentence, WOS can contribute ‘‘relatively’’ more to a further improvement in response speed for LVF targets than for RVF targets. This explanation implies that in situations where only the right hemisphere sentence information processing is available, the ability to discriminate words may be enhanced greatly by the additional use of word outline shapes.

We conclude that although there may be a very large difference in the processing of sentence information by the two hemispheres (see, e.g., Faust, 1998; Faust and Chiarello, 1998), there is a smaller difference in the processing of WOS by the two hemispheres. Nevertheless, we suggest that the processing of WOS information may differ in the two cerebral hemispheres.

There has been some discussion in the literature regarding visual form representations in the left and right hemispheres. Researchers have suggested that there are two separate computational systems for the encoding of visual word forms (Marsolek, 1995; Marsolek et al., 1992). These authors argue that feedback from semantic and other postvisual subsystems is used when an abstract visual form subsystem learns to classify different shapes as belonging to the same category, allowing for abstracted word shape identification (Marsolek, 1995). Following this line of reasoning, we suggest that the representational system that uses form-specific information differs from the system that uses abstract form information. Thus, the brain can encode visual word forms in either one of the two ways. The mechanism that represents form-specific information is dedicated to distinguishing between different forms. The output from such a mechanism would emphasize the fit of the perceived word shape to stored shapes. This mechanism may operate more effectively in the RH. The mechanism that represents abstract form is dedicated to specify the identity of the word or letter cluster and their arrangement. Although processing only visual information, the output from such a mechanism can also categorize visual forms in light of feedback from semantic and other postvisual subsystems. This mechanism may operate more effectively in the LH. Since the computations performed by each system are incompatible with each other, they may, therefore, be preferred differentially by the different neural systems, one in the RH and the other in the LH.

The difference between the effect of word shapes and congruent sentences as joint co-primes on the RT to the following word target appearing in the RVF and LVF may be understood in light of the previous discussion. We suggest that the RH utilizes the form-specific mechanism to identify word shape. Thus the output available may be indifferent to the semantic processing, but rather be affected by the extent to which the word outline shape prime fits the envelope of the target word. With regard to the information in the priming sentence, previous research (Faust, 1998) has shown that the RH uses the semantic relations between individual words in the priming sentence and the target word to aid in word recognition. The two sources of information differ, one is a visuo-spatial system while the other is lexico-semantic (Faust, 1998). Consequently, the two sources of information in the RH are orthogonal to each other.

In the LH, on the other hand, WOS information may be processed and stored in an abstract and nonspecific manner and, thus, be affected by semantic and other postvisual subsystems. Thefore, we suggest that the output of the system processing WOS in the LH emphasizes the meaning content of the word outline shape and *interacts* with semantic subsystems. The available evidence seems to indicate that the LH is able to build a conceptual representation of the meaning of the priming sentence and process it at the message level (Faust, 1998). It is possible that, in contrast to the RH, the two sources of information, word shape identification and the processing of the priming sentence, interact in the LH because they both may have access to meaning-based subsystems.

The finding that both hemispheres can utilize WOS in the recognition of words is also of interest when considering the information available from parafoveal scanning during normal reading. The reader of English text obtains coarse textual information during reading by scanning to the right (RVF), while the reader of Hebrew text scans to the left (LVF) (Pollatsek, Bolozky, Well, & Rayner, 1981). The present findings imply that WOS information can be utilized by both readers. However, it is not yet clear whether the reader of English uses the same mechanisms as the Hebrew reader during parafoveal scanning. Further research is necessary to determine whether the two readers utilize this information to the same extent and whether they both extract the same or different kinds of information from the WOS, scanned by the different visual fields.

It is quite possible that certain circumstances or tasks would be more advantageous to one of the mechanisms than the other, thus, yielding seeming superiority to one hemisphere over the other. Future research will test the processing of WOS by the two hemispheres with a variety of linguistic contexts, such as single word primes, scrambled sentences, and incomplete sentences with different levels of constraint to examine the interaction between visuo-spatial and verbal mechanisms. In the present experiment, we examined a relatively long SOA (700 ms) which allowed for strategic use of the primes. In future research, shorter SOAs will be used to examine their effectiveness under more automatic priming conditions. In addition, since visual information from the parafovea is important in reading (e.g., Balota & Rayner, 1991), we are also investigating the combination of priming sentences presented to the central visual field combined with parafoveal presentation of word outline shapes as co-primes in a lateralized lexical decision task.

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