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A comparison of upper vs. lower and right vs. left visual fields using lexical decision

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A series of experiments using the lexical decision task was conducted in order to investigate the functional differences between the upper and lower visual fields (UVF, LoVF) in word recognition. Word–nonword discrimination was swifter and more accurate for word stimuli presented in the UVF. Changing the eccentricity did not affect the UVF advantage over the LoVF. UVF superiority over LoVF was found to be equivalent for both right and left visual hemifield (RVF, LVF). In general, presenting related word primes enhanced all visual field differences in a similar manner (UVF over LoVF and RVF over LVF). However, primes consisting of semantically constraining sentences enhanced the RVF advantage over the LVF, but did not affect the UVF and LoVF differentially. The argument is made that UVF superiority cannot be due to perceptual or attentional differences alone, but must also reflect top-down information flow.

Almost 50 years ago, Mishkin and Forgays (1952) published a seminal study that commenced the investigation of visual field differences in word recognition. They reported that words presented to the right visual field (RVF) were recognized more accurately than those presented to the left visual field (LVF), a phenomenon that has been vastly explored since then. Mishkin and Forgays also reported differences between the upper and lower visual fields (UVF and LoVF, respectively), but this phenomenon has been generally ignored in the scientific literature.

The ubiquitous finding in the literature is that responses to words are faster and more accurate when presented to the RVF than when presented to the LVF. The RVF advantage is reported much more often for words but less often for nonwords (Chiarello,1985, 1988). The RVF advantage can be enhanced by semantic and linguistic priming (Burgess & Simpson, 1988; Chiarello, 1985; Faust & Kravetz, 1998). The purpose of the present study was to investigate and clarify differences in word/nonword discrimination between the UVF and LoVF and compare them to the oft-reported RVF–LVF asymmetry.

There are several reasons for expecting differences between the UVF and the LoVF in word/nonword discriminations. The various parts of the visual field are mapped in anatomically separated portions of the visual cortex. The left and right hemifields are represented each

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at the contralateral hemisphere. Within each hemisphere, the UVF and LoVF mappings are separated by the calcarine fissure. The lower part of the visual field is represented above the fissure in V1, whereas the upper part is represented below the fissure. Accordingly, the extrastriate mapping of the visual field is split; the LoVF is represented dorsally and the UVF ventrally, separated by V1 (Felleman & VanEssen, 1991; Horton & Hoyt, 1991; Sereno et al., 1995).

Some functional differences between the UVF and the LoVF have been reported. Simple reaction times are swifter to targets in the LoVF (Payne, 1967), but this is probably limited to low-spatial-frequency stimuli (Cocito, Favale, & Tartaglione, 1977). Luminance thresholds are lower in the LoVF periphery (Riopele & Bevan, 1952; Sloan, 1947), which may be related to the higher receptor densities in the upper hemiretina from 10° eccentricity on (Van Buren, 1963; Skrandies, 1987). Contrast thresholds are lower for LoVF for low-spatial-frequency gratings (Lundh, Lennerstrand, & Derefeldt, 1983; Rijskijk, Kroon, & van der Wildt, 1980). Pursuit eye movements are better in the LoVF (Tychsen & Lisberger, 1986), but there is a UVF advantage in saccadic eye movements, especially at greater eccentricities (Heywood & Churcher, 1980). Also, the detection of random-dot stereograms is faster in the LoVF for convergent (near) disparities, but faster in the UVF for divergent (far) disparities (Julesz, Breitmeyer, & Kropfl, 1976).

With these differences in mind, Previc (1990) suggested that the anatomical segregation promoted the functional specialization of UVF and LoVF for different types of visual processing, which was ecologically convenient. Typically, objects closer to the observer appear lower in the visual field, and distant objects are seen above the horizon, thus the LoVF and UVF became specialized for near and far vision, respectively. The type of visual processing of each hemifield was therefore adapted to the task that it usually performed. The principal task in LoVF is the perception and manipulation of objects in the peripersonal space, which require visuomotor coordination and spatial and stereomotion perceptual capabilities. Stimuli appearing in the LoVF are usually blurred and in motion, thus the LoVF became specialized for global and low-spatial-frequency processing. In contrast, far vision involves visual search tasks with object recognition as the goal. Object recognition requires the discrimination of fine details, hence the UVF specialized in high-spatial-frequency and local processing.

The specialization of the UVF and LoVF is in agreement, according to Previc (1990), with the functional segregation of the dorsal (occipito-parietal) and ventral (occipito-temporal) visual cortical pathways (Maunsell & Newsome, 1987; Ungerleider & Mishkin, 1982; Van Essen & Maunsell, 1983), the dorsal stream processing spatial relations and movement, and the ventral stream form and object identification.

Previc's (1990) approach has received empirical support from recent studies that investigated functional differences between UVF and LoVF. For example, the global–local dichotomy was explored in a study that used Navon's (1977) hierarchical letter stimuli (Christman, 1993). Global features were detected more swiftly when presented to the LoVF, whereas a UVF advantage appeared for the detection of local features. Similarly, another study found a LoVF advantage for the perception of illusory contours, a task that involves global processing (Rubin, Nakayama, & Shapley, 1996).

In a study of the use of coordinate and categorical judgements of the same stimuli, reaction times were faster to LoVF stimuli for coordinate judgements, but not for categorical judgements (Niebauer & Christman, 1998). These findings support the claim that the LoVF plays a major role in localization, whereas UVF is adapted for object recognition.

Reading is a task that requires the discrimination of static, high-spatial-frequency stimuli (i.e., letters, words) and a local processing strategy. If that is the case, it should be performed better in the UVF, which specializes in that type of processing, than in the LoVF. Only a few studies following Mishkin and Forgays (1952) examined differences in letter and word perception between the UVF and LoVF. In most of the studies UVF and LoVF differences were not the major concern of the study, and stimuli were presented above and below fixation only as a control condition. In earlier experiments that tested single letters, numbers, or letter strings as target stimuli the findings are inconsistent. There have been reports of UVF advantages (Hellige, Cowin, Eng, & Sergent, 1991; Klein, Berry, Briand, D'entremont, & Farmer, 1990; Schwartz & Kirsner, 1982), LoVF advantages (Skrandies, 1987), or no significant differences between the visual fields (Webb, Fisher-Ingram, & Hope, 1983; Worral & Coles, 1976).

The results of the few studies that tested words are also inconclusive. In the experiment by Mishkin and Forgays (1952), the accuracy of word recognition was strikingly higher for LoVF than for UVF stimuli. Unfortunately, care must be taken when interpreting this finding. The lighting conditions, as stated in their paper, were different for UVF and LoVF and possibly contributed to the asymmetry. Also the word stimuli were very long, and the scoring method was very complicated as it included partial answers as well.

Another study used the lexical decision task to investigate the effects of spatial attention on word processing (McCann, Folk, & Johnston, 1992). Statistical analyses of UVF and LoVF performance are reported only in one of the experiments of this study (Experiment 1), in which no significant difference was found. Finally, about the same number of subjects showed a UVF bias as a LoVF bias in a near-threshold word categorization task (Lambert, Beard, & Thompson, 1988).

In the present study, we used the lexical decision task to test the hypothesis of differential functioning by the UVF and LoVF, and compared RVF versus LVF differences with UVF versus LoVF differences. Based on the literature we expected to find an RVF advantage over LVF using the lexical decision task. We also expected the RVF advantage to increase with semantic or linguistic priming. However, we expected the UVF–LoVF comparison to be more complicated. As the LoVF is better at basic sensory capabilities (i.e., there are a larger number of photoreceptors resulting in greater sensitivity in the LoVF than in the UVF), we might expect a LoVF advantage for processing all types of visual stimuli (Skrandies, 1987), whether they are words or nonwords. On the other hand, the hypothesized processing style of the UVF (see e.g., Christman, 1993; Niebauer & Christman, 1998; Previc, 1990) is more appropriate for object recognition, and thus a UVF advantage may be predicted for discriminating words from nonwords. In either case, the UVF–LoVF asymmetry stems basically from differences in processing at early visual perceptual stages. Consequently, the UVF–LoVF differences should not interact with semantic or linguistic priming, which occur at later (post-perceptual) stages. These predictions were examined in a series of experiments, in which perceptual variables (e.g., retinal eccentricity) and semantic variables (e.g., associate word priming, linguistic constraint) were manipulated.

EXPERIMENT 1

Experiment 1 examined only the UVF–LoVF comparison. In this experiment, subjects performed a lexical decision task to word and nonword stimuli presented to one of two retinal locations, 3° above and 3° below central visual fixation.

Methods

Participants

A total of 28 students from Bar-Ilan University (17 females and 11 males) participated in this experiment. Participants were native Hebrew speakers, ranged in age from 19 to 26 years, and were right-handed (Oldfield, Edinburgh questionnaire, 1971). All participants had normal or corrected vision. The participants gave informed consent and received credit towards introductory psychology requirements.

Apparatus and stimuli

The experiment was performed on a 486 PC computer with SVGA resolution. The TScope unit (Haussman, 1992) was used to measure reaction times and present visual stimuli. Subjects sat at a distance of 60 cm from the screen, and a chin-rest was used to prevent head movements.

The stimuli were 200 randomly chosen words from a pool of 500 four-letter Hebrew nouns and 200 randomly chosen nonwords from the companion 500 pool of nonwords. The 500 nonwords were constructed by randomly changing one of the letters of each word. All nonwords were orthographically and phonologically legal. Because of the lack of reliable Hebrew word frequency tables, a subjective frequency measure was used. The words were presented to another sample of similar subjects who rated word frequency on a 1–7 scale and performed a simple lexical decision task with them. Words were then classified according to their frequency rating and response time (RT) in the lexical decision task.

Stimuli were yellow on a black background, about 2° of visual angle wide and approximable 0.5° high. Stimuli were presented at two locations, 3° above and below fixation in the centre of the screen (distance was measured from the centre of the word). Participants responded to 50 words and 50 nonwords presented to each location, counter-balanced across subjects. The words presented to the UVF and LoVF were balanced for frequency.

Procedure

Each trial started with a mouse-button press by the participant, followed by a fixation symbol that appeared on the centre of the screen for 400 ms. A word/nonword then appeared for a 150-ms duration, after which it disappeared together with the fixation symbol. Participants responded as to whether they saw a word or a nonword and pressed one of two mouse buttons, with their right index finger, to report their decision. The use of only one responding hand has been reported not to be a relevant variable (not significant either as a main effect or as an interacting variable) in laterality studies of lexical decision (Babkoff & Benn-Uriah, 1983; Babkoff & Faust, 1988). Button assignment was counterbalanced: Half of the subjects responded with the right button for words and with the left for nonwords, whereas the other half used the opposite configuration. Participants were instructed to respond with maximum speed and accuracy and to avoid eye movements during the trial. Subjects signalled that they were ready for the next trial by pressing the middle mouse button.

TABLE 1
Mean RT and accuracy rates for words and nonwords in Experiment 1

	RT[a]				*Accuracy*[b]			
	Words		*Nonwords*		*Words*		*Nonwords*	
Visual field	*M*	*SEM*	*M*	*SEM*	*M*	*SEM*	*M*	*SEM*
UVF	793	28	899	26	88.7	1.5	87.5	1.2
LoVF	830	29	891	31	81.8	2.4	89.4	1.2
UVF advantage	37*		−8[c]		6.9*		−1.9[c]	

[a] In ms.

[b] In percentages.

[c] *NS*.

* $p < .05$.

Results

Data were analysed using repeated measures analysis of variance (ANOVA) with two factors (visual field and lexicality), separately for RT and accuracy measures (Table 1). In all of the analyses reported in this paper, only RTs lying within 2.5 standard deviations were included. When all RTs were included the results were the same.

Overall, subjects responded faster to words than to nonwords, $F(1, 27) = 38.7, p < .05$. Also, a visual field by lexicality interaction was found, $F(1, 27) = 8.64, p < .05$. Although there was a UVF advantage for words, there was no difference between visual fields in responding to nonwords. For accuracy, only the interaction was found to be significant, $F(1, 27) = 11.82, p < .05$—that is the UVF advantage appeared for word stimuli only.

Responses tended to be more conservative to LoVF stimuli for β ($M = 2.25$, $SEM = 0.5$) than to UVF stimuli ($M = 1.00$, $SEM = 0.7$) field, $t(27) = 2.48$ $p < .05$. The UVF advantage in d' ($M = 2.56$, $SEM = 0.1$ vs. $M = 2.38$, $SEM = 0.1$) was not significant ($p > .1$).

EXPERIMENT 2

In Experiment 2 we examined UVF–LoVF asymmetry, parametrically, within a broader context of lexical decision for a variety of retinal locations. The purpose was to examine and compare UVF–LoVF asymmetry with RVF–LFV asymmetry along the vertical–horizontal axes at parafoveal and peripheral retinal locations. The asymmetry in perceptual characteristics and processing style of the UVF and LoVF (high–low spatial frequency, global–local perception) has been reported for RVF and LVF comparisons (Bryden & Underwood, 1990). Visual characteristics—for example, sensitivity, acuity, and spatial resolution—decrease with increasing retinal eccentricity. Some models of RVF–LVF comparisons (Christman, 1989; Grabowska & Nowicka, 1996; Sergent, 1982) posit that the right–left visual field asymmetry in lexical decision is caused, at least partially, by better processing of high spatial frequencies by the left hemisphere. The density of visual receptors decreases as distance from the fovea increases. If the effect of reduced spatial resolution is similar to lowering spatial frequency, then the RVF advantage should diminish at greater eccentricities. If, however, increasing eccentricity does not affect the RVF–LVF difference, then one may conclude that reduced spatial resolution is not the major cause of the asymmetry. The same reasoning applies to UVF–LoVF differences. The decrease in sensitivity and acuity with increasing eccentricity is larger in the UVF than in the LoVF (Pointer & Hess, 1989; Skrandies, 1987). If the upper–lower asymmetry is caused by differences in spatial resolution, we should expect the UVF–LoVF differences to decrease with increasing retinal eccentricity. If increasing eccentricity has no effect on the differences between UVF and LoVF in discriminating words from nonwords, we may conclude that this is not a major source of the asymmetry. Stimuli were, therefore, presented at various distances from the centre of the visual field, in the upper, lower, central, right, and left regions.

Method

Participants

A total of 56 students from Bar-Ilan University (35 female and 21 male) participated in this experiment. All participants were native Hebrew speakers and ranged in age from 19 to 26 years. All participants were right-handed (Edinburgh questionnaire, Oldfield, 1971), and had normal or corrected vision. The participants, who gave informed consent, received credit towards introductory psychology requirements.

Stimuli and procedure

In this experiment all 500 words and companion nonwords were used. During the experiment words and nonwords were presented in the centre and at 24 positions around the fixation point, at eccentricities of 3°, 5°, and 8° for a total of 25 retinal locations. The results were used to build a *performance map* of retinal word/nonword discrimination. Stimuli were presented in eight positions at each eccentricity: right, left, up, down, and diagonally. A total of 25 locations were used (8 positions × 3 distances + centre; see Figure 1). A total of 40 stimuli (20 words and 20 nonwords) were presented in each one of the possible locations, each participant responding to a total of 1,000 stimuli. Stimulus duration was 150 ms. To avoid

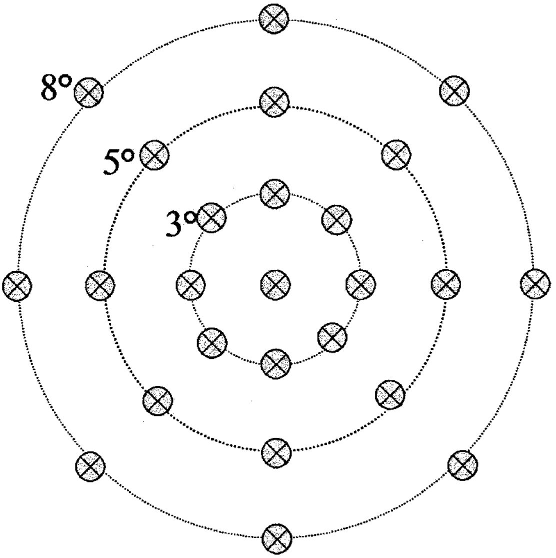

Figure 1. Visual field location for stimuli presentation in Experiment 2.

repetition effects each word and nonword appeared only once during the experiment. In each of the retinal locations, half of the words presented had high frequency and half low frequency. The order of stimuli and location was randomized for each subject, with the only restrictions that each block contained the same number of words and nonwords. Five words and five nonwords presented at each of the 25 locations were included in each block. As stimuli were randomized for each subject separately, the items were not perfectly counterbalanced over conditions. Nevertheless, a post hoc analysis revealed that across subjects about 90% of the items appeared more than once in each condition (word/nonword and location). Each experimental session began with 30 training trials. Testing occurred in two separate sessions of two 250-stimuli blocks each, with a short break between blocks.

Results

The three variables of the experiment—horizontal position (right/left), vertical position (up/down), and eccentricity (0°, 3°, 5°, 8°)—constituted an incomplete design that made a global ANOVA impossible. Instead, hypotheses were tested with a series of a priori within-subject contrasts with one degree of freedom (Judd & McClelland, 1989, chap. 14). For each subject, mean correct RT and accuracy were calculated and analysed separately. A contrast value was computed for each main effect and interaction separately for RT and accuracy. Mean RT and accuracy levels for words are presented in Table 2. Significance levels were adjusted using the Bonferroni procedure.

RT

For the word stimuli, the effect of eccentricity was significant, $t(55) = 9.92$, $p < .001$. Mean RT increased from 744 ms ($SEM = 13.4$) at the centre, to 814 ms ($SEM = 14.3$) at 3°, 857 ms ($SEM = 14.3$) at 5°, and 911 ms ($SEM = 18.4$) at 8°. RTs were significantly swifter for RVF stimulation ($M = 841$ ms, $SEM = 14.4$) than LVF stimulation ($M = 877$ ms, $SEM = 15.7$), $t(55) = 7.22$, $p < .001$. This pattern held for all of the axes (Table 2). There was an advantage to the UVF ($M = 849$ ms, $SEM = 15.8$) over the LoVF ($M = 876$ ms, $SEM = 16.4$). This latter pattern, nine out of nine comparisons of equivalent positions in upper and lower visual fields, is significant with a binomial test (50% probability, $p < .002$). An overall comparison of UVF and LVF yielded, $t(55) = 2.54$, $p = .013$. However, the Bonferroni adjustment required $p < .004$ for significance. The RVF advantage over the LVF remained constant (about 35 ms) across eccentricities, and the same was true for the UVF, which was on average 26 ms faster than the LoVF. RT analysis by quadrants shows that performance was the fastest at the upper-right quadrant ($M = 837$ ms, $SEM = 15.0$) followed by the lower-right ($M = 851$ ms, $SEM = 16.4$), the upper-left ($M = 864$ ms, $SEM = 16.0$), and lower-left ($M = 890$ ms, $SEM = 17.0$). None of the interactions was significant.

A quadratic smooth-fit map of the RT results is shown in Figure 2. The contour elongation towards the right with an upward slant depicts the right and upper field advantages.

For the nonwords, the only significant effect was increased RT with eccentricity, which was similar to the one found for words, $t(55) = 7.0$, $p < .001$. There were no right or upper field advantages for nonwords.

TABLE 2
Mean RT and accuracy rates for word and nonword stimuli in Experiment 2

				RT[a]			*Accuracy*[b]		
Eccentricity		*Field*		*Left*	*Centre*	*Right*	*Left*	*Centre*	*Right*
3°	Words	Upper	*M*	819	801	793	81.9	86.8	89.8
			SEM	16	16	13	2.0	1.4	1.2
		Centre	*M*	832		789	82.7		90.5
			SEM	17		15	1.7		1.1
		Lower	*M*	853	830	798	81.2	84.1	89.2
			SEM	17	16	16	1.8	1.8	1.3
5°		Upper	*M*	860	847	793	78.3	82.9	89.3
			SEM	15	19	14	2.4	2.3	2.3
		Centre	*M*	862		789	77.2		86.1
			SEM	15		15	2.0		1.4
		Lower	*M*	890	869	798	76.0	75.6	82.7
			SEM	17	17	16	2.8	2.6	2.1
8°		Upper	*M*	915	893	876	67.0	67.9	74.9
			SEM	22	24	19	3.2	3.1	2.9
		Centre	*M*	933		871	64.8		77.0
			SEM	23		16	3.2		2.1
		Lower	*M*	927	959	911	62.5	61.4	75.2
			SEM	21	27	23	3.2	3.4	2.7
3°	Nonwords	Upper	*M*	927	907	911	85.0	87.0	89.9
			SEM	20	19	19	1.5	1.3	1.2
		Centre	*M*	928		905	86.9		87.1
			SEM	20		20	1.5		1.6
		Lower	*M*	913	897	894	84.8	88.1	89.7
			SEM	19	19	17	1.6	1.3	1.3
5°		Upper	*M*	940	935	959	86.8	87.3	87.8
			SEM	22	20	21	1.4	1.5	1.2
		Centre	*M*	932		935	86.8		86.2
			SEM	19		19	1.6		1.8
		Lower	*M*	944	952	913	87.8	84.8	87.2
			SEM	22	24	16	1.5	1.7	1.4
8°		Upper	*M*	977	981	965	81.8	80.8	80.4
			SEM	26	22	22	1.8	1.8	1.7
		Centre	*M*	960		966	81.7		83.0
			SEM	23		19	1.89		1.7
		Lower	*M*	950	989	949	83.4	81.0	84.0
			SEM	20	26	20	1.9	1.9	1.7

[a] In ms.
[b] In percentages.

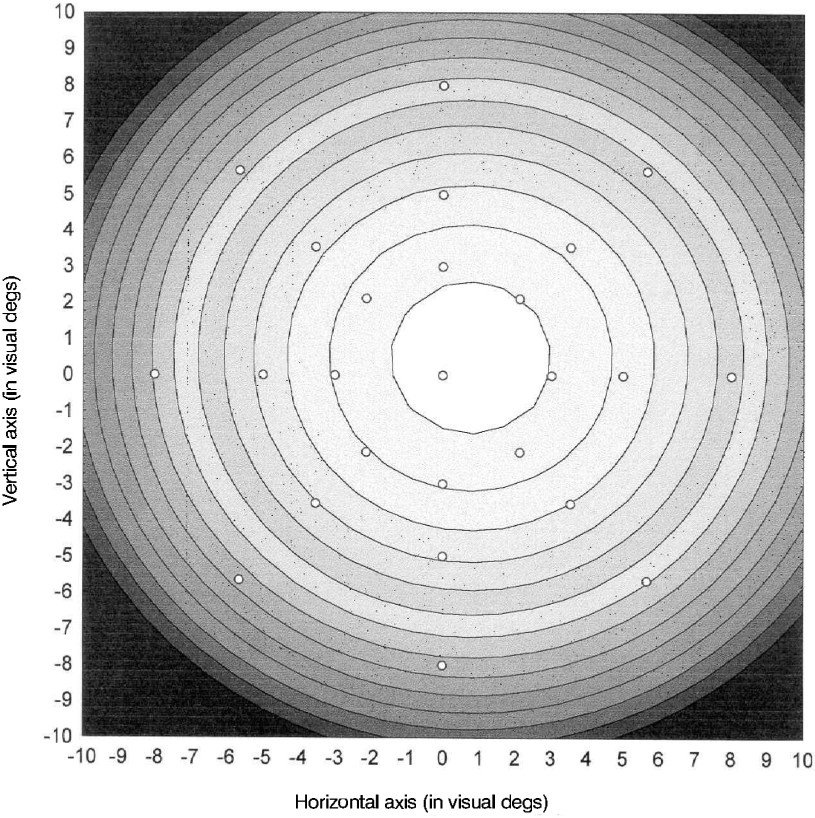

Figure 2. A quadratic smooth-fit map of the RTs in Experiment 2. Vertical and horizontal axes are shown in degrees of visual angle. Dots represent actual stimulus positions, contours represent equal-RT areas of 20 ms, starting at 800 ms. Contours are shifted towards the right and up depicting right and upper field advantages.

Accuracy

As expected, a main effect of eccentricity was found for word accuracy, $t(55) = 10.98$, $p < .001$, and performance decreased with longer distances from the centre. RVF accuracy was significantly greater than LVF accuracy (RVF: $M = 83.3\%$, $SEM = 1.4$; LVF: $M = 74.6\%$, $SEM = 1.9$), $t(55) = 7.73$, $p < .001$. As in the RT measures, the difference between upper and lower visual field did not reach significance ($p > .01$), but there was a trend for a slight advantage to the upper ($M = 79.3\%$, $SEM = 1.9$) over the lower ($M = 76.5\%$, $SEM = 2.0$) visual field.

The only interaction that approached significance was eccentricity by horizontal position, $t(55) = 2.31$, $p = .02$. Surprisingly, the RVF advantage was slightly greater at the distant locations than in the closer ones.

The only main effect that was significant for the nonwords was eccentricity, $t(55) = 5.95$, $p < .001$. Overall, there were no significant differences between the right and left, nor between the upper and lower visual fields. Only at the 3° eccentricity was there a RVF advantage, which disappeared at greater distances from the centre, causing a significant distance by horizontal position interaction, opposite to that found for words.

Signal-detection parameters were computed using accuracy data for words and nonwords. The pattern of results for d' were exactly the same as the accuracy for words—that is, the eccentricity effect and RVF advantage were significant, and there was a trend towards an UVF advantage. The criterion measure (β) revealed that although subjects responded overall in a conservative manner (tendency to respond “nonword”), the trend was accentuated in the LVF and the LoVF.

Discussion

The results of Experiment 2 replicate findings reported in the earlier literature. As expected, the distance from the centre decreased the discrimination of both words and nonwords. Also, consistent with the classic RVF advantage for lexical stimuli, accuracy and speed in responding to words were higher in the RVF than in the LVF, but like in many other studies, this was true for word stimuli only.

Nonetheless, whereas most studies have examined the RVF–LVF differences on the horizontal meridian at several locations relatively close to the fovea (Babkoff, Genser, & Hegge, 1985), the present study shows that the RVF advantage holds: (1) even at greater distances; and (2) both above and below fixation.

Models that stress the importance of stimulus quality on hemispheric differences (Sergent, 1982) predict the disappearance of the RVF advantage with increasing eccentricity. Information received from locations distant from the centre lack the spatial resolution and acuity that according to those models give rise to the RVF advantage. Our results do not agree with that view and show that the advantage for word stimuli did not decrease, and was even increased slightly, at the longest distance. On the other hand, for the nonword stimuli, the RVF advantage appeared only at the closest points, indicating a possible, but smaller, effect of perceptual quality.

Although the differences did not reach statistical significance with the Bonferroni correction, the better performance of the UVF was clear. The binomial comparison ($p < .002$) of RT to each one of the upper field positions with their lower field counterparts shows a clear advantage—that is, shorter RTs to words presented to the upper visual field locations (Table 2). Exactly the same pattern of results was obtained in an additional experiment in which 10 subjects repeated Experiment 2 four times, suggesting that the UVF advantage is stable and not reduced with practice.

These data confirm the conclusions from Experiment 1 and show the existence of upper visual field superiority in the lexical decision task. Words, but not nonwords, are responded to faster and more accurately when presented to the upper visual field.

Although from a basic sensory point of view the LoVF appears better equipped, its processing style may not be suitable for tasks like word recognition. The LoVF may specialize in global processing based on the low-spatial-frequency components of the stimulus (Christman, 1993), which do not exploit the peripheral advantages of the LoVF for object recognition. Conversely, the local processing and high-spatial-frequency specialization of the UVF may be more appropriate for word recognition.

If the asymmetry were due to attentional biases, one would expect the asymmetry for nonword as well as word stimuli. The results of Experiments 1 and 2 argue against such a conclusion. Similarly, visual search preferences cannot explain the word–nonword asymmetry.

The findings can be interpreted as differences in whole-word recognition. It may be that when stimulus quality is degraded words cannot be encoded as a whole unit and have to processed serially (Chiarello, Maxfield, Richards, & Kahan, 1995). Perhaps the stimulus quality in the LoVF does not permit parallel whole-unit encoding of words, whereas the stimulus qulaity in the UVF does. This would result in an advantage for words only.

Another interpretation refers to the facility of access to the ventral pathway in which the word recognition processes take place. If the processing of feature and letter recognition takes place at a cortical area adjacent to word-processing centres, then it may benefit by top-down processes from information contained in them. The first processing stages at the UVF could take advantage of the proximity to lexical centres and thus process information faster and better. LoVF representation is farther from the ventral stream and thus cannot benefit directly from that kind of information.

The finding of orthogonality between the right–left and up–down asymmetry is interesting. Despite the striking similarity of the processing styles of the right and upper fields, and of the left and lower fields, no interaction between their effects was found in Experiment 2. The differences in performance in the visual field quadrants may suggest that hemispheric asymmetry in word recognition occurs at the later stages of processing. If the right–left differences occur at the perceptual stages only, and are similar in the upper and right fields and in the lower and left fields, the same performance level would be expected for the lower right and upper left quadrants. Thus, the significant difference between these quadrants found in the present study agrees with models that place hemispheric differences in word processing more centrally. Although they differ at the lexical level, both hemispheres process good-quality information coming from the UVF better than they process poor-quality stimuli arriving from the LoVF.

Findings from both Experiments 1 and 2 are in disagreement with those of Mishkin and Forgays (1952), who reported that word identification was considerably more accurate in the LoVF than in the UVF. The task used in this earlier study differed from the lexical decision task used here in a number of ways. First, in their study, participants reported which words were presented to them, and partial reports were taken into account (i.e., when half of the letters reported appeared in the word). The task instructions stressed letter and feature recognition. In the lexical decision task used in this experiment, only one letter differentiated words from nonwords. Second, Mishkin and Forgays included very long words (eight letters), and there was no time limit for responding. Third, as reported in their Method section, there was a difference in illumination between the upper and lower parts of the screen (UVF and LoVF). Consequently, it is not possible to make meaningful comparisons with their data.

Other more recent studies examined UVF vs. LoVF differences in word processing, but the tasks were greatly different from that used in this study (Lambert et al., 1988; McCann et al., 1992), making it very difficult to compare with the present study.

A general caveat to our findings should be discussed. In the series of experiments reported here, subjects were asked to maintain fixation and to refrain from moving their eyes during each trial, but the exact point of fixation and eye movements were not externally monitored.

Although this "instruction-only" fixation method has been widely used in the literature, recent studies (e.g., Jordan, Patching, & Milner, 1998) suggest that it might be inadequate, as subjects often show a biased fixation, which can be confounded with visual field advantage in performance. Also, variations in fixation accuracy between studies might be the reason for the contrasting findings in the literature. It is possible that in our experiments subjects' fixations were biased to the upper right and contributed to the asymmetry effect. Nevertheless, the fixation biases reported by Jordan et al. (1998) are small (< 1°) relative to the distances used in Experiment 2. The proportion of the bias (< 1°) becomes smaller as angle of eccentricity increases, therefore the effects of a fixation bias should become smaller with increasing eccentricity. But, in fact, our results showed that RVF and UVF advantages do not change with eccentricity. Thus, it seems unlikely that fixation accuracy alone underlies the visual field differences reported here. Furthermore, fixation bias can not account for the word–nonword asymmetry in RT and accuracy, and for the high-level interactions that will be reported in the following experiments.

EXPERIMENT 3

The source of the UVF advantage in lexical decision requires further investigation. The findings from the first two experiments suggest that high-level lexical factors are involved in the upper–lower asymmetry because it occurs for words but is absent in nonword stimulation. Yet, as noted earlier, word–nonword differences might originate from decision criteria and response bias. When stimulus quality is poor and a rapid recognition is impeded, there is a tendency to respond *nonword*, which in turn lowers accuracy for words and produces more correct nonword responses (although this does not affect d′ which takes both hits and false alarms into account).

In Experiment 3, a priming paradigm was used to compare top-down influences on the upper field advantage in word processing to that of the RVF advantage over LVF. A priming word was presented in the centre of the screen preceding the appearance of the target word, which could be presented in four locations relative to the centre: upper left, upper right, bottom left, and bottom right.

If the difference between UVF and LoVF remains constant whether the target was presented following a neutral or a semantically related word, this would imply that the asymmetry originates from the perceptual stages of processing. This is especially true if, at the same time, the RVF advantage is facilitated. On the other hand, finding greater facilitation from a related prime in the UVF compared to the LoVF would mean that at least part of the UVF advantage on lexical decision performance is semantic.

Method

Participants

A total of 35 students from Bar-Ilan University (22 females and 13 males) participated in this experiment. They were native Hebrew speakers and ranged in age from 19 to 26 years. All subjects were right-handed according to the Edinburgh questionnaire (Oldfield, 1971) and had normal or corrected vision. The subjects, who gave informed consent, received credit towards introductory psychology requirements.

Apparatus and stimuli

Prime words were prepared in a side study in the following manner: 300 words were selected randomly from the word pool in Experiment 1. The list was presented, in a questionnaire form, to another sample of similar students who wrote before each target another word and reminded them of it. The most frequent primes were selected, and a subsequent sample (25 subjects) rated the subjective relatedness of the primes and targets in a 1–7 scale (Chiarello, Senehi, & Nuding, 1987). The 200 pairs that were rated highest in relatedness were selected for the experiments. Nonword stimuli were the same as those in Experiment 1.

Stimulus presentation and response collection were performed with the equipment described on the previous experiments.

Procedure

Each trial began with the participant signalling readiness by pressing the middle button on the computer mouse. After the button press, a fixation symbol appeared at the centre of the screen and was replaced after 400 ms by a related prime word or the neutral word *ready* (in Hebrew). The fixation symbol appeared after 500 ms in place of the prime. Targets appeared 400 ms later in one of four possible locations (upper left, upper right, lower left, and lower right), at a distance of 3° from fixation for 150 ms. Participants decided whether the target was a word or a nonword and pressed one of two mouse buttons with their right index finger according to their decision. Button assignment was counterbalanced, half of the subjects responding with the right button for words and with the left for nonwords, whereas the other half used the opposite configuration. Participants were instructed to respond with maximum speed and accuracy and to avoid eye movements during the trial. Subjects signalled that they were ready for the next trial by pressing the middle mouse button.

Every participant responded to 400 stimuli: 50 words and 50 nonwords in each of the four locations, in two blocks of 200 trials with a short break between blocks. Half of the targets appeared after a related prime and half after a neutral prime. The order of stimuli and locations was randomized for each subject, and targets appeared only once during the experiment. Across subjects, words appeared on average three times in every condition. Each session started with 30 practice trials.

Results

Data were analysed with repeated measures ANOVA with three independent factors (prime type, horizontal location, and vertical location) separately for RT and accuracy. For each subject, mean correct RT and accuracy were calculated and analysed. Mean RTs and accuracy levels are shown in Table 3.

RT

The three main effects were significant for the RTs to word stimuli but not for nonwords. Targets were responded to faster after an associated prime (M = 846 ms, SEM = 24.8) than after a neutral prime (M = 890 ms, SEM = 26.3), $F(1, 34) = 35.7$, $p < .001$. RTs were shorter for targets appearing in the RVF (M = 836 ms, SEM = 25.0) than for those in the LVF (M = 900 ms, SEM = 26.5), $F(1, 34) = 46.4$, $p < .001$. Also, responses were swifter to UVF stimuli (M = 851 ms, SEM = 25.5) than to LoVF stimuli (M = 885 ms, SEM = 27.6), $F(1, 34) = 4.3$, $p < .05$.

The interactions of horizontal position by prime type and of vertical position by prime type were significant, $F(1, 34) = 6.4$, $p < .05$, and $F(1, 34) = 4.7$, $p < .05$, respectively. Associated

TABLE 3
Mean RT and accuracy rates for words and nonwords in Experiment 3

			Related prime		*Neutral prime*	
	Field		*Left*	*Right*	*Left*	*Right*
			RT[a]			
Words	Upper	*M*	863	784	895	862
		SEM	27	22	27	28
	Lower	*M*	909	828	932	870
		SEM	30	27	28	29
Nonwords	Upper	*M*	962	958	972	944
		SEM	27	30	28	26
	Lower	*M*	976	966	962	945
		SEM	29	30	27	27
			Accuracy[b]			
Words	Upper	*M*	81.3	90.4	72.9	83.1
		SEM	2.7	1.7	3.5	2.1
	Lower	*M*	75.0	84.8	62.3	76.2
		SEM	2.8	2.0	3.4	2.8
Nonwords	Upper	*M*	80.9	79.9	81.9	82.9
		SEM	2.4	3.0	2.2	2.3
	Lower	*M*	80.1	76.1	80.5	79.5
		SEM	2.4	2.6	2.1	2.5

[a] In ms.
[b] In percentages.

prime facilitation was 60 ms in the RVF, but only 27 ms in the LVF. Similarly, facilitation in the UVF was larger than that in the LoVF (55 vs. 33 ms), and UVF advantage increased from 23 ms after neutral primes to 45 ms after associative primes.

Accuracy

Only the three main effects were significant for words; none was significant for nonwords. Responses were more accurate for words presented after associative primes (M = 82.9%, SEM = 1.5) than after neutral primes (M = 73.6%, SEM = 2.0), $F(1, 34) = 59.3$, $p < .001$. RVF stimulation (M = 83.6%, SEM = 1.5) was more accurate than LVF (M = 72.9%, SEM = 2.2), $F(1, 34) = 47.2$, $p < .001$. UVF stimulation was more accurate than LoVF (M = 81.9%, SEM = 2.2 vs. M = 74.6, SEM = 2.3), $F(1, 34) = 6.0$, $p < .05$.

Discussion

The results showed RVF and UVF advantages as well as related prime facilitation for the word stimuli. The prime-by-location interactions were found for RT but not for accuracy. There was no speed–accuracy trade-off. On the contrary, there was a strong inverse correlation between measures; when word recognition was difficult participants erred more, and their decision took longer (see Babkoff & Faust, 1988). Apparently, the variability in RT reflects processing differences and is not due to fast guess responses. Therefore, it is probable that the absence of interactions in the accuracy data is due to poor measure sensitivity.

Facilitation by priming to RVF stimuli was larger than that to LVF stimuli, suggesting that the left hemisphere made better use of prior information. Automatic priming effects (i.e., short SOA or small proportions of related primes) are usually either the same in RVF and LVF (Chiarello, Burgess, Richards, & Pollock, 1990; Chiarello et al., 1987; Egline, 1987; Richards & Chiarello, 1995; Walker & Ceci, 1985) or greater in the LVF (Chiarello, 1985, 1991). Conversely, studies with controlled priming (long SOA or high proportion of related primes), in which subjects are allowed to orient their attention or expectancies, report larger priming effects with RVF stimulation (Burgess & Simpson, 1988; Chiarello, 1985; Chiarello et al., 1987). In our experiment, the long SOA (900 ms) and proportion of related primes permitted the latter type of priming.

The prime type by vertical position interaction implies that the lexical decision process in the UVF was affected by prime word information to a greater extent than that in the LoVF. One may conclude, therefore, that the UVF advantage is parallel to the RVF advantage. In both cases, the advantage is found for word stimuli only. Associative priming augments both advantages. Whereas results from Experiment 2 may reflect similarities between the right–left and up–down asymmetries in perceptual components, Experiment 3 illustrated the resemblance in context effects. The greater amount of controlled priming facilitation in the RVF is probably related to post-lexical factors (Chiarello, 1985). Although it has been demonstrated that the right and left hemispheres acquire meaning from text and utilize it in a different manner (Chiarello, 1991), there is no basis for assuming the existence of a UVF advantage in this case.

EXPERIMENT 4

Faust and her colleagues have reported message-level effects on hemispheric differences (Faust, 1998; Faust & Babkoff, 1997; Faust, Babkoff, & Kravetz, 1995; Faust & Kravetz, 1998). In general, they found that the left hemisphere uses sentence-meaning information in subsequent word recognition, but that the right hemisphere uses only the associative information between the words in the sentence.

In a recent experiment, Faust and Kravetz (1998) manipulated the semantic constraint of incomplete sentences used as primes for a lexical decision task. For example, “The cop caught the . . .” and “The car was opened by the . . .” were used respectively as high- and low-constraint primes for the target word *thief*. Faust and Kravetz found that the linguistic constraint level facilitated the performance in the RVF but not in the LVF. In other words, only the left hemisphere made use of sentence meaning for recognizing words. The same paradigm was used in the Experiment 4 in order to compare the right–left and upper–lower asymmetries. We hypothesized that although linguistic constraint should enhance the RVF advantage in lexical decision, there would be no enhancement of the UVF–LoVF differences.

Method

Participants

A total of 30 students from Bar-Ilan University (19 females and 11 males) participated in Experiment 4. They were native Hebrew speakers and ranged in age from 19 to 26 years. All subjects were right-handed according to the Edinburgh questionnaire (Oldfield, 1971) and had normal or corrected vision. The subjects, who gave informed consent, received credit towards introductory psychology requirements.

Apparatus and stimuli

Prime sentences and targets were borrowed from Faust and Kravetz (1998), but only high-constraint, low-constraint, and neutral primes were used. High-constraint sentences highly predicted the target that would follow them (e.g., "The gardener watered the . . ."), low-constraint sentences were only slightly predictive (e.g., "The merchant sold the . . ."), and neutral sentences were general statements that did not predict the target (e.g., "The next word appearing will be . . ."). Ten different neutral primes were used throughout the experiment.

Procedure

The course of the experimental session was identical to the one presented in Experiment 3, with he exception of the presentation time of the primes, which was increased to 1,000 ms to allow sufficient time for reading the sentences.

The experiment consisted of 100 targets with their respective primes. In order to avoid stimulus repetition, stimuli were divided randomly into 12 lists of 300 trials. For each condition (four positions and three prime types) the list contained 17 target words and 8 nonwords. No target was presented more than twice on each list. If a target appeared more than once, it never appeared in the same location or after the same prime. A different list was assigned randomly to each subject. Over the entire experiment and database the target words appeared on average five times in each of the conditions. The experimental session included two blocks of 150 trials, with a short break between blocks, and 30 practice trials at the beginning.

Results

Data were analysed using within-subjects ANOVA with three factors: level of constraint (high/low/neutral), horizontal position (right/left) and vertical position (up/down). Separate analyses were performed for correct RT and accuracy data. Mean correct RT and accuracy are shown in Table 4.

Level of constraint, horizontal position, and vertical position for RT to words were significant, $F(2, 58) = 23.9, p < .001$, $F(1, 29) = 67.9, p < .001$, and $F(1, 29) = 5.6, p < .05$, respectively. RT decreased as level of constraint increased, and RT was shorter to RVF stimuli ($M = 736$ ms, $SEM = 20.2$) than to LVF stimuli ($M = 802$ ms, $SEM = 20.5$). RT was shorter to UVF stimuli ($M = 760$ ms, $SEM = 19.5$) than to LoVF ($M = 778$ ms, $SEM = 21.2$). No significant effect was found for nonwords.

The only significant interaction was between constraint level and horizontal position, $F(2, 58) = 3.6, p < .05$. The difference between neutral and low-constraint priming was approximately the same (32 ms) in the RVF and LVF, but the difference between high- and low-constraint priming was greater in the RVF (63 ms) than in the LVF (34 ms). Similarly,

TABLE 4
Mean RT and accuracy for words in Experiment 4

		High constraint		*Low constraint*		*Neutral*	
		Left	*Right*	*Left*	*Right*	*Left*	*Right*
				RT[a]			
Upper	*M*	756	678	790	733	828	773
	SEM	21	19	22	26	25	24
Lower	*M*	781	689	814	761	841	783
	SEM	18	18	21	24	24	27
				Accuracy[b]			
Upper	*M*	89.8	89.6	84.9	88.2	80.1	84.7
	SEM	1.5	2.1	2.0	1.7	2.5	2.2
Lower	*M*	87.9	90.8	87.2	90.5	81.7	88.7
	SEM	2.0	1.6	1.3	1.8	2.0	1.7

[a] In ms.
[b] In percentages.

RVF advantage was fairly equivalent to neutral and low-constraint priming (56 and 55 ms), but was significantly enhanced by high-constraint sentence primes (85 ms).

Although it seems that UVF advantage was slightly greater for the high- and low-constraint primes than for the neutral primes, the interaction of vertical position with constraint did not reach significance, $F < 1$.

The effects for the accuracy measure were weaker, and the differences were very small. Main effects of constraint level and horizontal position were significant, $F(2, 58) = 13.9$, $p < .001$, and $F(1, 29) = 17.9$, $p < .001$, respectively. Accuracy increased with linguistic constraint, and there was a slight RVF advantage ($M = 88.7\%$, $SEM = 1.3$) over LVF ($M = 85.3\%$, $SEM = 1.4$).

Discussion

As in Experiment 3, significant effects were found for RT but not for accuracy data. Accuracy level was high ($M = 87\%$), possibly blurring the differences between conditions. Also, RT and accuracy disparity is not a consequence of speed–accuracy tradeoff, because in conditions in which RTs were short, accuracy rates were high (Babkoff & Faust, 1988).

As predicted, increasing the level of linguistic constraint facilitated lexical decision performance in general. Facilitation was greater for RVF stimulation, although it occurred for LVF as well. These results agree with previous studies in hemispheric differences (Faust & Kravetz, 1998) and indicate that the left hemisphere utilizes message-level information whereas the right hemisphere used intra-lexical information of the words in the sentence.

Results from the UVF–LoVF asymmetry also support this interpretation of RVF versus LVF differences in priming effects, as the UVF advantage was not enhanced by highly constrained sentences. The effects of linguistic constraint effects are assumed to occur at later stages of processing, and although it might be argued that each hemisphere uses its own language processor, it is not reasonable to expect different language processes for UVF and LoVF stimulation. The separation along the horizontal axis occurs only at the visual and associative cortical areas, which in turn send information to a common centre for linguistic processing. The present results indicate that high-level information does not interact with the early stages of word encoding, which may differ for the upper and lower parts of the visual field.

GENERAL DISCUSSION

The main conclusion from experiments in the present study is that word discrimination is performed better in the UVF than in the LoVF. These results imply different processing styles for UVF and LoVF (Previc, 1990). Reading involves local processing of high-spatial-frequency stimuli, much like other kinds of object recognition tasks for which the UVF is specialized. This is despite the fact that reading is usually performed in the peripersonal space, which is dominated by the LoVF (Brannan, 1990). Thus, it seems that there are visual tasks, like reading, that in spite of occurring more frequently in the peripersonal space are, nevertheless, performed better when stimuli appear in the UVF. This may not be incompatible with Previc's view, as visual pathways evolved by ecological pressures throughout hundreds of thousands of years, in which reading played no role.

The UVF advantage, as reported in the present study: (1) occurs for word stimuli only; (2) is not affected by changes in eccentricity; and (3) is increased by single-word associative priming. Thus, peripheral perceptual or attentional differences alone without including semantic factors (e.g., top-down information flow) cannot account for the results.

Several alternatives may be considered. Saccadic eye movements are more efficient in the UVF (Heywood & Churcher, 1980) and might provide an alternative explanation for the results. However, the duration of the stimuli presented in this study was very brief (150 ms) and ended before eye movements could occur. Covert orienting (Eviatar, 1995), UVF attentional biases (Geldmacher & Heilman, 1994), and search direction (Efron, Yund, & Nichols, 1990) might also be proposed as alternative interpretations for some of the findings, but they do not explain the finding that UVF–LoVF differences were found for words only, not for nonwords. In addition, none of the above interpretations can explain the enhancement of the difference by single-word priming.

The asymmetries across the vertical and horizontal axes have been found to be quite similar (Niebauer & Christman, 1998). RVF and UVF advantages showed the same pattern in the present Experiments 2–3. However, the results from Experiment 4 indicate that the UVF and RVF advantages may, in fact, be dissociated.

Although priming by associative words augmented both RVF and UVF superiority, the source of the facilitation may not be the same. The difference between RVF and LVF has been reported to increase only when priming is controlled (i.e., long SOA or high probability), but with automatic priming the asymmetry is not affected and may even decrease (Chiarello, 1985; Chiarello et al., 1990; Richards & Chiarello, 1995). This has been interpreted as the greater ability of the left hemisphere to suppress irrelevant meanings during controlled priming, and it reflects post-lexical differences (Chiarello, 1991). If this is correct then the differences between RVF and LVF may involve post-lexical factors.

In contrast, it is less reasonable to expect that post-lexical factors account for the enhancement of the UVF advantage in associative priming. It may be argued that priming is more effective with high-quality stimulation, but there is evidence that priming is better when stimuli are degraded (Durgunoglu, 1988, Experiment 4). It seems more likely that UVF–LoVF asymmetry emerges during word encoding or early lexical access stages and may be the consequence of better top-down information flow to the visual areas that represent the UVF, which are closer to the ventral processing stream.

Manipulating the message-level information magnified the RVF advantage, but had no effect on the UVF advantage. This result emphasizes the distinct sources of the two asymmetries. When considering models of lexical processing for the UVF–LoVF asymmetry, the pattern of results appears to fit a modular model in which the lexicon is not influenced by hierarchically higher modules (Fodor, 1983). On the one hand there is evidence for better top-down information flow to cortical areas representing UVF stimulation. On the other hand, message-level information does not seem to interact with UVF–LoVF differences stemming from stages in which the lexicon is accessed. An open model would predict that information flows freely throughout all stages, thus sentence meaning should influence the UVF advantage in lexical and prelexical levels.

Further research could better define the source of the UVF–LVF asymmetry by manipulating variables at various levels of processing, as well as attentional and task factors. Also, subsequent studies should test if the same advantage and priming effects occur for equivalent tasks in object recognition.

Results from the present study have immediate practical value for real-world applications: specifically, when designing display equipment for situations in which word stimuli are presented while users fixate and attend to other parts of the visual field, as in the case of displays on pilot helmets. On those instances, the optimal position for word display would seem to be the upper right quadrant.

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