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Semantic Processing in the Neglected Visual Field: Evidence from a Lexical Decision Task

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The present study examined the possibility of a dissociation between visual information processing and conscious awareness of that processing in patients with unilateral visual neglect. Implicit processing of visual information was measured in the context of a semantic priming task (Experiment 1) in which patients made lexical decisions to centrally located targets following the presentation of lateralised picture primes. Like normal controls, patients with unilateral neglect showed equivalent priming when related picture primes were presented to the left or to the right visual field. This contrasts with the performance of a patient with a dense left hemianopia without neglect who did not show priming from the affected field.

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To contrast performance on the implicit task with that on a task requiring explicit awareness of visual information, Experiment 2 used a delayed discrimination task, in which patients had to match a lateralised target to one of two centrally presented alternatives. As expected, patients with neglect, as well as a hemianopic patient, had marked difficulty in discriminating targets presented in the left visual field.

The dissociation between processing of meaning and conscious awareness of this information is difficult to reconcile with theories of neglect that imply a complete interruption in the early processing of sensory information. Rather, current models should accommodate the possibility that neglect reflects only a partial disruption in the formation of visual representations. Alternatively, neglect can be conceptualised as a disorder in accessing these representations intentionally.

INTRODUCTION

A number of different theories have been proposed to account for the phenomenon of hemispatial neglect (for a review, see Friedland & Weinstein, 1977; Heilman, Watson, & Valenstein, 1985; Mesulam, 1985), but most current accounts assume that neglect reflects an attentional deficit. The details of this view have been elaborated in a number of ways. Heilman and his colleagues (Heilman et al., 1985; Watson & Heilman, 1979), for instance, have proposed that attentional problems may exist at several functional (and perhaps anatomical) levels ranging from the processing of incoming sensory information to the readiness to respond to stimuli in the neglected side of space. Kinsbourne (1970; 1987) has proposed that neglect reflects an innate bias of the left hemisphere to direct attention to the contralateral side of space. He argues that this bias is usually opposed by inhibition from the right hemisphere, which has its own, albeit less powerful, bias. Following right-hemisphere damage, the left hemisphere's bias is unopposed, thus orienting attention exclusively to the right side of space. In an attempt to define the attentional problems in terms of elementary cognitive processes, Posner and his colleagues (Posner, Walker, Friedrich, & Rafal, 1984) have proposed that neglect patients have a selective inability to disengage from stimuli presented in the ipsilateral side of space. Taken together, these findings suggest that hemispatial neglect may be due not only to contralateral inattention, but also to ipsilateral capture (Mark, Kooistra, & Heilman, 1988; Marshall & Halligan, 1989).

Whatever attentional impairments are at work in neglect, little is known about the actual fate of information falling in the neglected hemispace, as most theories of neglect are vague or contradictory about this issue. It is often implied, however, that the impairment in selective attention causes the patient to lose completely information presented in the contralesional field. This is functionally comparable to a higher order "sensory" deficit, in which information in the neglected field is in effect "filtered out" (Broadbent, 1971) and receives little or no complex visual analysis. For example, Heilman et al. (1985) suggest that contralateral inattention may occur following damage either to multimodal sensory convergence areas or to primary or association cortices. In the former case, this produces an inability (op. cit., p. 261) to be "aroused to, or process, multimodal contralateral stimuli," whereas in the latter case, damage produces an inability to "synthesise contralateral unimodal sensory input." Similarly, Mesulam (1985, p. 157) postulates that damage to the right posterior parietal cortex causes neglect because the "sensory template of the extrapersonal world" is compromised in such a way that it (op. cit., p. 144) "becomes permanently skewed toward the right hemispace without a possibility of flexible leftward shifts." In a similar vein, Bisiach argues (Bisiach, Capitani, Luzzatti, & Perani, 1981, p. 543) that neglect is caused by a disruption of "the left half of the spatial framework of visual representations." Thus, each of these theories implies that sensory information is unavailable for the higher-level operations involved in visual recognition and semantic coding.

Alternatively, however, attention may not be necessary for sensory information processing but may be required only for conscious awareness of that sensory information. Certainly, attention is not a necessary condition for sensory processing under normal, albeit experimental, circumstances. For example, Marcel (1983) showed that even though normal subjects are unable to report that stimuli are being presented, they do process the information for meaning. One explanation for such findings is that the conscious actualisation of a percept is the result of a number of fundamentally different processes. The detection of such basic features as edges, textures, and shadings begins preattentively and outside of conscious awareness (Marr, 1982; Treisman & Gormican, 1988). As processing proceeds, increasingly higher levels of feature abstraction and integration are added until the object is recognised as a cohesive percept to which meaning can be attached (Biederman, 1987; Marr, 1982; Witkin & Tenenbaum, 1983).

Although the early processes described in these theories may occur automatically, the later "synthetic" operations may be mediated by attention and carried out serially (e.g. Neisser, 1967; Treisman & Gormican, 1988). Furthermore, overt or "voluntary" response to visual stimuli may depend on the same processing levels in later vision that are necessary for conscious awareness. Consequently, an interruption at several levels of processing may prevent a percept from reaching conscious awareness, though the information contained within the percept may nevertheless be processed sufficiently at more elementary stages to activate semantic information.

The dissociation between cognitive processing and conscious awareness of information occurs not only in normal individuals as the result of experimental manipulations; it can also be demonstrated in a variety of neuropsychological syndromes (for a review, see Schacter, 1990). Patients who perform poorly on tasks that require explicit use of their impaired function may perform much better on tasks that tap this same function implicitly. Some of the domains in which this has been demonstrated include lexical access in severely aphasic patients (Blumstein, Milberg, & Shrier, 1982; Milberg, 1988; Milberg & Blumstein, 1981; Milberg, Blumstein, & Dworetzky, 1987), procedural and motor skill acquisition in amnesics (Charness, Milberg, & Alexander, 1988; Cohen, 1984; Glisky, Schacter, & Tulving, 1986; Kinsbourne & Wood, 1975; McGlinchey-Berroth, Milberg, & Charness, 1990b; Milberg et al., 1988; Milner, 1962; Milner, Corkin, & Teuber, 1968), implicit priming in amnesia (see Shimamura, 1986), face recognition in prosopagnosics (Bauer, 1984; De Haan, Young, & Newcombe, 1987), and implicit object knowledge in agnosics (Margolin, Friedrich, & Carlson, 1983).

In the present study, we examine to what extent a similar dissociation may exist in patients with hemispatial neglect. There have already been occasional reports demonstrating that some information in the neglected hemispace is processed at least part of the way through the sensory association cortex. In an investigation of reading disabilities in right-hemisphere neglect patients, Kinsbourne and Warrington (1962, p. 343) concluded from the pattern of paralexic errors that "in some rudimentary manner the total word length was perceived," as their subjects' paralexic substitutions were of approximately the same length as the target word. More recently, similar findings have been reported by Ellis, Flude, and Young (1987). Likewise, evidence of processing without awareness was obtained by Marshall and Halligan (1988). These authors presented a neglect patient with two pictures of a house, one of which had flames on the left and one of which did not. Even though the patient judged the pictures to be identical, she nevertheless was able to discriminate implicitly between the two by choosing which one she would prefer to live in. McGlinchey-Berroth, Kilduff, and Milberg (Note 1) demonstrated that in a figure copying task, some neglect patients' performance on the neglected side improved dramatically with the minimisation of visual feedback.

In their discussion of the effect of parietal lobe lesions on attention, Posner et al. (1984) accommodate this literature partially. They suggest (op. cit., p. 1873) that the ability to shift attention simply provides subjects with a more efficient "routing of the stimulus to centres responsible for awareness," in a way similar to that in which eye movements improve the efficiency of processing visual information "by bringing the high acuity portion of the visual system to bear upon the stimulus." By suggesting that focused attention simply provides a more expedient processing route, they imply that the neglected field (being outside of focused attention) is akin to a "peripheral attentional field" from which it can be assumed that some visual processing may occur, though they make no claims about the quantity or quality of this processing. The question arises, therefore, as to the level of processing accorded to information that is not specifically attended.

Using a double simultaneous stimulation (D.S.S.) same/different judgment paradigm, Volpe, LeDoux, and Gazzaniga (1979) demonstrated that although patients were unable to report the identity of a stimulus presented to the neglected side of space, they nonetheless were able to judge whether this stimulus matched another stimulus presented to the intact hemispace. More recently, Audet, Bub, and Lecours (1991) demonstrated that a neglect patient responded more quickly to a centrally located target letter if the target was flanked by the same letter in the neglected hemispace. These findings suggest that some physical identity information can be extracted from the neglected field and can influence performance, provided that the task does not require an explicit response to that information (Riddoch & Humphreys, 1987).

In the present study we examine whether information in the neglected field may be processed for meaning, even though this meaning is not consciously available. This is done using an implicit semantic priming task in which subjects make lexical decisions to a centrally located letter string. These letter strings were preceded by a laterally presented picture prime, which could either be semantically related or unrelated to the target letter string. Simultaneously, a filler picture consisting of randomly jumbled features was presented to the opposite visual field. These pictures were aligned horizontally and presented briefly (200msec.) It was felt that double simultaneous presentation of the priming stimuli would duplicate conditions for unilateral extinction (see Heilman et al., 1985) and, coupled with subsaccadic stimulus display times, would minimise the possibility of subjects shifting their attention overtly toward the critical prime. Therefore, this procedure was thought to be particularly conservative with respect to the hypotheses outlined later. If pictorial information presented in the neglected hemispace is processed sufficiently to activate relatively abstract semantic representations of visual information, neglect patients, like normal controls, will show semantic priming effects irrespective of the visual field in which the critical prime is presented. Performance on the semantic priming task is contrasted with that on a delayed discrimination task. This task is identical to the priming task with regard to the presentation of the critical priming stimuli, but it requires conscious awareness of the information in the neglected field. As such, it serves as an important control to ensure that any priming effects observed are not attributable to explicit processing of the priming stimuli. Since the delayed discrimination task is expected to reflect the behavioural manifestations of the neglect syndrome, performance of the neglect patients should be at chance levels when the target is presented initially in the left visual field and significantly above chance when presented initially in the right visual field.

It is an assumption of our hypothesis that elementary and pre-attentive visual processing in the damaged hemisphere, thought to be mediated by the geniculostriate system, proceeds normally and is necessary for priming to occur. Therefore, we also evaluate a patient with a small lesion in the right occipital lobe with a complete hemianopia but no higher-order visual perceptual deficits. It is hypothesised that, for this patient, performance in the left visual field will be at chance, irrespective of the degree of explicit knowledge required for accurate performance. However, if this patient does show priming in the contralesional field, it would suggest that visual information carried through the extrastriatal visual system is sufficient to activate semantic information. Although the phenomenon of "blindsight" suggests that form information may be carried by this system (Weiskrantz, 1986), the possibility that this information is capable of contacting higher-order semantic representations has not been reported previously.

GENERAL METHOD

Subjects

Four patients with left-sided visual neglect and one patient with a dense left visual field hemianopia, who showed no evidence of neglect, participated as subjects in this study. In addition, a control group comprised of 5 males and 5 females without any history of neurological damage or disease participated in the study. They were matched as closely as possible with the brain-damaged patients with regard to age (mean = 61 years) and education (mean = 14 years).

Each potential subject (in the patient groups) was given a number of clinical tests that are used in the diagnosis of neglect. These included:

1. *Horizontal line bisection.* Patients were asked to place a cross in the midpoint of a series of singly presented horizontal lines of different lengths. Black, Yu, Martin, and Szalai (1990) recently reported that this task may be the most sensitive measure of neglect.
2. *Target cancellation (letters, shapes and lines).* These tasks are designed to assess visual field exploration (Weintraub & Mesulam, 1987). The patient was presented with two fields of targets and distractors, consisting of one task of letters and another of shapes. The subject was required to circle the targets as indicated. In a third task consisting of a field of two-inch lines deviating from the horizontal by various degrees, the subject was asked to trace each line with a pencil line.

3. *Figure drawing.* A simple drawing task was also administered in which patients were asked to copy a cross presented in front of them.

4. *Single word reading.* Neglect patients occasionally omit the first syllable when reading compound words. Therefore, we used a single word reading task to examine to what extent hemispatial neglect extends to processing of lexical information (Benson & Geschwind, 1969; Heilman, Bowers, Valenstein, & Watson, 1987).

5. *Double simultaneous stimulation.* Testing was conducted in the visual, auditory, and tactile modalities using a standardised protocol (Kaplan, Verfaellie, De Witt, & Caplan, 1990).

6. *Anosognosia scale.* To rate the patient's awareness of his illness and disabilities, a series of questions were devised and presented to the patient in the context of a brief, unstructured conversation. These were modelled after the awareness rating scale of Anderson and Tranel (1989).

The patients who were ultimately recruited showed evidence of left visual field neglect on at least four of the above assessments.

Neglect Patients

Patient 1. This patient was a 52-year-old, right-handed female. She had completed 16 years of schooling and her primary language was English. She was tested 10 days post-onset of a large right middle cerebral artery cerebral vascular accident (C.V.A.) encompassing the temporo-parietal junction, confirmed by C.T. On neurologic exam she evidenced poor attention, no affective prosody, and severe impersistence. She sustained dense left hemiparesis but no field deficits were clinically evident upon confrontation testing.

Patient 2. This patient was a 61-year-old, right-handed male. He was a high-school graduate whose primary language was English. He was tested 21 days after onset of a large middle cerebral artery C.V.A. affecting most of the right parietal and superior temporal lobes and extending deep into the white matter. The neurologic exam was remarkable for moderate impersistence, severe spatial impairment, poor insight, severe weakness of the hand, and a partial left visual field cut involving the outer left perimeter, with severe neglect in the remaining portions of the left visual field. Attention span was unaffected.

Patient 3. This patient was a 42-year-old, left-handed male. His primary language was English and he had completed 16 years of education. He was tested 9 days post-onset. C.T. revealed a large right frontal infarction involving premotor and motor cortex and subcortical, but not paraventricular, white matter. His neurologic exam indicated a mild attentional disturbance, left paresis, primarily in the face but also mild in the hand, and no impersistence. There was no sensory loss or visual field defect.

Patient 4. This patient was a 58-year-old, right-handed female. She was a high school graduate, and her primary language was English. She had suffered a hypertensive intracerebral haemorrhage. She was tested one month post-onset when C.T.-scan revealed lucency of the right lateral putamen, paraventricular white matter, and deep frontal and temporal white matter. Examination revealed marked motor impersistence and aprosody at the time of testing. She did not show evidence of a visual field defect, but neglected the left visual space, particularly to double simultaneous stimulation.

Hemianopic Patient

Patient 5. This patient was a 72-year-old right-handed male. He was a high school graduate whose primary language was English. He was tested 11 days post-onset of a small right occipital haemorrhage in the medial portion of the calcarine fissure, confirmed by C.T. His neurological exam indicated a dense left hemianopia with no paresis or other sensory loss. Further, his attention span was normal with no impersistence. Prosody and insight were normal. There was no evidence of neglect.

Apparatus

The experiments employed an Apple Macintosh SE micro-computer. The software was designed for the control of stimulus presentation, timing, and the recording of responses with millisecond accuracy. Manual responses were recorded via 2 telegraph keys interfaced with the computer via a modified keyboard. Face position relative to the computer screen was maintained with a standard ophthalmological chin-rest, centred 12 inches from the screen. The chin-rest height was adjustable so that the individual subject's eyes were at the same level as the fixation point presented on the monitor.

Procedure

All subjects were tested in a quiet, softly lit laboratory space located either at the West Roxbury Veterans Administration Hospital or at the Braintree Hospital. The entire protocol, including the experiments and neuropsychological testing, was conducted over a varying number of sessions lasting one to two hours each, depending on the patient's level of fatigue. In the first session(s), background information and neuropsychological data were collected. The two experiments were then administered in the next session, in the order of Experiment 1 followed immediately by Experiment 2. All of the patients completed the entire protocol within a two-week period.

EXPERIMENT 1

As stated earlier, the purpose of this experiment was to determine if visual information may be processed for meaning in the neglected field when information processing is assessed implicitly by means of a semantic picture priming task. Evidence of processing in the neglected space is expected to be revealed by an overall semantic priming effect that is not dependent on the visual field in which the priming stimuli appear.

Method

Stimuli and Design

In this experiment, pictures served as the priming stimuli and letter strings (words and nonwords) served as targets. To construct the target stimuli, 120 high-frequency words were chosen from the norms of Francis and Kuçera (1982). Half of these stimuli were used as real word targets, and the other half, matched for word length, were changed into nonwords by substituting 1 letter, but respecting the rules of English orthography.

The priming stimuli consisted of 70 pictures of concrete common objects and were selected from the corpus of line drawings developed by Snodgrass and Vanderwort (1980). On critical trials, a priming stimulus was presented in either the left or right visual field. Simultaneously, a filler stimulus was presented in the opposing field, so as to avoid a stimulus-induced bias in the patient's allocation of visual attention. The filler stimuli were constructed by dividing all of the priming pictures into small pieces and randomly re-mixing the pieces to form new, semantically meaningless fillers. In this manner 170 filler stimuli were constructed. An attempt was made to match these fillers to the priming stimuli with regard to the amount of visual information they contained as well as overall visual intensity. Additionally, they were judged by two independent raters to ensure that the resulting stimuli were not meaningful.

In the 60 trials in which the target stimulus was a real word, 3 different types of primes were used. One third (i.e. 20) of the primes were semantically related to the target, one third were unrelated to the target, and the final one third were composed of 2 meaningless filler "priming" stimuli that served to balance the number of word and nonword target trials. On the 60 trials in which the target stimulus was a nonword, half of the primes were real objects, and the other half were neutral primes consisting of scrambled pictures. The order of the trials was randomised for each subject.

Procedure

At the beginning of each trial, an asterisk centred on the video display monitor was displayed for 500msec. This was followed immediately by the presentation of the prime and filler stimuli for 200msec. The relatively short exposure of the priming stimuli was employed to minimise the possibility of saccadic eye movements. The prime and filler were centred 1.5 degrees to the left and right of the centre of the display monitor. Following an inter-stimulus-interval (I.S.I.) of 400msec., the target string was displayed centrally and remained on the screen until a response was made by the patient. This time course is depicted graphically in Fig. 1. Yes/No decisions as well as the latency (in milliseconds) from target onset to patient's response were recorded by the computer.

The subjects were told that two events would appear on the computer screen, one immediately following the other. It was explained that the first event would be composed of two "drawings" that might or might not represent an actual object. They were asked to focus on the centrally located fixation point, as the drawings would only be displayed for a very brief period of time. In addition, they were told that the second event appearing on the screen would be a letter string that might or might not spell a real English word. They were instructed to simply watch the display monitor and to respond only to the second event by depressing with the index finger of their right hand the telegraph key marked "YES" if the target letter string was a word and to depress the key labelled "NO" if it was not a word. The telegraph keys were oriented vertically so as to minimise the risk of a rightward bias in response. Prior to responding, the subject rested their index finger on a board mid-way between the two

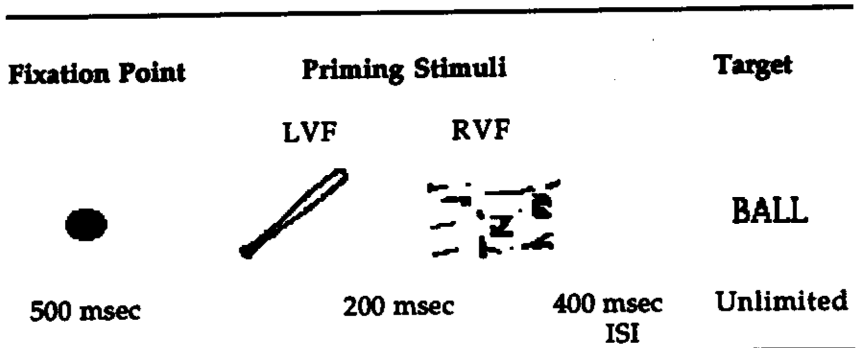

FIG. 1 Example and time course of a left visual field prime and related target in Experiment 1 (pictures represent bitmap approximations of actual test stimuli).

telegraph keys. They were encouraged to respond as quickly and as accurately as possible.

The subjects were tested individually in a session lasting no longer than 30 minutes. After practice, they were presented with 120 experimental trials, divided into 6 blocks of 20 trials each. During the course of testing, the patients were watched carefully by the examiner to ensure that they maintained attention to the task. Patients were given a brief rest after each block.

Results

For each patient, the mean response latency for correct lexical decisions to words and nonwords was calculated as a function of prime condition. Because only trials on which word targets were preceded by related and unrelated primes are directly relevant to this study, only these conditions are considered further. Mean response latencies, standard deviations, and error rates for the remaining conditions are presented in Appendix A.

During the course of testing, patients occasionally seemed to lose the set of the task (e.g. sitting and staring at the monitor, or looking away from the monitor). This behaviour probably reflects the generalised deficits in attention frequently ascribed to this patient group (Mesulam, 1985). In these cases, the patients were reminded to respond in order to trigger the next experimental trial. However, to eliminate these invalid trials from the analyses, response latencies more than two standard deviations removed from the mean of that trial's condition were eliminated. This procedure resulted in eliminating a maximum of three data points for any one subject, and did not appear to be systematically related to any particular condition. The corrected means and standard deviations, as well as the lexical decision error rates, are presented in Table 1.

For the purpose of analysis, the data obtained from the neglect patients and the hemianopic patient were treated as independent case studies and examined separately. In addition, the data from the neglect patients were combined and analysed as a group. Data from the control subjects were treated as a group only. Because response latencies for the brain-damaged patients were significantly longer than those obtained from the control subjects, a direct statistical comparison between the neglect patients and the control group was not performed. Instead, we focus on similarities/differences in the pattern of results obtained for the patients and the control group.

Prior to individual data analysis, each of the brain-damaged patients' data were tested for normality by means of the Chi Square goodness-of-fit test and transformed where necessary. To normalise the data, a log trans-

TABLE 1
Results for Real-Word Targets Preceded by Related and Unrelated Primes in Experiment 1

Subject	L.V.F Related	L.V.F Unrelated	R.V.F Related	R.V.F Unrelated	L.V.F.[a] Priming	R.V.F.[a] Priming
Patient 1	3950[b] (1801)[c] 3[d]	7206 (4084) 4	4647 (2640) 1	7252 (3154) 3	3256	2605
Patient 2	1604 (449) 0	1808 (492) 0	1196 (235) 0	1676 (570) 0	204	480
Patient 3	932 (119) 2	1509 (721) 0	1127 (329) 1	1302 (622) 1	577	175
Patient 4	1718 (248) 0	2328 (1806) 0	1546 (280) 1	1890 (1376) 0	610	344
Patient 5 (hemianopic)	1623 (394) 1	1651 (604) 0	1205 (307) 0	1391 (637) 0	28	186
Control Group (n = 10)	956 (378) 1	1026 (462) 3	960 (411) 0	982 (362) 0	70	22

[a]The priming score reflects the difference in latency to related and unrelated trials.
[b]Corrected mean decision latencies (msec).
[c]Standard deviations.
[d]Total errors.

form was applied to the data of one neglect patient (Neglect 1), the log of residuals was computed for another (Neglect 3), and the square root of the residuals was used to normalise the data of the hemianopic patient. These data were then analysed using the Wald Chi Square with Prime (related, unrelated) and Visual Field (LVF, RVF) as within-subjects factors. This test allows analysis of repeated measures designs with incomplete data, using maximum likelihood to estimate missing data (B.M.D.P./V5, 1990).

Neglect Patients

Patient 1. Results of the Wald Chi Square revealed a marginally significant effect of related versus unrelated primes ($\chi_{(1)} = 3.24, P < 0.07$). The overall priming effect, derived by subtracting the decision latency on related prime trials from that on unrelated prime trials, equalled 2930msec. The effect of visual field was not significant ($\chi_{(1)} = 0.35$, $P > 0.05$), indicating that the visual field in which the critical prime was presented did not affect the patient's decision times. The interaction between visual field and prime type was also nonsignificant ($\chi_{(1)} = 0.001$, $P > 0.9$), suggesting that the magnitude of priming was not affected by the visual field in which the priming pictures were presented.

Patient 2. The Wald Chi Square indicated a significant effect of visual field ($\chi_{(1)} = 4.34$, $P < 0.03$), indicating that on the average, targets preceded by right visual field (R.V.F.) primes were responded to 270msec. faster than targets preceded by left visual field (L.V.F.) primes (mean L.V.F.: 1706; mean R.V.F.: 1436). The effect of prime type was also significant ($\chi_{(1)} = 6.95$, $P < 0.008$). The mean response latency to targets preceded by related pictures was 1400msec., and the mean response latency to targets preceded by unrelated pictures was 1742msec., yielding a priming effect of 342msec. The interaction between visual field and prime type was not significant ($\chi_{(1)} = 1.15$, $P > 0.2$), suggesting that the priming effect did not differ in the left and right visual fields.

Patient 3. The Wald Chi Square indicated a significant effect of prime type ($\chi_{(1)} = 4.10$, $P < 0.04$). The mean response latency to targets preceded by related pictures was 1030msec., and the mean response latency to targets preceded by unrelated pictures was 1406msec., yielding a priming effect of 376msec. The effect of visual field ($\chi_{(1)} = 0.07$, $P > 0.5$), as well as the interaction between visual field and prime type ($\chi_{(1)} = 0.001$, $P > 0.9$), were not significant. Thus, the priming effect did not differ as a function of the visual field in which the critical prime was presented.

Patient 4. The Wald Chi Square revealed a significant main effect of prime type ($\chi_{(1)} = 5.35$, $P < 0.02$). The mean response latency to targets preceded by related pictures was 1632msec., and the mean response latency to targets preceded by unrelated pictures was 2110msec., yielding a priming effect of 477msec. The effect of visual field was nonsignificant ($\chi_{(1)} = 1.30$, $P > 0.2$). The interaction between visual field and prime type was again nonsignificant ($\chi_{(1)} = 0.15$, $P > 0.694$), suggesting that the priming effect did not differ in the left and right visual fields.

Group Analysis of Neglect Patients

To determine the overall reliability of the findings for the lexical decision task, the trimmed mean correct decision latencies presented in Table 1 for cases 1 through 4 were collapsed to form one data set. Similar to the independent analyses, the Wald Chi Square for repeated measures was then used to determine the within subject effects of visual field (L.V.F., R.V.F.) and priming condition (related, unrelated).

Even though the number of neglect patients sampled was small, the results of this group analysis were significant and consistent with the individual analyses and the predictions specified earlier. A slight advantage was found for target words preceded by a critical prime in the R.V.F. (2580msec.) compared to the L.V.F. (2632msec.). This advantage, however, was not significant ($\chi_{(1)} = 1.03$, $P = 0.874$). In contrast, priming condition produced a robust 1032msec. advantage for related primes compared to unrelated primes ($\chi_{(1)} = 9.77$, $P = 0.002$). Decisions to targets preceded by semantically related pictures averaged 2090msec. whereas those preceded by unrelated pictures averaged 3122msec. Although slightly more priming was found when critical primes were presented in the L.V.F. (1162msec. priming effect) than in the R.V.F. (901msec. priming), this interaction was not significant ($\chi_{(1)} = 0.16$, $P = 0.693$). Thus, priming was not dependent on the visual field in which the priming stimuli were presented in this sample of patients.

Hemianopic Patient

The Wald Chi Square indicated that the visual field in which the priming picture was presented significantly affected this patient's decision latencies ($\chi_{(1)} = 4.34$, $P = 0.04$), such that decisions were made more quickly when the critical prime was presented in the R.V.F. (1298msec.) compared to when it was presented in the L.V.F. (1637msec.). The overall effect of prime type was not significant ($\chi_{(1)} = 0.02$). The mean response latency to targets preceded by related pictures was 1414msec. and the mean response latency to targets preceded by unrelated pictures was 1521msec., yielding an overall priming effect of 107msec. The interaction between visual field and prime type was also nonsignificant ($\chi_{(1)} = 1.15$) for this patient. However, the pattern of results suggests that the priming effect was greater in the R.V.F. (mean = 186msec.) than in the L.V.F. (mean = 28msec.).

Control Group

The data were analysed by means of a two-way repeated measures analysis of variance with prime type (related, unrelated) and visual field (L.V.F., R.V.F.) as within-subjects factors. This analysis revealed a highly significant priming effect ($F_{(1,9)} = 11.38$, $P < 0.01$), indicating that target words preceded by related primes were responded to significantly faster than target words preceded by unrelated primes. The mean latency for related targets was 958msec., and the mean latency for unrelated targets was 1004msec., indicating an overall priming effect of 46msec. The effect of visual field was not significant ($F_{(1,9)} = 0.96$; mean L.V.F. = 991msec.; R.V.F. = 971msec.), nor was the interaction between priming condition and visual field ($F_{(1,9)} = 0.66$).

Discussion

A group analysis of the neglect patients sampled revealed that word/nonword judgments for centrally located target items were significantly affected by lateralised picture priming stimuli. Moreover, this effect did not appear to be dependent on the patients having seen the critical priming picture in their non-neglected right visual field, as no evidence was observed of an interaction between visual field and prime type. In other words, the picture primes presented in the neglected visual field were as effective in influencing performance as when they were presented in the intact visual field. As Table 1 indicates, this finding was consistent for each of the four neglect patients tested. Statistical analyses conducted on the individual neglect subjects indicated that this effect was highly significant in patients 2, 3, and 4 and marginally significant in patient 1.

The same pattern of results was found for the age-matched control subjects. The priming condition significantly affected subsequent lexical decisions independently of the visual field the critical prime was presented to. This basic priming effect replicates countless other studies and indicates that the picture priming procedure used in the current investigation was effective in demonstrating a contextual effect of lateralised picture stimuli on subsequent word/nonword decisions. Also similar to the neglect patients, visual field by itself was not a significant factor affecting performance in the control group.

The findings from the neglect patients and the control subjects contrast with the findings of a hemianopic patient. Although the interaction between visual field and prime type was not found to be significant, the pattern of data clearly suggests little or no priming in the L.V.F. compared to the effect observed in the R.V.F. This pattern of results is consistent with a loss of elementary visual processes in the right hemisphere and indicates that processing to the level of semantic activation requires the elementary intrahemisphere processes dependent on the direct visual pathways emanating from the occipital lobe.

Finding a semantic priming effect in neglect patients supports previous reports indicating that visual sensory information may be processed in the neglected left visual field at least part of the way through the sensory pathways. Further, it suggests that the information available in the neglected space can be processed for meaning. Though unlikely, it is possible that the observed priming resulted from the fact that the priming pictures were actually processed to levels sufficient to support awareness. In other words, we cannot rule out the possibility that priming occurred because the picture primes were actually not neglected by the neglect patients. This possibility is investigated in Experiment 2.

EXPERIMENT 2

This experiment involves a direct discrimination of pictures presented in the neglected field under conditions virtually identical to those in the lexical decision experiment. This second experiment provides a critical control for Experiment 1 in that it uses the same stimuli and presentation conditions, but requires an explicit response. The performance of the neglect patients in this task is expected to be at chance in the left visual field and above chance in the right visual field.

Method

Stimuli and Design

The stimuli for this experiment consisted of 60 line drawings of objects, identical to those used in Experiment 1. Thirty of these were used as targets, whereas the remaining 30 were used as foils. The foils were visually and semantically unrelated to the target. They were selected with the additional proviso that the right side of the foil should be sufficiently different from the target so as to allow correct discrimination even if patients only explored the right side of the picture. Additionally, 30 scrambled pictures were constructed by recombining pieces of the target pictures in a manner similar to that described in Experiment 1. These scrambled pictures were used as neutral fillers and were presented simultaneously with a target picture in the opposite visual field. The target picture appeared equally often in the left and right visual fields. Following each presentation of these lateralised stimuli, a test trial was presented, consisting of the target picture as well as a foil, presented vertically one on top of the other. The positioning of the correct choice on either the top or bottom of the display was counterbalanced across trials and the order of the trials was randomised for each subject.

Procedure

At the onset of each trial, an asterisk was presented on the centre of the screen for 500msec. This was followed by the simultaneous presentation of a target stimulus and a neutral filler, centred 1.5 degrees to the left and the right of centre, for 200msec., again to minimise the possibility of eye movements. Following an I.S.I. of 400msec., the target stimulus and a foil were presented in midline, centred 2 degrees above and below the centre of the screen. In order to provide the subject with unlimited time to explore these stimuli, they remained on the screen until a response was made. Responses were recorded automatically by the computer. An example of a trial and time course is presented in Figure 2.

Subjects were instructed to keep their eyes on the fixation point, and to be ready for the presentation of two stimuli, which would be presented only briefly. They were then asked to attend to the two vertically aligned stimuli, and to depress one of two keys, also aligned vertically, to indicate which of the two stimuli appearing on the video monitor they had just viewed. They were asked to depress the telegraph key labelled "TOP" if they thought they had just seen the picture located on the top and to depress the key labelled "BOTTOM" if they thought they had just seen the picture located at the bottom.

Testing did not exceed 20 minutes. During this time, the subjects were presented with 10 practice trials followed by 60 experimental trials.

Results

In this task, chance performance was calculated as a window of probability (with $P = 0.05$) surrounding the absolute chance performance of 50%. According to this calculation, chance performance was determined as lying between 37% correct and 63% correct in each visual half field.

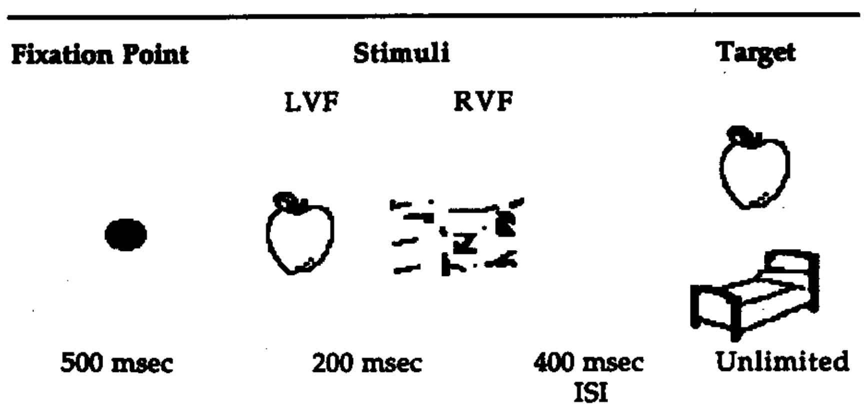

FIG 2. Example and time course of a trial in Experiment 2 (pictures represent bitmap approximations of actual test stimuli).

Patient 1. The patient correctly chose only 50% of the pictures that had been presented in the L.V.F. (chance performance) but was correct on 81% of the trials in which the target was presented in the R.V.F. The difference between fields was significant ($\chi^2_{(1)} = 10.26$, $P < 0.001$). Correct performance on this task was a function of the visual field in which the determinant was initially presented.

Patient 2. This patient correctly chose 75% of the pictures that had been presented in the L.V.F. and 94% of the pictures that had been presented in the R.V.F. Although this patient's performance was greater than chance in the L.V.F., his performance was significantly better in the R.V.F. than the L.V.F. ($\chi^2_{(1)} = 9.6$, $P < 0.01$).

Patient 3. Performance was at chance in the L.V.F. (50% correct) but was above chance in the R.V.F. (70% correct). Though chance performance was observed for L.V.F. stimuli and above chance for R.V.F. stimuli, the difference in accuracy across the two fields was not significant ($\chi^2_{(1)} = 2.62$, $P > 0.05$).

Patient 4. Unlike the previous 3 cases, this patient performed identically in the left and right visual fields ($\chi^2_{(1)} = 0.0$, $P = 1.0$), responding correctly on only 50% of the trials. She was fatigued during this test session and had great difficulty in remaining alert. We were unable to schedule a repeat session with better alertness.

Combined as a group, the neglect patients averaged chance performance in the L.V.F. (56% correct) and above chance in the R.V.F. (74% correct). Overall, accuracy in performing correct discriminations was significantly better in the R.V.F. than in the L.V.F. ($\chi^2_{(1)} = 9.69$, $P < 0.01$).

Hemianopic Patient

The data from the delayed discrimination task was similar to that found in the neglect patients. The percentage of correct discriminations in the L.V.F. was 44%, whereas the percentage of correct discriminations in the R.V.F. was 81%, resulting in a significant effect of visual fields on performance ($\chi^2_{(1)} = 14.77$, $P < 0.001$).

Control Group

The control subjects had very little difficulty in performing the delayed discrimination task, with only a total of six errors across all ten subjects. Four of these errors occurred when the discriminant was presented in the L.V.F. and two occurred when it was presented in the R.V.F.

Discussion

The results of the delayed discrimination task were in sharp contrast to those from the lexical decision task. Three of the four patients tested (patients 1 through 3) performed better when the discriminant was presented in the right visual field as opposed to the left visual field. Patient 4 performed at chance in both fields. Given the window of chance performance, patients 1 and 3 performed at chance levels in the left visual field, while performing at greater than chance in the right visual field. Patient 2's performance was above chance in both fields but was significantly better in the right than in the left. We attribute the poor performance of patient 4 to observed fluctuations in concentration during this test. The results from the hemianopic patient were as expected in this task. This patient performed at chance in the blind field and better than chance in the normal field. As expected, the normal controls performed this task virtually without error.

GENERAL DISCUSSION

This investigation demonstrates that patients with clinical evidence of unilateral, left visual neglect who have reduced (or no) capacity for explicit discrimination of meaningful pictorial stimuli in the left visual field, can extract semantic information implicitly from the same visual stimuli. Furthermore, it appears that in the context of a lexical decision task, they can do so as efficiently for information presented to the neglected field as for information presented to the intact field. This demonstrates conclusively that at least some "neglected" visual sensory information is processed to a level of cognition sufficient to activate semantic representations. In contrast, the data obtained from the hemianopic patient were consistent with a breakdown of elementary visual processes, as this patient showed better performance in both the priming and discrimination task when pictures were presented in the right visual field. Thus, it appears that visual semantic priming is dependent on the integrity of supporting sensory cortical structures. Additionally, the finding of a visual field dependency for priming effects in the case of hemianopia but not in the case of neglect may provide a behavioural means with which to distinguish between these two patient groups who may perform similarly on standard confrontation tests of the visual fields (Kooistra & Heilman, 1989; Walker, Findlay, Young, & Welch, 1991).

The semantic priming effects reported here are difficult to reconcile with any account of neglect that postulates that information is filtered out early in the course of visual processing or is lost due to damage to cortical structures needed to sustain basic sensory representations. Rather, the current data suggest that the pathways critical for the formation of visual representations are at the most only partially disrupted. It may be that only a small but critical subset of the visual information is processed without awareness, but is done so to a degree sufficient to activate semantic representations. The primitive array of basic line segments and distinctive features that are typically processed preattentively (and without awareness) may under some circumstances be sufficient to specify recognisable objects (Marr, 1982) and thereby activate semantic representations. Perhaps this array of visual features is processed without the specification of consistent topological or relational information provided by focussed attention (e.g. Treisman & Gormican, 1988) and is thus treated as "noise" and not assigned sufficient motivation significance to command conscious awareness (Mesulam, 1985, p. 157). Audet et al.'s (1991) recent demonstration of letter identity priming in the contralesional hemispace must at least partially be based on the processing of basic visual features and is consistent with such explanations of neglect.

Alternatively, it is possible that complete sensory representations are created but "cut off" from conscious awareness. For example, highly detailed visual information may initially be maintained as part of a buffer representation. This buffer may be available long enough to allow for short-lived semantic activation but not long enough for this information to be transferred into a more permanently accessible form that permits conscious awareness and/or volitional access (Riddoch & Humphreys, 1987). The latter possibility may be conceptualised as the cognitive equivalent of motor neglect (Heilman et al., 1985), in that the patient cannot intentionally use available information. Another possibility is that complete representations must be inspected by a selective attention mechanism in order for the information to reach conscious awareness. Given that this mechanism cannot disengage itself from information in the intact hemisphere (Posner et al., 1984), information in the neglected space may simply not be inspected and thus cannot reach awareness. At this preliminary stage each of these accounts of neglect are of course quite speculative and await future research. However, the finding that patients with hemispatial neglect can process "neglected" information should help to clarify the nature of this puzzling disorder as well as further our understanding of normal higher-order vision.

A final methodological caution may be raised in the interpretation of the current results. It could be argued that the discrimination/recognition task inherently requires that more attention be directed toward the prime stimulus than does the lexical decision task. Thus lexical decision might provide for less ipsilesional "capture" (Posner et al., 1984) and greater availability of perceptual information than does the discrimination procedure. A direct methodological answer to this issue would be very difficult to obtain. One might ensure that attention directed to the prime be more equivalent across tasks by intermixing trials of the two procedures. Subjects would then have no a priori knowledge of the task and might be induced to attend equally to all prime trials. However, this possibility would have to be explored with patients sufficiently intact to handle the complex set requirements of this procedure. Although there is no current evidence that extinction or neglect are mitigated by instructions to be passive vis-à-vis ipsilesional information, this possibility should also be explored in future research. At this point, one can at least be confident that the forced-choice discrimination task is a conservative and sensitive control for access to contralesional information. Farah, Manheit, and Wallace (1991) recently demonstrated that forced-choice discrimination (similar to the control discrimination procedure described here) was in fact quite sensitive to visual information in patients who otherwise showed neglect under conditions of extinction. Therefore, patients who are otherwise susceptible to conditions producing ipsilesional capture may still show access to contralesional visual information with the forced-choice discrimination method used in this study.

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APPENDIX A

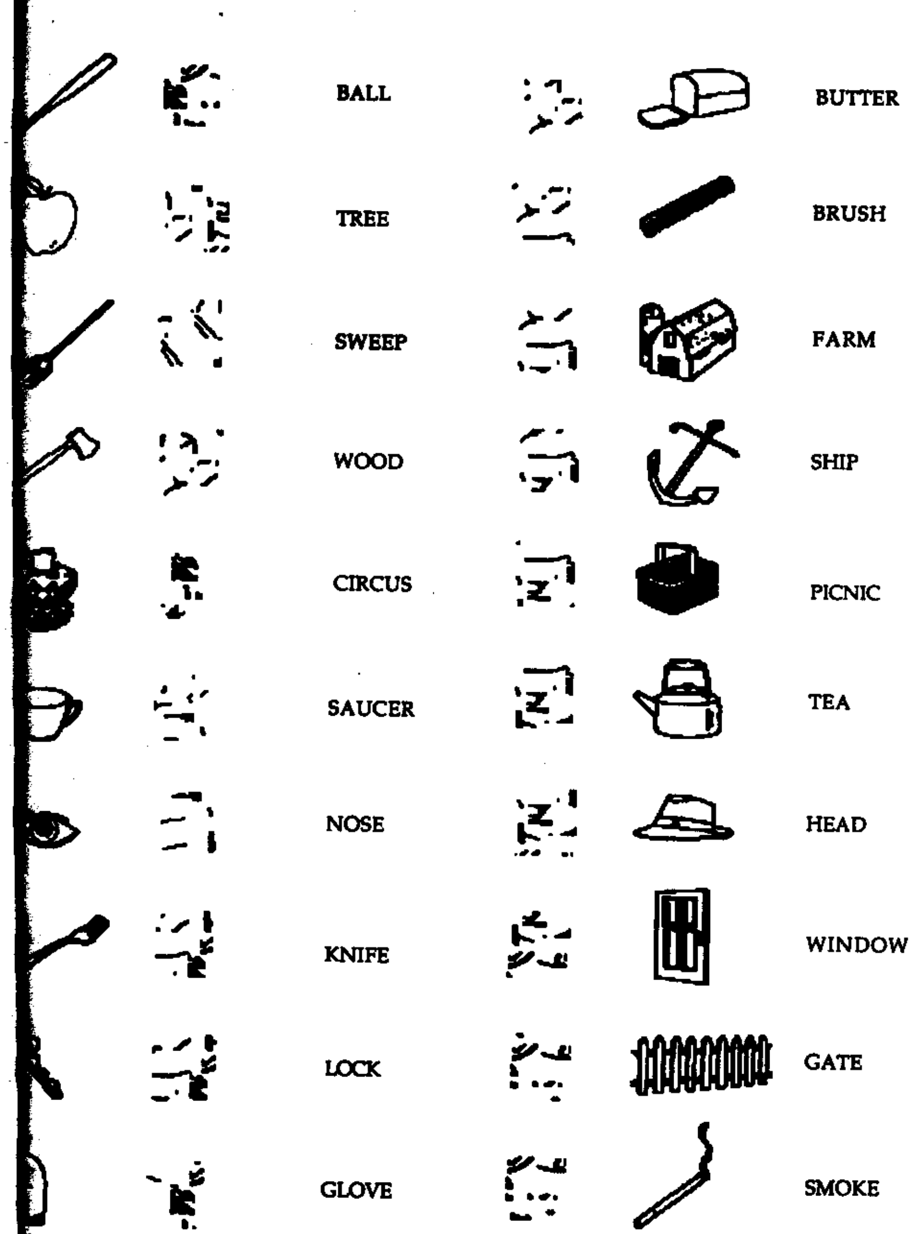
Correct Mean Response Time, Standard Deviation, and Errors for Experiment 1: Semantic Priming in the Neglected Visual Field for Neutrally Primed and Nonword Targets

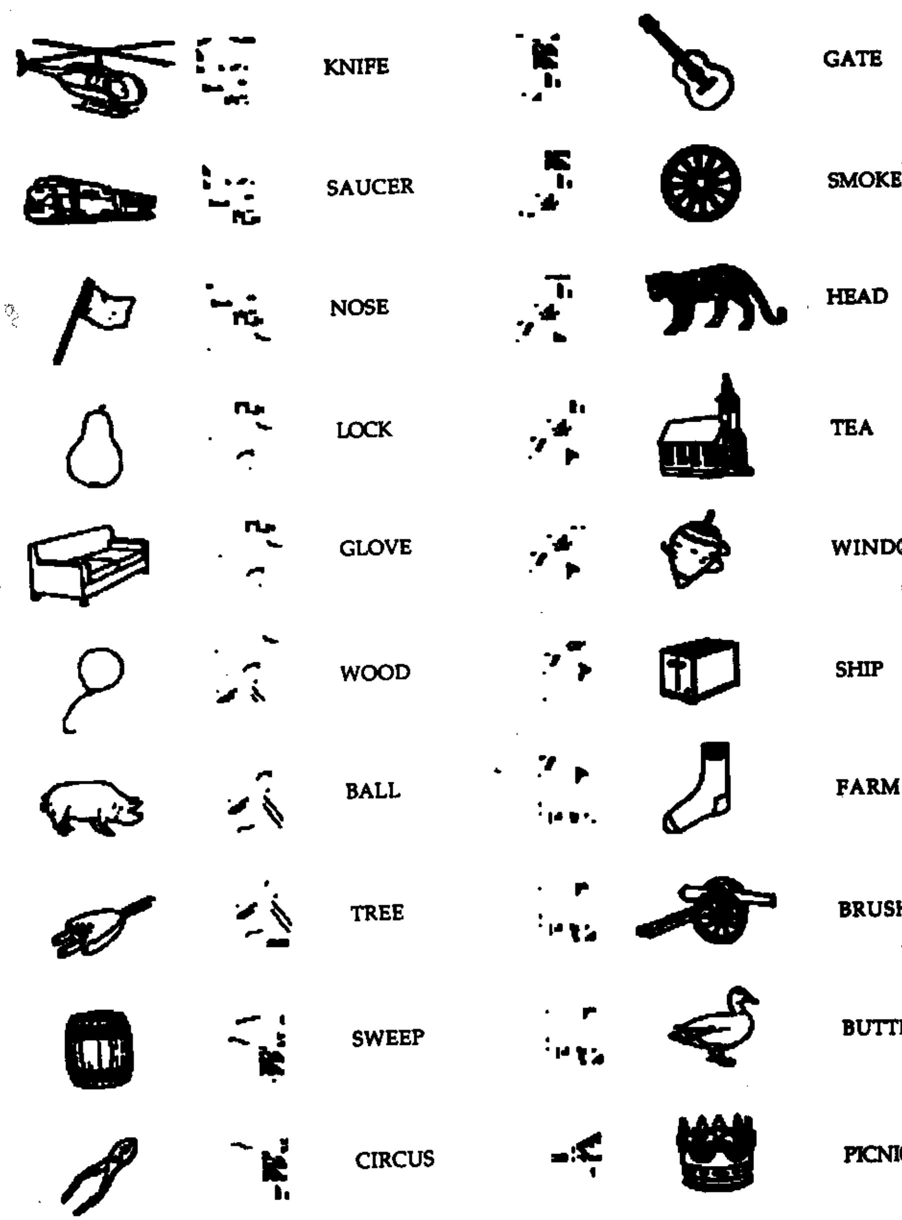
	Trial Type (prime/target)			
Subject	*Scrambled/ Word*	*Picture Left/ Nonword*	*Picture Right/ Nonword*	*Scrambled Left & Right/ Nonword*
Neglect 1	7893 (4823) 6	8412 (5099) 8	9054 (4946) 7	8053 (2636) 11
Neglect 2	1567 (325) 0	2933 (859) 0	2786 (955) 0	2936 (1625) 4
Neglect 3	1580 (1468) 4	2902 (2646) 5	1760 (742) 4	2276 (1754) 13
Neglect 4	2176 (1685) 0	3734 (2573) 1	2647 (1358) 0	3191 (2095) 3
Hemianopic	1539 (617) 0	1959 (721) 0	1723 (525) 0	1558 (721) 0
Normal Conrols (n = 10)	1028 378 1	1623 1326 0	1460 872 10	1476 995 11

APPENDIX B

Test Stimuli for Experiment 1: Picture Priming in Neglect

The pictures on the following pages represent bitmap approximations of actual test stimuli.

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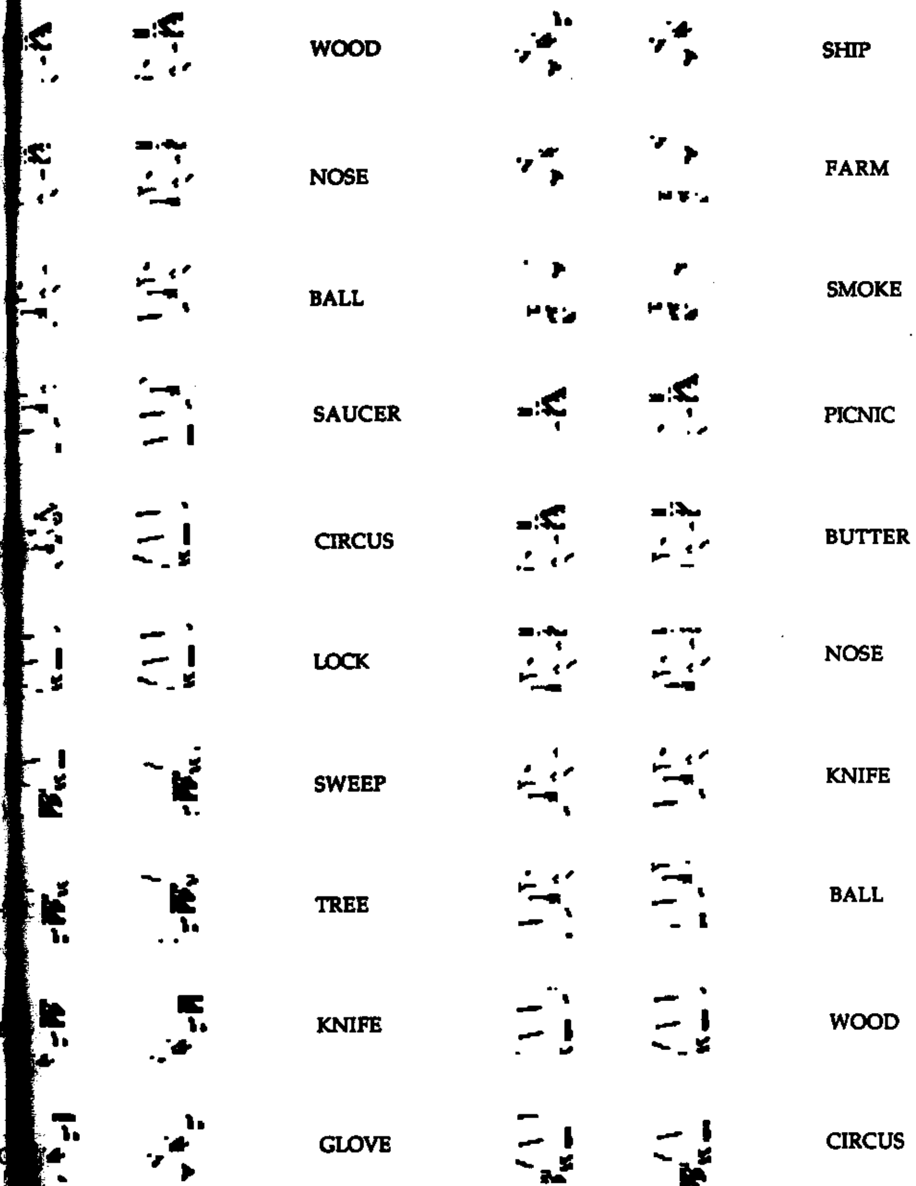
FARM
BRUSH
BUTT
PICNI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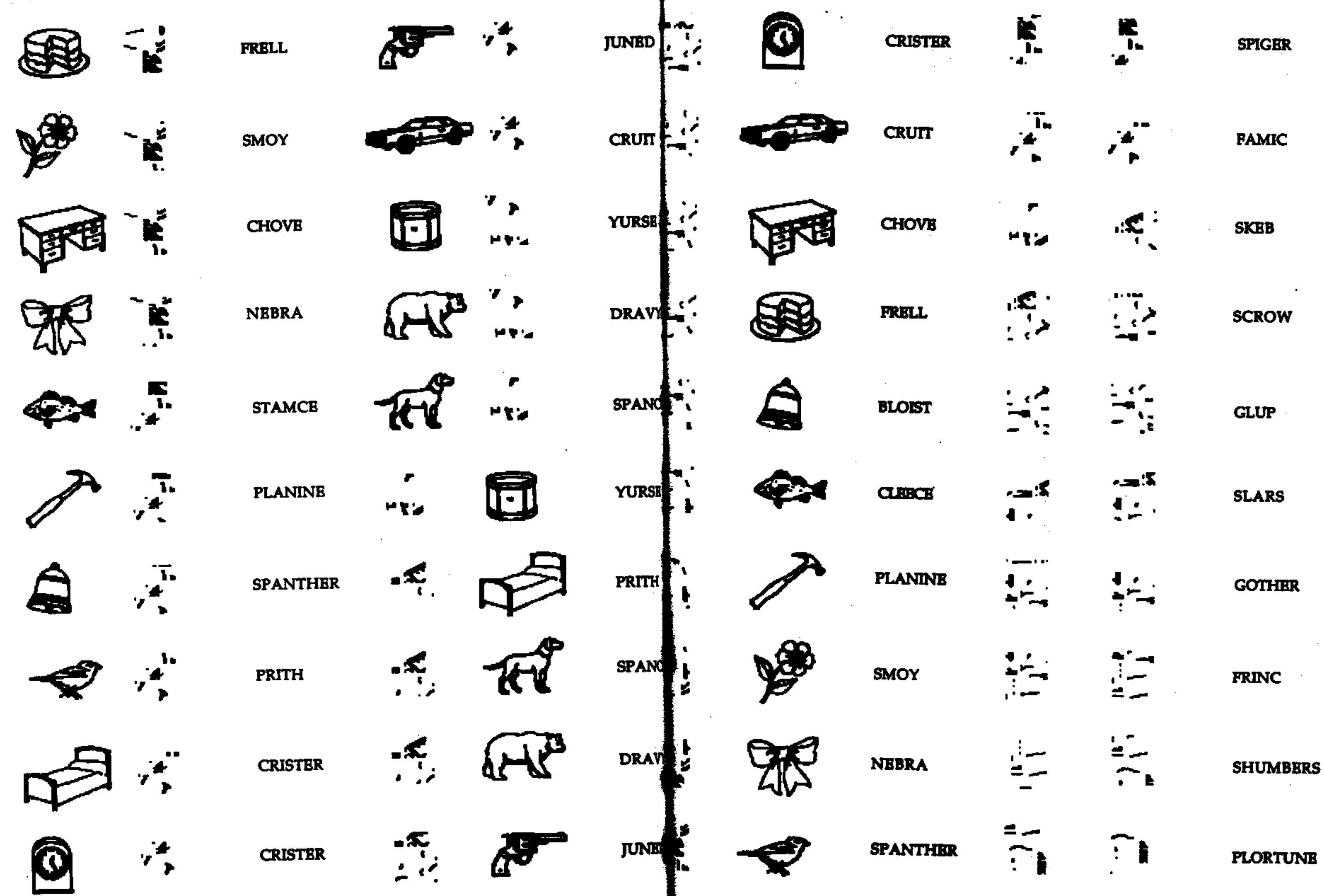
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CHOVE
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SCROW
STAMCE
SPANC
BLOIST
GLUP
PLANINE
YURSE
CLEECE
SLARS
SPANTHER
PRITH
PLANINE
GOTHER
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SMOY
FRINC
CRISTER
DRAV
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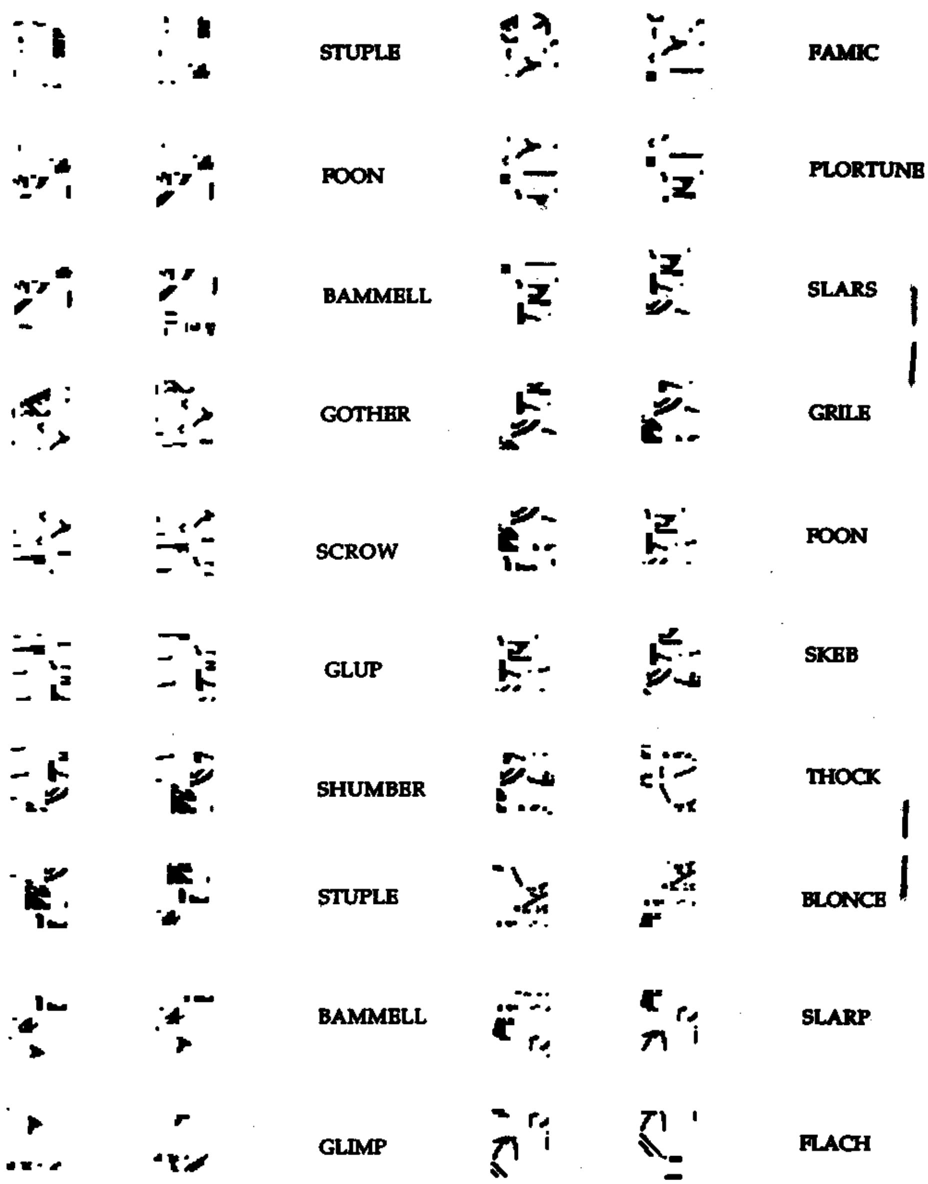
SHUMBERS
CRISTER
JUNE
SPANTHER
PLORTUNE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STUPLE
BLONCE
BAMMELL
SLARP
GLIMP
FLACH