Role of Anterior and Posterior Attention Networks in Hemispheric Asymmetries during Lexical Decisions

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Abstract

■ The role of the left and right hemisphere was examined during semantic priming by antonyms, remote associates, and unrelated words. Targets presented directly to the left hemisphere showed an early facilitation and a late developing inhibition, while targets presented directly to the right hemisphere showed a late developing facilitation of strong and weak associations and little evidence of inhibition. When a visual cue was given prior to each target word, reaction times were facilitated equally in both visual fields and for all prime target relationships. When the priming task was combined with shadowing, reaction times generally increased and all evidence of inhibition in left hemisphere processing disappeared. This supported the idea that the inhibition found in the left hemisphere was due to its interaction with the anterior attention network. ■

INTRODUCTION

One of the most remarkable features of cerebral organization is the different functions of the left and right hemispheres (Gazzaniga, 1985). The most dramatic evidence for lateral asymmetry comes from the study of patients following section of the corpus callosum and anterior commissure. In these split-brain patients, it is possible to examine the functioning of each cerebral hemisphere in isolation, as the left and right hemispheres no longer communicate. The study of patients with unilateral brain damage also demonstrates a clear functional difference between hemispheres.

One theoretical interpretation of lateral asymmetries in normal persons is the attentional model first advanced by Kinsbourne (1970). According to Kinsbourne's reasoning, the functional specialization of the hemispheres explains only small amounts of asymmetry in the performance of normal persons because the two divisions are linked at various levels by transverse commissures. The sizable asymmetry often reported is the product of different allocations of attention between hemispheres, which may increase, diminish, or even reverse the asymmetries due to functional specialization.

Kinsbourne (1970) proposed that verbal activity would activate a large portion of the left hemisphere and, as a result, language activity would lead to a tendency to turn the head and eyes to the right and an attentional bias to the right side of space. Even the expectancy for verbal input could serve to activate the left hemisphere. On the other hand, nonverbal material would serve to activate the right hemisphere and bias attention to the left. His attentional model has influenced many studies of perceptual laterality (Bryden, 1982).

Some of the difficulties of Kinsbourne's original model have been pointed out. Hellige, Cox, and Litvac (1979) examined the influence of concurrent verbal memory on verbal laterality tasks. The effects of concurrent verbal memory tasks, which should prime the left hemisphere according to the Kinsbourne prediction, produced a reduction of the left hemisphere advantage as load induced by memory set size increased. To explain this result, they proposed that the left hemisphere functions as limited-capacity information processing. To deal with these results, Kinsbourne and colleagues advanced the idea that low loads produce activation and enhanced improvements of stimuli in the opposite visual field while high loads interfere with processing contralateral stimuli.

These ideas would be strengthened if they were combined with an anatomical analysis of attention itself. Imaging techniques led to ideas about the functional anatomy of the attentional system (Posner & Petersen, 1990). The posterior attention system involves at least portions of the parietal cortex, associated thalamic areas of the pulvinar and reticular nucleus, and parts of the midbrain's superior colliculus and it has a role of orienting attention to a location in space. The anterior attention system involves areas of the midprefrontal cortex and is used to detect events, including the semantic processing of language. The anterior system is thought to be involved when one attends to word meaning in the semantic priming task. According to Posner (1988), the difference between Kinsbourne (1970) and Hellige et al. (1979) might relate to the dissociation between the posterior and anterior systems. In light load tasks orienting of the posterior attention system may be the major contributor to performance, while in the high load tasks the ability to focus the anterior attention on higher level processing may be more important. The present research tries to examine directly the role of anterior and posterior attention systems in hemispheric asymmetries during semantic processing of words.

While it is well accepted that the left hemisphere plays a major role in language function, some role in language has also been attributed to the right hemisphere. In one divided visual field study, each hemisphere presented its own unique profile in semantic priming (Burgess & Simpson, 1988). Dominant meanings of ambiguous words (Money–Bank) involved mainly left hemisphere activation while subordinate meanings (i.e., River–Bank) were facilitated in the right hemisphere and inhibited in the left hemisphere. Burgess and Simpson (1988) argued that the right hemisphere has a special role in ambiguity resolution.

According to one view of semantic priming the inhibitory effects when an unrelated word is compared to a neutral condition are due to attention (Posner & Snyder, 1975). Thus it is possible that the inhibition of the subordinate meaning by the left hemisphere is due to attending to the dominant meaning. However, while Burgess and Simpson (1988) seem to suggest that allocation of attention may be causing their pattern of results their study did not include the neutral condition necessary for measuring the inhibition effect.

Semantic priming is thought to depend on the prime activating items in the semantic network which lies in the left inferior prefrontal cortex (Petersen, Fox, Posner, Minton, & Raichle, 1988). Semantic activation spreads through this network over time. It is hypothesized that the left hemisphere has a dominant role in inhibiting unrelated stimuli by active attention to likely meanings, while the right hemisphere emphasizes the passive continued maintenance of both strongly related and distantly related words. In the present study, targets were primed by antonyms, remote associates, or unrelated words. Antonyms serve as the highly associated word pairs.

The goal of this study was to determine the role of posterior and anterior attention systems in lateral differences in word processing. The first experiment is designed as a conceptual replication of Burgess and Simpson (1988). It allows examination of the lateral differences in prime patterns that were previously reported by Burgess and Simpson. The second experiment determines the role of the posterior attention system. The third experiment determines the role of the anterior attention system alone and in relation to the posterior system.

RESULTS

Mean RTs for correct responses, along with error proportions of three experiments, are shown in Tables 1 through 3, respectively. Statistical analyses were carried out on mean RT for correct word responses. A parallel analysis was carried out on the error proportion. All facilitation and inhibition effects were assessed relative to the neutral condition.

Experiment I

Visual field, word pair relationship, and SOA are within-subject factors for a repeated measures ANOVA, which was conducted. A significant main effect for visual field was found, $F(1, 29) = 44.7$, $p<.001$ with, as expected, lower RTs to targets presented to the right visual field. This is consistent with previous findings of the left hemisphere advantage in lexical decisions. The effect of relationship was significant, $F(3, 27) = 10.7$, $p<.001$. A significant main effect for SOA was also shown, $F(1, 29) = 22.7$, $p<.001$. Visual field and SOA interacted, $F(1, 29) = 12.2$, $p<.01$, with the difference between the two SOA's larger in the right visual field than in the left visual field. The three-way visual field × word pair relationship × SOA interaction was significant, $F(3, 27) = 4.3$, $p<.02$. This interaction was examined separately for each visual field (Fig. 1).

For left visual field targets, the two-way interaction of word pair relationship × SOA was not significant, $F(3, 27) = .69$. However, both main effects of word pair relationship and SOA were significant, $F(3, 27) = 6.0$, $p<.01$, $F(1, 29) = 34.7$, $p<.001$, respectively. Simple main effect tests showed that at the 67 msec SOA, unrelated targets were marginally inhibited, $F(1, 29) = 4.2$, $p<.05$. At the 750 msec SOA, facilitation occurred for the antonym targets, $F(1, 29) = 16.4$, $p<.001$, but not for remote associated target, $F(1, 29) = 0.05$. There was no significant inhibition for unrelated target, $F(1, 29) = 1.7$. These results indicate that when the targets are presented to the left visual field, the longer the SOA, the stronger is the facilitation of relevant pairs. There is little evidence of any inhibition.

For right visual targets, the two-way interaction of word pair relationship × SOA was significant, $F(3, 27) = 7.7$, $p<.001$. Both main effects of word pair relationship and SOA were also significant, $F(3, 27) = 10.4$, $p<.001$, $F(1, 29) = 5.2$, $p<.04$, respectively. Simple main effects tests showed that at the 67 msec SOA, only antonym targets have a facilitatory trend, $F(1, 29) = 3.1$, $p<.09$. At the 750 msec SOA, inhibition for unrelated targets occurred, $F(1, 29) = 33.3$, $p<.001$ and remote associated targets were also inhibited, $F(1, 29) = 5.7$, $p<.03$, while the antonym targets were still significantly facilitated, $F(1, 29) = 6.1$, $p<.02$. These results indicate that when the targets are presented to the right visual field, the

Table 1. Mean Lexical Decisions Latencies (in msec) and Error Proportions for Each Target Condition

Prime	*Reaction Time*	*SD*	*Error Rate*
67 msec—left visual field			
Opposite	742	104	.13
Remote	766	114	.16
Unrelated	802	151	.22
Neutral	759	110	.23
67 msec—right visual field			
Opposite	668	103	.05
Remote	676	83	.075
Unrelated	700	116	.096
Neutral	689	92	.094
750 msec—left visual field			
Opposite	661	91	.044
Remote	698	112	.063
Unrelated	718	122	.14
Neutral	701	107	.094
750 msec—right visual field			
Opposite	613	64	.016
Remote	670	80	.066
Unrelated	698	89	.10
Neutral	640	62	.063

Table 2. Mean Lexical Decision Latencies (in msec) and Error Proportions for Each Target Condition

Prime	*Reaction Time*	*SD*	*Error Rate*
Uncued—750 msec—left visual field			
Opposite	654	107	.055
Remote	687	96	.062
Unrelated	710	122	.072
Neutral	709	107	.065
Uncued—750 msec—right visual field			
Opposite	677	103	.048
Remote	709	120	.034
Unrelated	696	87	.055
Neutral	682	95	.052
Cued—750 msec—left visual field			
Opposite	628	100	.048
Remote	639	103	.055
Unrelated	669	94	.097
Neutral	663	120	.062
Cued—750 msec—right visual field			
Opposite	628	100	.027
Remote	649	91	.069
Unrelated	659	97	.072
Neutral	635	94	.059

longer the SOA the more inhibition of remote associated and unrelated targets occurs.

An analysis of error rates indicates that they generally are greater when RTs are longer. Fewer errors were made on targets presented to the right visual field, $F(1, 29) = 22.8, p<.001$ and at the long SOA, $F(1, 29) = 31.8, p<.001$. The main effect of the word relationship was also significant, $F(3, 27) = 9.2, p<0.001$. Visual field and SOA interacted, $F(1, 29) = 23.1, p<.001$. That is, SOA was differently effective in each visual field.

Table 3. Mean Lexical Decision Latencies (in msec) and Error Proportions for Divided Attention Condition

Prime	*Reaction Time*	*SD*	*Error Rate*
Uncued—750 msec—left visual field			
Opposite	75	140	.062
Remote	755	161	.079
Unrelated	767	161	.069
Neutral	763	155	.069
Uncued—750 msec—right visual field			
Opposite	749	137	.037
Remote	744	127	.072
Unrelated	759	121	.083
Neutral	774	150	.062
Cued—750 msec—left visual field			
Opposite	744	144	.055
Remote	715	141	.076
Unrelated	720	121	.062
Neutral	745	152	.072
Cued—750 msec—right visual field			
Opposite	693	138	.045
Remote	723	149	.069
Unrelated	717	115	.072
Neutral	707	132	.065

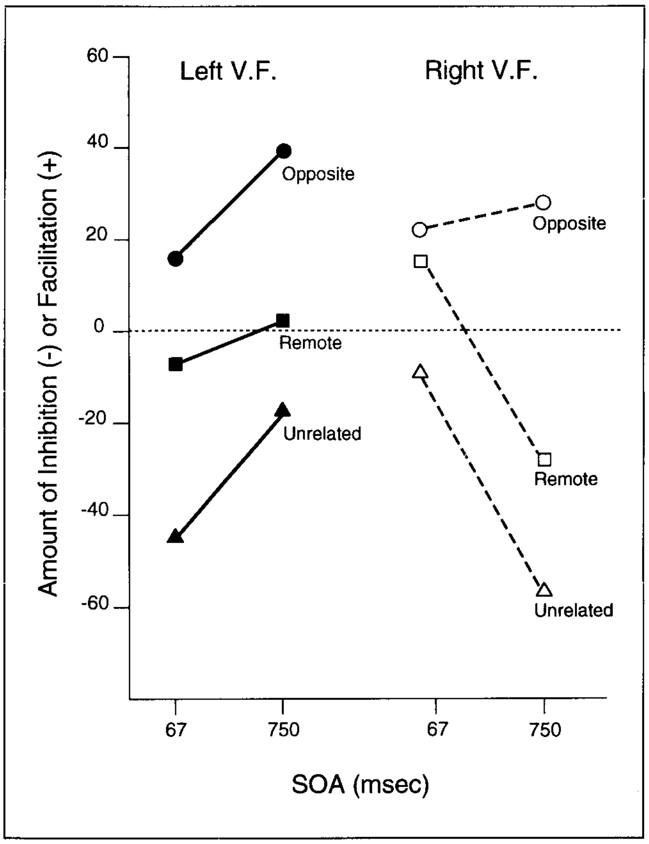


Figure 1. Mean inhibition or facilitation of opposite, remotely associated, and unrelated words at 67- and 750-msec SOAs for the left and right visual field. Experiment I.

Discussion

The results of experiment I were entirely consistent with those of Burgess and Simpson (1988). The left hemisphere facilitatory trend for highly associated targets occurred at both 67 and 750 msec SOAs. An inhibitory effect for unrelated and weakly associated targets occurs by 750 msec SOA. This pattern of results is similar to what would be expected if the stimuli were presented at fixation and subjects encouraged to attend to the prime (Posner & Snyder, 1975), a rapid facilitation that was maintained over time with a growing inhibition for targets that would be rarely correctly predicted. The results for targets presented directly to the right hemisphere contrast remarkably with the pattern found for the left hemisphere. At the 750 msec SOA, no inhibitory effect for unrelated and weakly associated targets occurred, while the highly associated targets are facilitated. This corresponds to the pattern expected with more automatic activation. If attentional mechanisms are thought to be the cause of the slowly developing inhibition, then the results of experiment I suggest that attention might be operating only in conjunction with the left hemisphere.

In order to determine the role of the posterior attention system on these patterns of priming, one-half the trial subjects was shown a brief visual cue immediately before the target and in the same field as the target. The cue was thought to direct attention to the field of the target. We expected to find faster RTs on cued trials since covert visual attention would be at the correct location. If the right visual field advantage observed in the experiment I and widely reported in studies with verbal stimuli (Beaumont, 1982) is due to the posterior attention system being biased toward the right visual field, perhaps because of lateral biases during reading, we might expect more improvement in the right field than in the left on cued trials. If the difference in pattern between the two fields is due to covert visual attention, we might also expect left visual field pattern to emerge only on uncued trials.

Experiment II

A repeated measured ANOVA was conducted on the mean RTs shown in Table 2. There was a highly significant effect of cue condition $F(1, 23) = 75.7$, $p<.0001$. However, no subjects spontaneously noticed the existence of the brief visual cues when they were questioned after the experiment. Nonetheless, RTs were 44.3 msec faster during cued trials than for uncued trials. Cue condition did not interact with visual field or word pair relationship, $F(1, 23) = .82$, $F(3, 21) = 1.04$.

There were no significant main effects for visual field, $F(1, 23) = .10$. However, main effects for word pair relationship were significant, $F(3, 21) = 13.1$, $p<.0001$. The only significant interaction was between visual field and word pair relationship, $F(3, 21) = 4.2$, $p<.02$.

The overall patterns of RTs (Fig. 2) were similar to those of experiment I with 750 msec SOA (Fig. 1). That is, in the left visual field, target words had trends of facilitation, while inhibition occurred for the right visual field targets. For example, remotely associated targets in the right hemisphere showed a trend of facilitation both in cued and uncued conditions, $F(1, 23) = 2.9$, $p<.1$, $F(1, 23) = 3.2$, $p<.08$. On the other hand, for left hemisphere targets, significant inhibition occurred both in cued and uncued conditions, $F(1, 23) = 6.0$, $p<.02$, $F(1, 23) = 4.9$, $p<.03$.

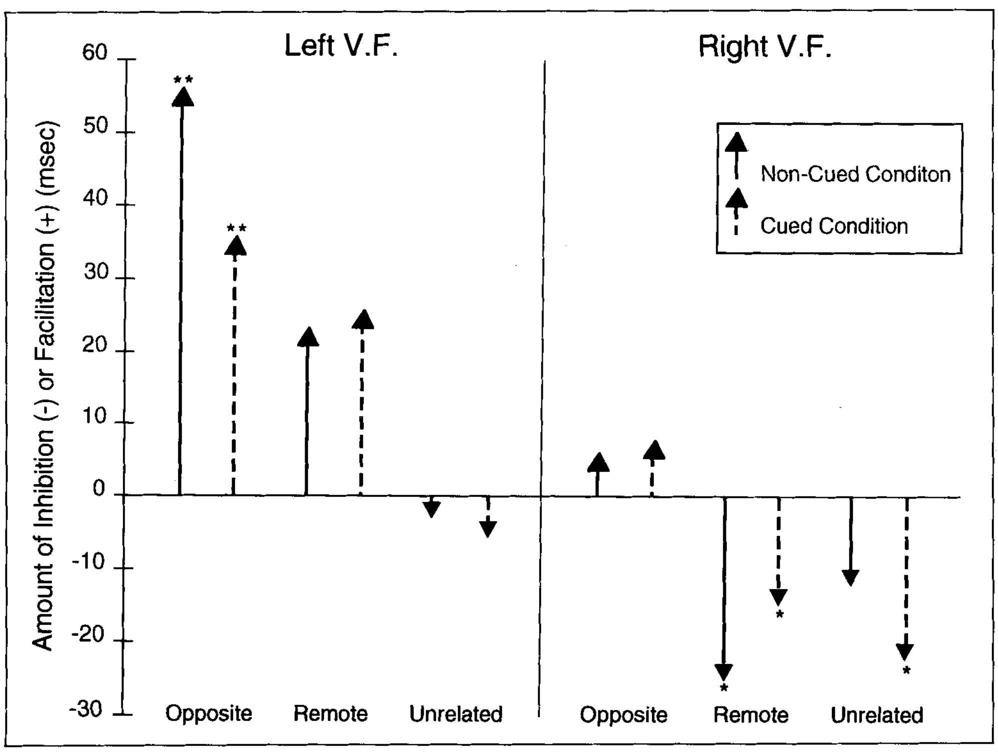
The analysis of error rate showed that neither visual field nor cue main effects were significant, $F(1, 23) = 1.03$, $F(1, 23) = .74$. However, the main effect of the word pair relationship was marginally significant, $F(3, 21) = 2.8$, $p<.07$, and it suggests that more errors were made on unrelated targets.

Discussion

Results of experiment II showed that cueing location facilitated reaction times equally in both visual fields and the right visual field advantage observed in experiment I disappeared even on uncued trials. When compared with results of experiment I at 750 msec SOA, there was an overall increase of reaction times to right visual field targets for all trials. The visual cue apparently worked to redistribute the more usual bias toward right visual field targets found in these experiments. Cueing did not affect the hemispheric patterns of semantic priming found in experiment I. These results show that the posterior attention system facilitated lexical decisions without affecting the hemispheric difference in semantic processing.

In experiment III, we used a concurrent auditory shadowing task to tie up the anterior attention system. We also included visual cues to the location of the target. We expect RTs to be slower in dual task trials when

Figure 2. Mean inhibition or facilitation of opposite, remotely associated, and unrelated words at noncued and cued conditions for the left and right visual field. Experiment II. $^*p<.05$; $^{**}p<.01$.



subjects both shadow and perform the lexical decision task together. If the patterns of semantic priming found in experiments I and II relate to the anterior attention system, they should be reduced in dual task conditions. If the posterior and anterior system operate separately in this task we should find additivity of RT effects due to shadowing and due to cueing.

Experiment III

A mixed ANOVA was run on the data of experiment III. The between-subjects factor corresponds to the shadowing condition. The mixed analysis of variance showed a significant shadowing effect, $F(1, 46) = 4.9, p<.03$. As expected, RTs significantly increase in the shadowing condition. The shadowing effect significantly interacted with the effect for word pair relationship, $F(3, 44) = 4.1$, $p<.01$ but with neither visual field nor cue condition, $F(1, 46) = .46$, $F(1, 46) = .56$.

The within-subject factors were visual fields, the word pair relationship, and visual cue condition. The word pair relationship effect and the cue effect were significant, $F(3, 44) = 6.7, p<.001$, $F(1, 46) = 12.9$, $p<.001$. The visual field effect was not significant, $F(1, 46) = .078$. The visual cue did not interact with any other factor.

Therefore, the analysis of RTs for each visual field was based on the average RTs for cued and uncued conditions. The results are are shown in Fig. 3. In the left visual field of Figure 3, facilitation was significant in the antonym and remotely associated targets, $F(1, 23) = 18$, $p<.001$, $F(1, 23) = 5.1, p<.04$. In the right visual field of Figure 3, inhibition was significant to the remotely associated and unrelated targets, $F(1, 23) = 12.3, p<.001$, $F(1, 23) = 9.6, p<.01$. Figure 3 shows that in the shadowing condition, all evidence of inhibition in the left hemisphere disappeared, while a tendency for facilitation was reduced in the right hemisphere. The analysis of error rate showed no significant effect.

Discussion

Results of experiment I suggested that the anterior attention system might inhibit the remotely associated and unrelated targets in the left hemisphere. In experiment III, auditory shadowing, which is supposed to use the anterior attention system (Posner, Sandon, Dhawan, & Shulman, 1990), resulted in disappearance of inhibition in the left hemisphere during lexical decisions. Therefore, the results of experiment III support the inhibitory role of the anterior attention system for semantic priming in the left hemisphere. The results also suggest the independence of the anterior and posterior attention systems, as the shadowing effect did not interact with the visual cue effect.

CONCLUSIONS

The present study examined the role of the anterior and the posterior attention networks in the process of making lexical decisions to lateralized words. The results were remarkably straightforward and consistent with previous models of lexical decision tasks. Experiment I showed

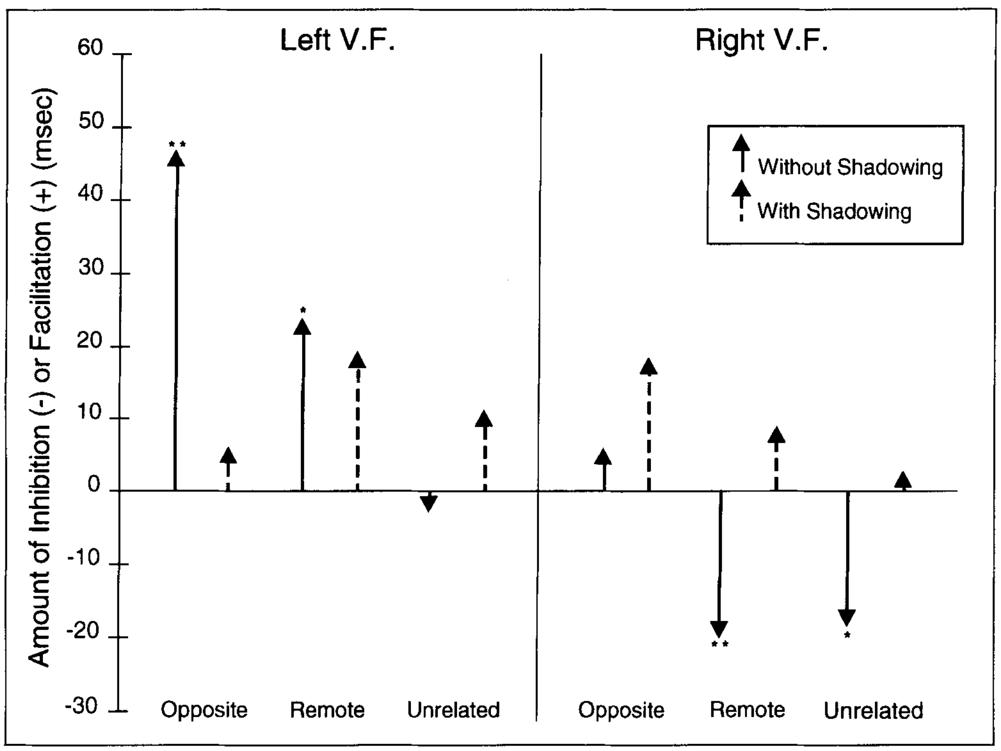


Figure 3. Mean inhibition or facilitation of opposite, remotely associated, and unrelated words at focal and divided conditions for the left and right visual field. Experiment III. *$p<.05$; **$p<.01$.

that the left hemisphere operates in accordance with the automatic and attended mechanisms that have been attributed previously to the system as a whole when targets were presented at fixation (Posner, 1978; Neely, 1977). Very rapid facilitation was found followed after a longer interval by a primarily inhibitory pattern. The right hemisphere pattern had no inhibition and involved unusually strong facilitation even at the longest interval.

In experiment II, the posterior attention system was manipulated by presenting a valid cue on half the trials immediately prior to the target. The cue had a powerful main effect of the type that has been described in many visual detection, search, and discrimination tasks. It speeded RTs by about 45 msec for both visual fields. This facilitation in no way affected the lateralized patterns found in experiment I. Cueing the subject's attention to a target location appears to speed processing but not change the patterns characteristic of the two hemispheres. The cue did not seem to act via the conscious attention of the subject, since no subjects introspected its presence. One feature of the data of experiment II was somewhat surprising, the right visual field advantage that is usually observed for verbal targets and that was found in experiment I disappeared even on no cue trials. Comparison of uncued trials in experiment II with the results of experiment I at the same SOA revealed that an increase of RTs to the right visual field targets resulted in disappearance of the right visual field advantage in experiment II. RTs to the left visual field targets were almost identical in both experiments I and II. Assuming that the lateral advantage for the right visual field is related to a covert attention bias usually assigned to the right of fixation in reading, this evidence suggests that the use of visual cues might facilitate more balanced attention to both visual fields even when no cues are presented. However, this is only a post hoc explanation of the data pattern between separate experiments that could also have arisen from other factors.

While the posterior system had no important effect on the hemispheric priming patterns, the anterior attention system, thought to be involved in semantic processing (Petersen et al., 1988), clearly did. The effect was to abolish all evidence of inhibition and establish symmetry between the two hemispheres. Since attention has been traditionally thought to create inhibition (Neely, 1977; Posner, 1978), this is confirmation of the role traditionally given to attention in semantic priming. Burgess and Simpson (1988) speculated on the basis of the time course of processing for high and low dominance items in the two hemispheres that difference could be a result of attentional mechanisms. Thus, these results support their basic idea.

How do we imagine that these asymmetric semantic priming effects take place? The basic idea is that patterns of activation occur in parallel in each cerebral hemisphere. Beeman (1990) summarized results that the right hemisphere processes infrequent or less dominant associations. Right frontal patients lose the ability to appreciate humor and show evidence of lost associative skills needed to produce inferences during discourse that are made very automatically by normal subjects. However, Beeman's results may not indicate that the basic underlying associative networks differ between the hemispheres. Instead, the left associative network might interact more readily with the active (attended) expectations and thus quickly reduce the effectiveness of low associations, less dominant meaning of ambiguous words, and even inferences that would be achieved through activation of related ideas. If the right hemisphere does not interact with attention as readily, one would expect it to process a more general facilitatory pattern. These hemispheric asymmetries may be compared with those obtained from PET studies of processing visual and auditory words (Petersen, Fox, Posner, Mintun, & Raichle, 1989). In one task, subjects were asked to name the most frequent use of an item. A left lateralized area conforming to the semantic network was found active as well as a midline area related to attention. It is possible that no right frontal activation was found because the instruction to deal with the dominant use brought attention to the left hemisphere and since attended brain areas are more active (Corbetta, Meizin, Dobmeyer, & Shulman, 1990) and PET has a relatively high threshold, that was all that was found to be active. We view the interaction between the anterior attention system and semantic processing as much like that between the posterior system and aspects of the visual word form. For the latter, there are now specific computational models (LaBerge & Brown, 1989; Mozer & Behrmann, 1990) and we expect that the same will be possible for the anterior attention interaction with the semantic network.

In experiment III no significant interaction between the anterior and the posterior attention systems was observed. However, in Posner, Sandon, Dhawan, and Shulman (1989), auditory shadowing was shown to delay shifts of visual attention. From this interaction, they argued that the anterior attention system relates semantic and visual spatial information. On the other hand, Pashler (in press) has demonstrated that under some conditions visual attention shifts can be free from the higher selective mechanisms of attention. The lack of statistical interaction between the anterior and the posterior systems is consistent with the Pashler (in press) finding that both attention systems can work independently. Their strong anatomical connections as well as other cognitive results suggest that they often work together, but the constraints governing their interaction are not yet clear.

The present study may be seen as a complement to the findings outlined in the previous paper (Compton, Grossenbacher, Posner, & Tucker, 1991). Together they draw on prior PET studies of anatomy, using both high density ERP methods and dual task and cueing to explore the neural systems underlying lexical decisions. The results of the present experiments show that the associative processing underlying semantics is different when the target is presented to the right rather than the left visual field. This difference may or may not reflect a difference in the underlying semantic networks in the two hemispheres. However, these asymmetries do depend on the availability of the anterior attention system. They disappear when this system is kept busy by a divided attention task. It should be possible to use imaging methodologies to further explore the basis of these asymmetries.

METHOD

Subjects

In the first, second, and third experiments, respectively, 30 (15 male, 15 female), 24 (11 male, 13 female), and 24 (12 male, 12 female) right-handed undergraduate students participated. All were native English speakers with normal or corrected-to-normal vision. Handedness was assessed by a five-item hand preference questionnaire (Bryden, 1982), which yields an index ranging from +1.00 (extreme right-handed preference) to −1.00 (extreme left-handed preference). All participants had an index of at least +0.60. Subjects were paid $5.00 per hour for their participation.

Stimuli

Each trial involved two stimuli, a prime and a target. One stimulus list consisted of 48 pairs of four different relationships between prime and target. It included 12 antonym, 12 remotely associated, 12 unrelated, and 12 neutral pairs. The antonym pairs were selected on the basis of Roget's International Thesaurus (1977). The remote associates were taken from the Palermo and Jenkins (1964) norms and the Nelson, McEvoy, Walling, and Wheeler (1980) norms. The word Blank was always used as the neutral prime.

So that the target words do not appear repeatedly in one stimulus list, four word lists were prepared. A target that appeared in the antonyms condition in list A (Loose–Tight), appeared in the remotely associated condition of list B (Shoes–Tight), in the unrelated condition of list C (Noon–Tight), and in the neutral condition of list D (Blank–Tight). Thus, through four stimulus lists, subjects respond to the same target word following four different primes. Nonword targets were formed by replacing letters of real words, while maintaining pronounceability. All stimuli were horizontally presented.

Procedure

Subjects received four word lists in four separate blocks. Each block consisted of 48 word and 48 nonword targets. List order was counterbalanced and each list was presented in a different random order for every subject. The blocks were separated by brief rest periods during which feedback on accuracy was provided.

In the first experiment, each trial began with a fixation cross in the center of the screen. The prime was presented after a 500-msec SOA in the center location for 67 msec. This was followed by the mask for the balance of the SOA (67 or 750 msec). The target was presented at the end of the SOA for 200 msec randomly to the left or right visual field. The inner edge of the target was positioned 3° from the center of the screen. A mask followed the target for 50 msec. Subsequent trials were automatically presented. Response accuracy and reaction times were stored by computer for later analysis. Before the experiment, four blocks of practice trials (16 trials per block) were given.

In the second experiment, each trial begins with presentation of both a central fixation cross and two boxes below the cross. The inner edges of two boxes were approximately 1.5° either to the left or right of center. After 500 msec had elapsed, the prime word appeared centered above the cross for 67 msec and was then masked for 683 msec. When the prime word appears, the central fixation cross disappears. After a 750-msec SOA, the target occurred randomly for 150 msec in one of the two boxes. The inner edge of the target was 3° to the left or right of the center. Targets were not masked. On the cued trials, following a 583-msec interval after the prime presentation, the two boxes in which a target would appear, was brightened. All cues were valid indicators of the target location. On cued trials, there was a 100-msec interval between the onset of the cue and the onset of the target. Within each block of 96 trials, 50% were cued and 50% were uncued. Before the experiment, four blocks of practice trials (16 trials per block) were given.

The procedure of the third experiment is the same as the second experiment except the shadowing task was added. During the shadowing task, subjects were asked to repeat the auditory tape as accurately as possible. In four blocks of practice trials (24 trials per block), the first two blocks were lexical decision alone. After this practice, subjects were instructed to perform the lexical task while maintaining the speed and accuracy of their shadowing. The last two blocks of practice were combined with the shadowing.

In all three experiments, subjects were instructed to fixate on the central cross and to attend to the first (prime) stimulus in each trial. Their task was to determine whether the second stimulus (target) was or was not a real English word. Responses were made by pressing one of two response keys with the index and middle fingers of the right hand. Subjects were asked to respond as quickly and accurately as possible. In the second and third experiments, subjects were informed that a target will appear either in the right or left box. In the second and third experiments subjects were not informed about the cue until completion of the experiment.

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REFERENCES

Beaumont, J. G. (1982). Studies with verbal stimuli. In J. G. Beaumont (Ed.), *Divided visual field studies of cerebral organization.* New York/London: Academic Press.

Beeman, M. (1990). *Coherence inferencing and structure building in the cerebral hemispheres.* Unpublished doctoral thesis. University of Oregon, Eugene, OR.

Bryden, M. P. (1982). *Laterality: Functional asymmetry in the intact brain.* New York: Academic Press.

Burgess, C., & Simpson, G. B. (1988). Cerebral hemispheric mechanisms in the retrieval of ambiguous word meanings. *Brain and Language, 33,* 86–103.

Chiarello, C., Burgess, C., Gage, L. & Pollock, A. (1990). Semantic and associative priming in the cerebral hemispheres: Some words do, some words don't, . . . sometimes, some places. *Brain and Cognition, 38,* 75–104.

Compton, P., Grossenbacher, P., Posner, M. I., & Tucker, D. M. (1991). A cognitive–anatomical approach to attention in lexical access. *Journal of Cognitive Neuroscience, 3,* 305–313.

Corbetta, M., Meizin, F. M., Dobmeyer, S., Shulman, G. L., & Petersen, S. E. (1990). Selective attention modulates neural processing of shape, color and velocity in humans. *Science, 248,* 1556–1559.

Gazzaniga, M. S. (1985). *The social brain.* New York: Basic Books.

Hellige, J. B., Cox, P. J., & Litvac, L. (1979). Information processing in the cerebral hemispheres: Selective hemispheric activation and capacity limitations. *Journal of Experimental Psychology: General, 108,* 251–279.

Kinsbourne, M. (1970). The cerebral basis of lateral asymmetries in attention. *Acta Psychologia, 33,* 193–201.

Kinsbourne, M., & Byrd, M. (1985). Word load and visual hemifield shape recognition: Priming and interference effects. *Attention and Performance X* (pp. 669–681). Hillsdale, NJ: Lawrence Erlbaum.

LaBerge, D., & Brown, V. (1989). Theory of attentional operations in shape identification. *Psychological Review, 96,* 101–124.

Mozer, M. C., & Behrmann, M., (1990). On the interaction of selective attention and lexical knowledge: A connectionist account of neglect dyslexia. *Journal of Cognitive Neuroscience, 2,* 96–123.

Neely, J. H. (1977). Semantic priming and retrieval from lexical memory. *Journal of Experimental Psychology: General, 106,* 226–254.

Nelson, D. L., McEvoy, C. L., Walling, J. R., & Wheeler, J. W., Jr. (1980). The University of South Florida homograph norms. *Behavior Research Methods and Instrumentation, 12,* 16–37.

Palermo, D. J., & Jenkins, J. J. (1964). *Word association norms—grade school through college.* Minneapolis, MN: University of Minnesota Press.

Pashler, H. (In press). Dual-task interference and elementary mental mechanisms. In D. E. Meyer & S. Kornblum (Eds.) *Attention and Performance XIV,* Hillsdale, NJ: Lawrence Erlbaum.

Petersen, S. E., Fox, P. T., Posner, M. I., Mintun, M., & Raichle, M. E. (1988). Positron emission tomographic studies of the cortical anatomy of single-word processing. *Nature (London), 331,* 585–589.

Petersen, S. E., Fox, P. T., Posner, M. I., Mintun, M., & Raichle, M. E. (1989). Positron emission tomographic studies of the processing of single words. *Journal of Cognitive Neuroscience, I,* 153–170.

Posner, M. I. (1978). *Chronometric explorations of mind.* Hillsdale, NJ: Lawrence Erlbaum.

Posner, M. I. (1988). Structure and functions of selective attention. In T. Boll & B. Bryant (Eds.), *Master lectures in clinical neuropsychology and brain function: Research, measurement, and practice.* Washington, D.C.: American Psychological Association.

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience, 13,* 25–42.

Posner, M. I., & Snyder, (1975). C.R.R. Facilitation and inhibition in the processing of signals. *Attention and Performance V* (pp. 669–681). New York: Academic Press.

Posner, M. I., Sandon, J., Dhawan, M., & Shulman, G. L. (1989). Is word recognition automatic? A cognitive-anatomical approach. *Journal of Cognitive Neuroscience, 1,*50–60.

Roget's International Thesaurus (4th ed.) (1977). New York: Harper & Row.