# Testing Memory for Unseen Visual Stimuli in Patients with Extinction and Spatial Neglect

**Patrik Vuilleumier[1], Sophie Schwartz[1], Karen Clarke[1], Masud Husain[2], and Jon Driver[1]**

## Abstract

■ Visual extinction after right parietal damage involves a loss of awareness for stimuli in the contralesional field when presented concurrently with ipsilesional stimuli, although contralesional stimuli are still perceived if presented alone. However, extinguished stimuli can still receive some residual on-line processing, without awareness. Here we examined whether such residual processing of extinguished stimuli can produce implicit and/or explicit memory traces lasting many minutes. We tested four patients with right parietal damage and left extinction on two sessions, each including distinct study and subsequent test phases. At study, pictures of objects were shown briefly in the right, left, or both fields. Patients were asked to name them without memory instructions (Session 1) or to make an indoor/outdoor categorization and memorize them (Session 2). They extinguished most left stimuli on bilateral presentation. During the test (up to 48 min later), fragmented pictures of the previously exposed objects (or novel objects) were presented alone in either field. Patients had to identify each object and then judge whether it had previously been exposed. Identification of fragmented pictures was better for previously exposed objects that had been consciously seen and critically also for objects that had been extinguished (as compared with novel objects), with no influence of the depth of processing during study. By contrast, explicit recollection occurred only for stimuli that were consciously seen at study and increased with depth of processing. These results suggest implicit but not explicit memory for extinguished visual stimuli in parietal patients. ■

## INTRODUCTION

Neglect is characterized by a loss of awareness for stimuli in space opposite to a brain lesion, usually in the right inferior parietal lobe (Heilman, Watson, & Valenstein, 1993). These patients may fail to direct attention towards contralesional events and often show perceptual extinction on double simultaneous stimulation: They fail to detect a left stimulus when presented with another stimulus on the right side, although they can perceive the same left stimulus when presented alone (Driver & Vuilleumier, 2001). Our study asked whether implicit and/or explicit memory might arise for these extinguished stimuli.

Previous neuropsychological studies showed that some residual on-line processing may still take place for extinguished stimuli, despite unawareness. This can range from preattentive grouping mechanisms, presumably relying on intact visual cortex (Vuilleumier, Valenza, & Landis, 2001), to the extraction of structural representations and semantic classification of words and objects (Ladavas, Paladini, & Cubelli, 1993; McGlinchey-Berroth, Milberg, Verfaellie, Alexander, & Kilduff, 1993; Berti & Rizzolatti, 1992), thought to involve temporal lobe areas (see the review in Driver & Vuilleumier, 2001). Moreover, recent functional imaging results (Driver, Vuilleumier, Eimer, & Rees, 2001; Vuilleumier, Sagiv, et al., 2001; Rees et al., 2000) showed that ventral visual pathways can be activated in patients with extinction in the absence of conscious awareness for the stimulus. However, it is unknown whether such activation can be sufficient to create neural traces lasting beyond the brief period of a single stimulus presentation, so as to affect subsequent performance on measures of implicit or explicit memory even after several minutes have elapsed.

Memory can take different forms. While it can manifest in a direct (or explicit) manner, such as when people consciously recollect or recognize a past event, it can also manifest in an indirect (or implicit) manner, such as when performance is influenced by prior exposure to a stimulus, without explicit recollection of that exposure (e.g., Schacter, 1992; Tulving & Schacter, 1990; Warrington & Weiskrantz, 1968). For instance, completion of word stems or identification of degraded pictures can be facilitated by previous exposure to these items, regardless of whether people actually remember having seen them before (e.g., Bowers & Schacter, 1990; Snodgrass & Feenan, 1990). The neural substrates underlying

[1]Institute of Cognitive Neuroscience, London, [2]Imperial College School of Medicine, London

**Table 1.** Clinical Characteristics of the Patients

| *Patients* | *Age* | *Sex* | *Lesion* | *Onset (Months)* | *Neurological Deficits* | *Line Bisection (Mean Deviation)* | *Cancellation (Number of omitted targets)* | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | *L* | *R* |
| C. W. | 66 | M | R PW infarct | 26 | L hand paresis | +35% | 15/30 | 0/30 |
| M. M. | 83 | M | R P infarct | 6 | L hand weakness | +2% | 0/30 | 0/30 |
| S. V. | 61 | F | R FTPW infarct | 48 | L hemiplegia and L hypesthesia | +8% | 17/30 | 0/30 |
| V. K. | 52 | M | R FP infarct | 7 | L hand weakness | +3% | 10/30 | 0/30 |

F = frontal; P = parietal; T = temporal; W = subcortical white matter; R = right; L = left.

implicit and explicit memory are at least in part distinct (e.g., Rugg et al., 1998; Vaidya, Gabrieli, Verfaellie, Fleischman, & Askari, 1998; Moscovitch, Vriezen, & Goshen-Gottstein, 1993; Tulving & Schacter, 1990). Amnesic patients with hippocampal or diencephalic damage can demonstrate intact performance on indirect memory tests such as word fragment or picture completion (e.g., Cermak, Talbot, Chandler, & Wolbarst, 1985; Warrington & Weiskrantz, 1968). Similarly, indirect memory tests in normal subjects often seem unaffected by task manipulations that reduce performance on explicit memory tests, such as shallow versus deep processing or divided versus focused attention during encoding (e.g., Jacoby & Kelley, 1991; Craik & Lockhart, 1972).

Such findings have led to proposals that implicit memory may reflect the reactivation of traces formed within perceptual systems that process a given type of stimulus (Schacter, 1992; Tulving & Schacter, 1990), although some controversies remain. For instance, a contribution of conscious recall during indirect memory tests is often difficult to rule out (Rugg, 1995; Jacoby & Kelley, 1991). Further, while exposure to stimuli under conditions of inattention impairs explicit memory, it is debated whether this leaves implicit memory entirely unaffected (Mulligan & Hornstein, 2000; Ganor-Stern, Seamon, & Carrasco, 1998; Schmitter-Edgecombe, 1996; Szymanski & MacLeod, 1996; Parkin, Reid, & Russo, 1990) or whether implicit learning is

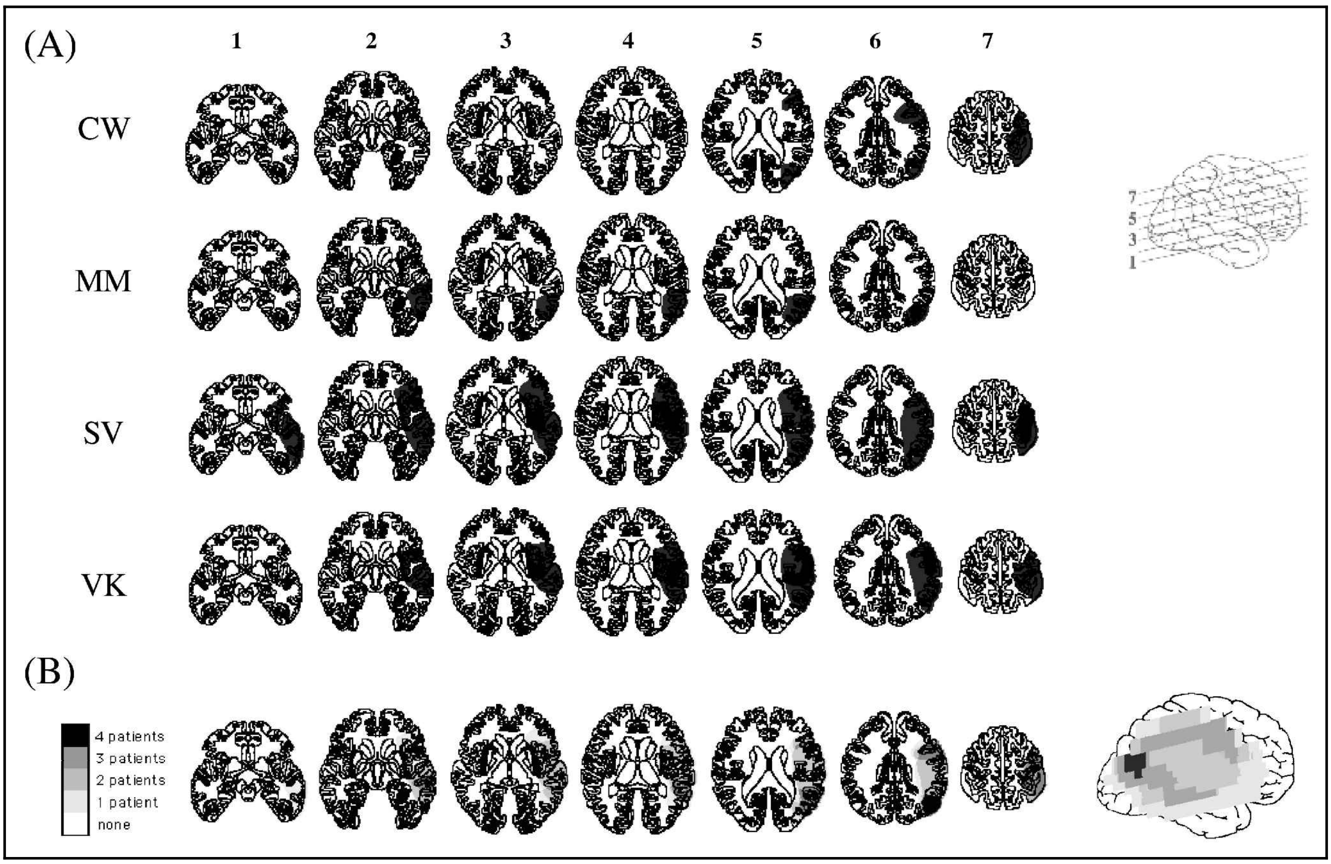



**Figure 1.** Reconstruction of brain lesions. (A) Axial sections showing damaged areas in each patient. (B) Overlap of lesions showing common involvement of the right posterior parietal cortex.

also suppressed with strict inattention (Crabb & Dark, 1999; Bentin, Moscovitch, & Nirhod, 1998; MacDonald & MacLeod, 1998).

Here we studied perceptual learning using both direct and indirect tests of memory in four patients who had left spatial neglect and extinction. All the patients had lesions centered on the right parietal cortex (Table 1 and Figure 1), with intact visual fields on both sides, but reliable left extinction on double visual stimulation. Memory was assessed both for objects that the patients had consciously seen and for objects that had been extinguished from awareness. Both direct and indirect memory tests were given on two sessions, which each included distinct "study" and "test" phases.

The "study" phase was a typical visual extinction task. Pictures of objects were briefly shown in the right (RVF), left (LVF), or both visual fields (Figure 2A). On Session 1, the patients were asked simply to name and locate the pictures (e.g., "duck on the right and nothing on the left"). They were not informed that memory for these stimuli would be probed later. We expected that the patients would fail to detect many left-side stimuli on bilateral trials (i.e., show extinction). This was followed by a "test" phase, which took the form of a visual identification task for fragmented pictures and constituted an indirect memory test (see Warrington & Weiskrantz, 1968). Patients were now shown fragmented versions of the same ("old") objects previously presented during the extinction task, intermingled with fragmented pictures of other ("new") objects, and they were asked to identify them all. Each test picture started with a very fragmented version and then continued with progressively completed versions until the patient correctly identified the object (Figure 2B). Fragmentation systematically decreased in eight different levels (from 1 = "most fragmented" to 8 = "most complete"), according to a procedure previously described by Snodgrass et al. (1987, 1990). Each fragmented picture appeared in the RVF or LVF alone, following a central fixation cross, and remained on the screen until the patient made a response. "Old" objects always appeared on the same side as in the study phase and "new" objects appeared either on the right or left side (equally probable). A recognition threshold was determined for

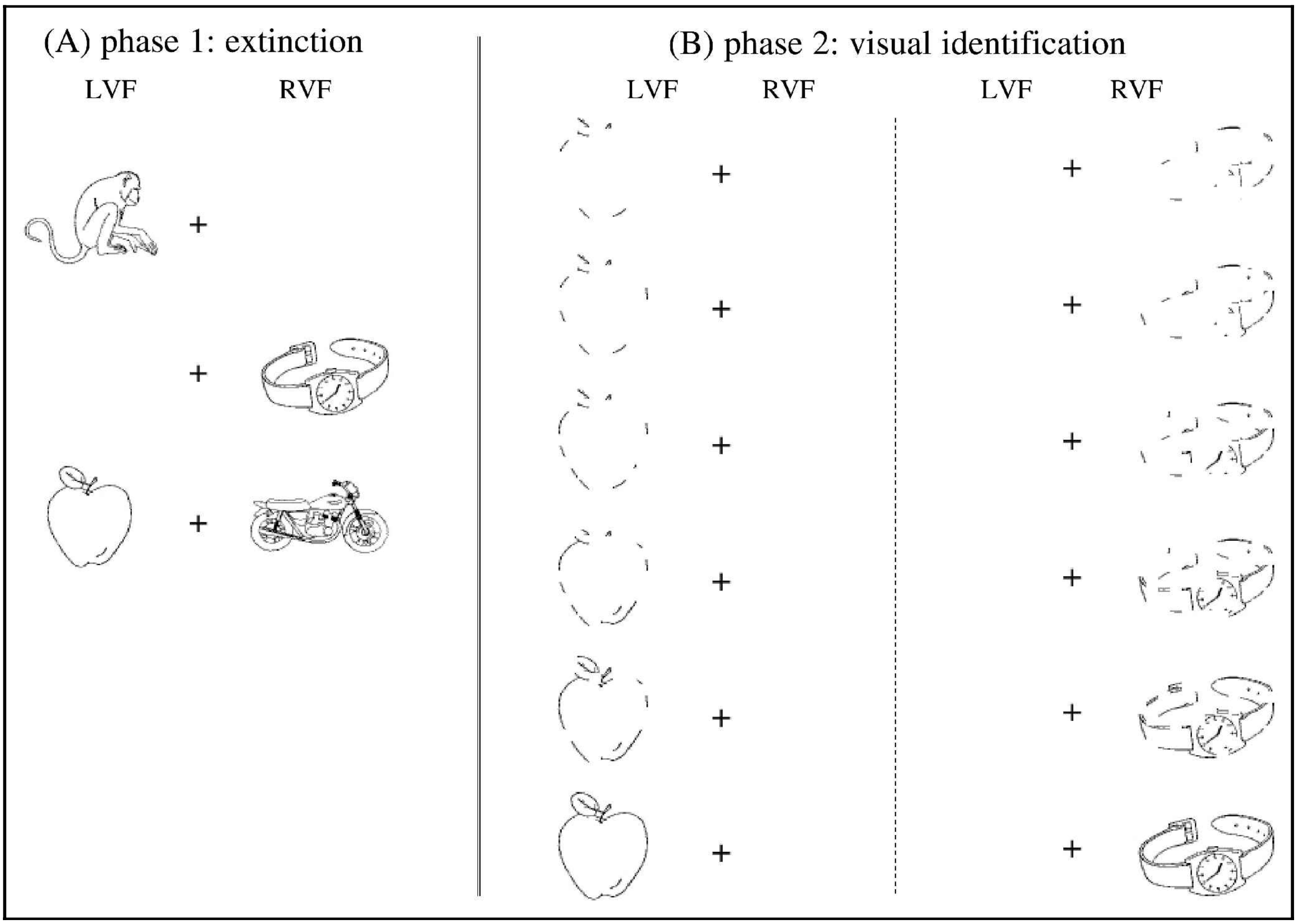



**Figure 2.** Example of stimuli. (A) In the first phase (study), objects were shown in the RVF, LVF, or both fields. (B) In the second phase (test), pictures of fragmented objects were shown one at a time in the RVF or LVF, following a stepwise clarification procedure with eight levels for each object. Thresholds for correct identification served as an indirect memory test. The complete object was then also presented for a direct test of explicit memory.

each fragmented picture as the level of fragmentation at which the patient correctly identified the object. We predicted that "old" objects that had been consciously seen during the extinction study phase would have lower recognition thresholds than "new" objects, consistent with visual learning effects normally found on indirect memory tests (e.g., Parkin et al., 1990; Snodgrass & Feenan, 1990; Warrington & Weiskrantz, 1968). The critical new question was whether the indirect test would reveal similar learning effects for stimuli that had been extinguished in the LVF, and thus not consciously recognized before by the patients. We also probed explicit recall for "old" versus "new" objects, by presenting each object in full form after it had been identified and asking the patients to judge whether this item had been shown earlier (i.e., in study phase).

On Session 2, patients were again tested in successive "study" and "test" phases, using a different set of objects. Session 2 was similar to Session 1 except for two critical aspects during the extinction "study" task: (1) Patients were now explicitly informed that their memory for the objects would be tested in the subsequent "test" phase. (2) They had not only to name and locate the objects, but also to categorize each of them as indoor/outdoor. Both of these instructions were intended to encourage deeper processing of the items, because this is known to affect explicit recall but to have little or no effect on the more automatic implicit learning effects in normals (e.g., Jacoby & Kelley, 1991; Craik & Lockhart, 1972). If extinguished stimuli produce truly implicit learning due to processing without awareness, such effects should arise equally regardless of memory instruction and depth of processing at study (i.e., equally in both sessions). By contrast, explicit memory should be modulated by instructions and deeper processing (i.e., increased in Session 2 as compared to Session 1). The "test" phase of Session 2 was identical to Session 1 in all respects, except for the different objects used. All objects were randomly assigned to different conditions and counterbalanced across patients.

## RESULTS

### Study Phase: Visual Extinction

Stimuli presented in the RVF were correctly reported on 100% of unilateral and bilateral trials by all the patients (Table 2). In the LVF, unilateral stimuli were correctly reported on 78–100% of trials (mean 96%), not significantly different from RVF, $\chi^2(1) \leq 2.06$, $p \geq .51$. By contrast, LVF stimuli were detected on only 0–39% of bilateral trials (mean 18%), consistent with severe left extinction in all patients, $\chi^2(1) \geq 54.7$, $p < .001$ for left-side objects seen on unilateral versus bilateral trials. On just a few trials, the presence of a stimulus was detected in the LVF but the object was not identified (≤2 trials per patient out of 54 items across all conditions); these items were excluded from subsequent analyses. The rate of extinction did not differ between Sessions 1 and 2, $\chi^2(1) = 0.18$, $p = .66$, or between patients, $\chi^2(3) = 2.77$, $p = .43$.

**Table 2.** Visual Extinction Results in the Study Phase

| | | | *Number of Undetected Stimuli* | |
|---|---|---|---|---|
| *Patient* | *Stimulus Presentation* | | *Session 1* | *Session 2* |
| C. W. | Unilateral | RVF | 0/9 | 0/9 |
| | | LVF | 0/9 | 0/9 |
| | Bilateral | RVF | 0/18 | 0/18 |
| | | LVF | 11/18[a] | 12/18[a] |
| M. M. | Unilateral | RVF | 0/9 | 0/9 |
| | | LVF | 0/9 | 1/9 |
| | Bilateral | RVF | 0/18 | 0/18 |
| | | LVF | 16/18[a] | 17/18[a] |
| S. V. | Unilateral | RVF | 0/9 | 0/9 |
| | | LVF | 2/9 | 0/9 |
| | Bilateral | RVF | 0/18 | 0/18 |
| | | LVF | 18/18[a] | 16/18[a] |
| V. K. | Unilateral | RVF | 0/9 | 0/9 |
| | | LVF | 0/9 | 0/9 |
| | Bilateral | RVF | 0/18 | 0/18 |
| | | LVF | 13/18[a] | 15/18[a] |

LVF/RVF = left/right visual field.

[a]Extinction trials.

### Test Phase: Indirect Memory in Visual Object Recognition

For each patient and each session, identification thresholds were calculated as the mean level of fragmentation at which objects were correctly identified during the visual recognition task. Separate thresholds were calculated for "old" stimuli that were extinguished in the preceding study phase, as well as for "old" stimuli that had correctly been reported, and for "new" stimuli that were not previously presented. Thresholds were calculated separately for items presented in the LVF or RVF.

#### *Unilateral Stimuli at Study*

Identification of fragmented "old" objects was clearly facilitated as compared to "new" objects, indicating robust visual learning on this indirect test (Table 3 and Figure 3). We first compared the mean identification

**Table 3.** Indirect Memory Test: Mean Fragmentation Threshold for Object Identification in the Test Phase

| | | | *Mean Fragmentation Thresholds at Test* | | | |
|---|---|---|---|---|---|---|
| | | | *Session 1* | | *Session 2* | |
| *Patient* | *Object History* | | *LVF* | *RVF* | *LVF* | *RVF* |
| C. W. | new | | 6.78 | 7.33 | 7.06 | 7.26 |
| | seen at study | unilateral trials | 5.6 | 5.78 | 5.3 | 5.44 |
| | | bilateral trials | 5.57 | 5.89 | 5.17 | 5.65 |
| | extinguished | (bilateral trials) | 6 | – | 5.93 | – |
| M. M. | new | | 7.67 | 6.88 | 6.8 | 6.4 |
| | seen at study | unilateral trials | 5.89 | 5.89 | 6.36 | 5.78 |
| | | bilateral trials | 5 | 6.11 | 5 | 5.72 |
| | extinguished | (bilateral trials) | 6.06 | – | 6.16 | – |
| S. V. | new | | 7.53 | 6.43 | 6.93 | 6.47 |
| | seen at study | unilateral trials | 5.14 | 5.25 | 5.11 | 5.3 |
| | | bilateral trials | – | 5.28 | 5 | 5.29 |
| | extinguished | (bilateral trials) | 6 | – | 5.91 | – |
| V. K. | new | | 7.4 | 7.1 | 6.2 | 6.3 |
| | seen at study | unilateral trials | 5.67 | 5.22 | 5.5 | 4.56 |
| | | bilateral trials | 5.2 | 5.44 | 5.3 | 5.5 |
| | extinguished | (bilateral trials) | 6.31 | – | 6.4 | – |

LVF/RVF = left/right visual field.

thresholds for "old" objects that were consciously seen unilaterally in the LVF or RVF in the study phase (always on the same side at test) versus the mean thresholds for "new" objects presented in LVF or RVF. A nonparametric analysis of variance for paired data indicated a significant difference between these conditions in both sessions [Friedman test, Session 1: $\chi^2(3) = 9.98$, $p = .019$; Session 2: $\chi^2(3) = 9.6$, $p = .022$], reflecting lower recognition thresholds for "old" than "new" objects in both cases (Wilcoxon paired test, $Z = 3.53$, $p = .004$). RVF and LVF stimuli did not differ ($Z = 1.59$, $p = .11$). Overall, the mean fragmentation thresholds were 5.5 for objects previously consciously seen in unilateral trials versus 6.9 for new objects.

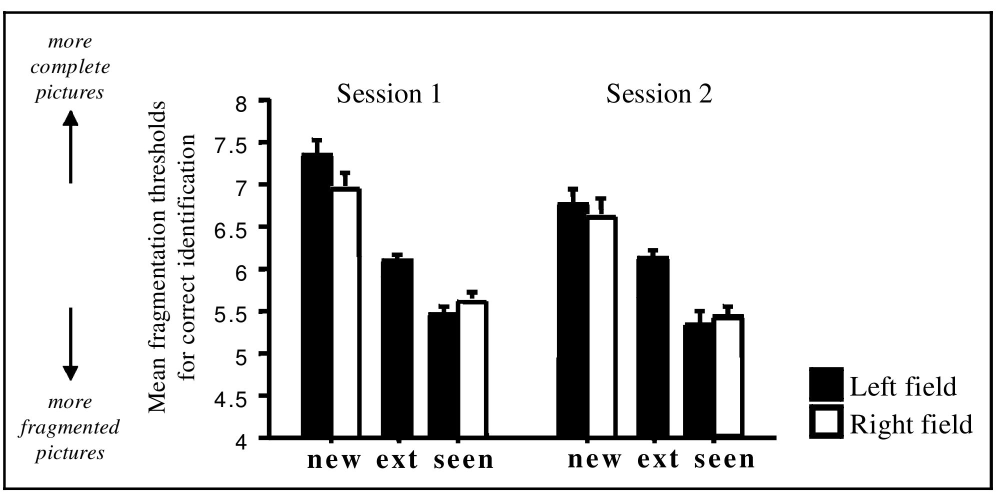



**Figure 3.** Implicit learning effects on the fragmented picture recognition test. The mean fragmentation level at which objects were correctly identified (averaged across patients ± one standard error) is shown for items presented in RVF or LVF as a function of whether they were new, consciously seen in Phase 1 (in same hemifield), or shown but extinguished in Phase 1 (in same left hemifield).

**Table 4.** Explicit Memory Results

| Patient | Object History | | Number of Items Remembered/Number of Items Presented | | | |
|---|---|---|---|---|---|---|
| | | | *Session 1* | | *Session 2* | |
| | | | *LVF* | *RVF* | *LVF* | *RVF* |
| C. W. | new | | 2/10 | 0/10 | 0/10 | 0/10 |
| | seen at study | unilateral trials | 6/9 | 8/9 | 8/9 | 9/9 |
| | | bilateral trials | 3/7 | 9/18 | 3/6 | 14/18 |
| | extinguished | (bilateral trials) | 2/11 | –/– | 0/12 | –/– |
| M. M. | new | | 0/10 | 0/10 | 0/10 | 1/10 |
| | seen at study | unilateral trials | 4/9 | 7/9 | 6/8 | 7/9 |
| | | bilateral trials | 1/2 | 12/18 | 0/1 | 13/18 |
| | extinguished | (bilateral trials) | 0/16 | –/– | 1/17 | –/– |
| S. V. | new | | 1/10 | 1/10 | 1/10 | 0/10 |
| | seen at study | unilateral trials | 6/7 | 8/9 | 9/9 | 9/9 |
| | | bilateral trials | 0/0 | 15/18 | 0/2 | 17/18 |
| | extinguished | (bilateral trials) | 2/18 | –/– | 0/16 | –/– |
| V. K. | new | | 0/10 | 0/10 | 0/10 | 0/10 |
| | seen at study | unilateral trials | 5/9 | 7/9 | 6/9 | 8/9 |
| | | bilateral trials | 4/5 | 11/18 | 2/3 | 14/18 |
| | extinguished | (bilateral trials) | 1/13 | –/– | 0/15 | –/– |

LVF/RVF = left/right visual field.

Identification of fragmented "old" objects did not improve in Session 2 as compared to Session 1 (mean threshold 5.5 vs. 5.4, $Z = 1.26$, $p = .21$), indicating that explicit memory instruction and deeper semantic processing during the study phase did not enhance the effect of visual learning on this indirect test (Table 4).

### *Bilateral Stimuli at Study*

Our critical question was whether perceptual learning can occur for objects that were previously presented but extinguished. A nonparametric analysis of variance for unpaired data was performed on the mean identification thresholds for "old" extinguished stimuli, "old" seen stimuli, and "new" stimuli. This revealed a significant difference between conditions in both sessions [Kruskal–Wallis test, Session 1: $H(2) = 19.95$, $p < .001$; Session 2: $H(2) = 19.16$, $p < .001$]. A direct comparison of extinguished and "new" stimuli showed that the former had lower identification thresholds (Mann–Whitney unpaired rank test, Session 1: $U = 0$, $p = .007$; Session 2: $U = 2.5$, $p = .021$), with a mean fragmentation level of 6.1 (range 5.9–6.4) versus 6.9 for "new" objects (range 6.2–7.7). This reveals priming influences from extinguished stimuli on fragmented object identification task, despite the intervening delay of several minutes. These effects were observed in each patient (Table 3), with the sole exception of V. K. in Session 2.

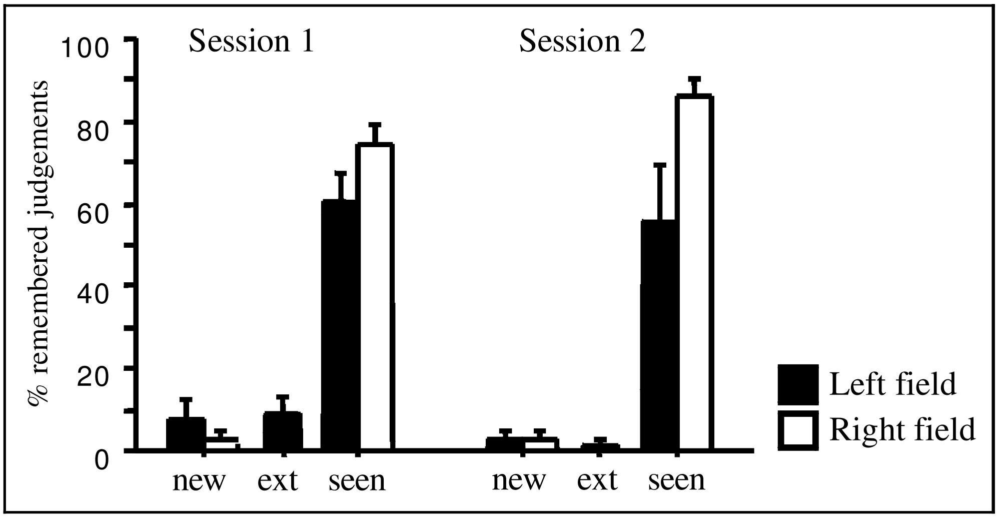
On the other hand, identification thresholds for previously extinguished stimuli were lower than those for stimuli that had been consciously seen at study (Mann–Whitney, Session 1: $U = 3$, $p = .007$; Session 2: $U = 3$, $p = .008$). Thus, the identification of previously extinguished stimuli fell between the performance for consciously seen stimuli and for entirely new stimuli (Figure 3), but nonetheless differed from each of these two conditions.

Identification thresholds for extinguished stimuli did not differ in Sessions 1 and 2 (Wilcoxon paired test, $Z = .55$, $p = .58$), suggesting no effect of intentional learning or deeper semantic encoding during study on this indirect memory test.

## Test Phase: Explicit Memory

Once patients had correctly identified an object at any given fragmented level, a complete picture was then shown again, and they were asked whether this item had

Figure 4. Explicit memory effects in the test phase. The proportion of objects that were recollected as having been seen before (averaged across patients ± one standard error) is shown for items presented in RVF or LVF as a function of whether they were new, consciously seen in Phase 1 (in same hemifield), or shown but extinguished in Phase 1 (in same left hemifield).




already been presented in the previous extinction phase (forced yes/no decision).

*Unilateral Stimuli at Study*

Explicit recognition was good for objects that had been consciously seen in unilateral displays at study (mean of correctly judged "old," Session 1: 68%; Session 2: 81%), while false alarms to new objects were rare (Session 1: 5%; Session 2: 2.5%). Again, we compared the responses for "old" objects that had been seen consciously in the LVF or RVF versus "new" objects (similarly tested in LVF or RVF). These conditions significantly differed in both sessions [Friedman analysis of variance, Session 1: $\chi^2(3) = 10.8$; Session 2: $\chi^2(3) = 10.3, p \leq .011$]. The rate of explicit recognition was much higher for "old" seen items than for "new" items, when pooled across visual fields [Session 1: $\chi^2(1) \geq 24.69$; Session 2: $\chi^2(1) \geq 50.22$, $p < .001$].

On the other hand, explicit recognition was higher for "old" stimuli presented in the RVF as compared to those presented in the LVF [Session 1: 83% vs. 61%; Session 2: 93% vs. 82%, $\chi^2(1) \geq 5.05$, $p \leq .025$], although all these stimuli had been similarly well reported during the extinction study phase. By contrast, judgments for "new" stimuli did not differ between RVF and LVF, $\chi^2(1) \leq 0.69$, indicating that this field effect did not arise from a response bias during memory test (see Figure 4).

Explicit recognition of "old" objects improved in Session 2, as compared to Session 1, $\chi^2(1) = 6.56$, $p = .010$, while there was no such effect on false alarms for "new" objects, $\chi^2(1) = 0.17$. This is consistent with the predicted enhancement of explicit memory due to intentional learning instructions and deeper semantic processing in the study phase of Session 2.

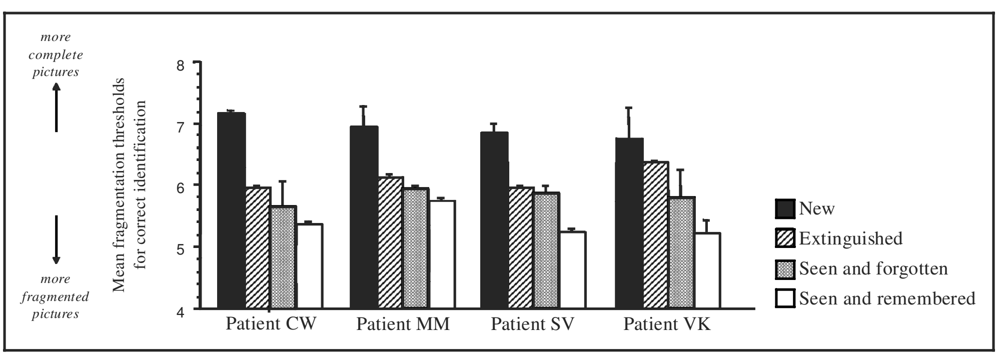
*Bilateral Stimuli at Study*

Here again, our critical question was whether memory in a direct test would unravel some influences from stimuli that were previously presented but extinguished. However, the rate of explicit recognition judgments for extinguished objects (Session 1: 8.6%; Session 2: 1.7%) was not different from the rate of guesses to "new" objects [Session 1: 5%, $\chi^2(1) = 0.72$; Session 2: 2.5%, $\chi^2(1) = 0.11$, $p \geq .39$]. Explicit recognition of extinguished stimuli did not differ between Sessions 1 and 2 [$\chi^2(1) = 1.69$, $p = .19$; see Figure 4].

## Relations of Indirect and Direct Memory Performance for Nonextinguished Stimuli

In the test phase, the patients failed to explicitly recognize some "old" objects although they had correctly reported them at study (i.e., during the extinction task). We compared the mean fragment-identification

Figure 5. Mean fragmentation level for identifying objects that were consciously seen and later explicitly remembered; or consciously seen but later forgotten; or extinguished; or were new (averaged for each patient across sessions ± one standard error).



thresholds for these seen but forgotten items to those for items correctly judged to be "old" (pooled over LVF and RVF), as well as to those for extinguished objects judged to be "new" and those for true "new" objects (Figure 5). The identification of forgotten items was somewhat more difficult than for the correctly judged "old" items (mean threshold of 5.8 vs. 5.3 across the two sessions, Wilcoxon paired test, $Z = 2.10$, $p = .035$), although it was still much better than identification of entirely "new" items (mean fragmentation 6.9, $Z = 5.02$, $p = .018$).

Furthermore, identification thresholds of consciously seen but forgotten objects were also slightly but significantly better than those for previously extinguished objects ($Z = 2.03$, $p = .049$), albeit with some variability between patients and sessions (see Figure 5).

### Effects of Retention Interval on Direct and Indirect Memory Tests

We examined whether the time that elapsed since the presentation of an object during the study phase (duration for one session: 45–54 min) or the number of intervening stimuli (36 trials in each study phase and 74 trials in each test phase) might influence subsequent performance on indirect and direct memory tests. Linear regression coefficients were calculated for fragment identification thresholds of extinguished or consciously seen objects, as a function of their trial rank in the test phase in each patient. These did not differ from zero [$t(7) \leq 1.95$, $p \geq .10$], indicating no significant effect of delay. Similarly, the rate of explicit recognition of "old" items did not show significant changes over time (rank sum test for sign fluctuations, $R' = 2293$, $p > .05$), and the proportion of correct recognition judgments did not differ between the first and the second half of test trials [$\chi^2(2) = 0.31$].

### Effects of Competition from LVF Stimuli on Direct and Indirect Memory for RVF Stimuli

The results above, indicating memory traces for extinguished LVF stimuli on the indirect fragment-identification test, suggest long-term influences of residual processing for these stimuli despite unawareness. Can such residual processing affect the strength of traces laid down by RVF stimuli that are simultaneously presented and consciously seen? We compared the mean identification thresholds for objects seen alone in the RVF at study versus objects similarly seen in the RVF but concurrently with an extinguished item in the LVF. These two conditions produced a similar degree of perceptual learning in the indirect test, with mean fragmentation thresholds of 5.4 versus 5.7, respectively (Wilcoxon test, $Z = 1.26$, $p = .21$). The proportion of correct explicit memory recognition for these RVF items was also similar [mean 88% vs. 75%, $\chi^2(1) = 3.32$, $p = .069$].

This suggests that extinguished stimuli in the LVF do not significantly affect the strength of memory traces for concurrent stimuli in the RVF. However, would LVF stimuli be more detrimental when consciously perceived? Two patients (C. W. and V. K.) correctly reported objects in the LVF on a few bilateral displays during the study phase (36% and 23%, respectively; see Table 1). (The two other patients, M. M. and S. V., extinguished most or all of LVF stimuli on bilateral trials in the two sessions, and so were not considered in the analysis below). In patients C. W. and V. K., one can therefore compare the learning effects for right-side items presented alone versus right-side items presented together with another item consciously seen on the left. Again, these two conditions showed a similar degree of learning for the right-side objects in the indirect test (mean fragmentation thresholds of 5.3 vs. 5.4, averaged for two sessions in the two patients; Wilcoxon test, $Z = 1.46$, $p = .14$). By contrast, explicit memory of the right-side objects decreased when the concurrent LVF stimuli had been consciously perceived, as compared to when they had been extinguished (mean 89% vs. 55% correct; $\chi^2(1) = 4.85$, $p = .027$). Thus, reporting two items on bilateral trials during the extinction task (instead of just one) later produced a significant cost for RVF stimuli on the direct but not the indirect memory test.

## DISCUSSION

This study provides a number of novel findings about the enduring effects of residual processing in extinction, and the relationships of perceptual learning to awareness. The first major finding was that extinguished stimuli in the LVF, although not consciously detected by our patients, could induce significant "implicit" learning effects in an indirect memory test performed tens of minutes later. Patients were able to identify pictures of objects at a greater degree of fragmentation when these objects had previously been presented, but extinguished, as compared to new objects that had never been presented before. Yet extinguished objects and new ones were both previously unseen stimuli from the perspective of the patients' phenomenal experience. Patients denied any explicit recollection of the extinguished stimuli that produced learning on the indirect test, as they did for the new stimuli. Moreover, this facilitation for identifying fragments of "old" objects, even when these had not entered the patients' awareness at study, was not influenced by explicit memory instructions and depth of semantic processing during encoding (i.e., Session 1 vs. Session 2). By contrast, this task manipulation did significantly affect explicit memory judgments (cf. Jacoby & Kelley, 1991; Craik & Lockhart, 1972). These results suggest that the perceptual learning for the extinguished stimuli in the indirect test was truly implicit, consistent with the lack of awareness for these stimuli at initial exposure and the failure to recognize them as "old" in the subsequent explicit memory test.

Our findings extend previous observations indicating that extinguished visual stimuli can undergo substantial processing despite contralesional inattention and unawareness, sometimes up to the stage of unconscious object categorization (e.g., Ladavas et al., 1993; McGlinchey-Berroth et al., 1993; Berti & Rizzolatti, 1992). Our results go beyond these observations in demonstrating that such on-line implicit processing can leave durable traces in the perceptual system to influence much later processing of related stimuli. An important implication is that residual processing capabilities in parietal patients do not merely constitute remnants of on-line perceptual processes that can be briefly activated in a stimulus-driven bottom-up manner, yet are insufficient to afford normal awareness. Some residual processes may evidently trigger plastic changes outlasting a stimulus presentation period, which can mediate learning effects and influence conscious perception of subsequent stimuli many minutes later (see also Vuilleumier & Sagiv, 2001).

Extinction is thought to reflect a deficit of attention towards contralesional stimuli (Driver & Vuilleumier, 2001; Heilman et al., 1993). In normal subjects, inattention typically induces a marked decrease in explicit memory, but can have little or no effect on implicit measures (e.g., Schmitter-Edgecombe, 1996; Szymanski & MacLeod, 1996; Jacoby & Kelley, 1991; Parkin et al., 1990), apparently supporting the view that implicit learning is mediated by purely data-driven processing in the perceptual system. Evoked potential studies also found repetition effects for previously unattended stimuli (Yamagata, Yamaguchi, & Kobayashi, 2000; Drysdale, Finlay, & Fulham, 1995; Otten, Rugg, & Doyle, 1993). However, it has been argued that some of these studies may not have completely eliminated attention to nominally unattended stimuli (Crabb & Dark, 1999; Bentin et al., 1998; MacDonald & MacLeod, 1998). In our patients, even extreme contralesional inattention for stimuli (i.e., to the extent that these were extinguished from awareness at encoding) did not abolish implicit memory traces, consistent with the role of automatic data-driven processes. Our results therefore support the view that implicit memory can still occur when explicit recollection is null, a condition that is rarely met in normal memory studies manipulating attention (see Rugg, 1995; Jacoby & Kelley, 1991).

Neurophysiological data in animals and functional imaging results in humans have suggested that the neural substrates of implicit visual memory might correspond to decreases in the firing rate of visual neurons when stimuli with similar properties are repeated (Wiggs & Martin, 1998; Desimone, 1996; Brown, Wilson, & Riches, 1987). Such repetition effects in single-cell recording studies were found in various regions of the inferior temporal cortex (Suzuki, Miller, & Desimone, 1997; Brown et al., 1987; Baylis, Rolls, & Leonard, 1985) and may reflect sharpening in neuronal assemblies that extract characteristic stimulus properties (Wiggs & Martin, 1998). Repetition effects can be remarkably stimulus-specific, last several hours, and arise regardless of whether the repeated stimuli are attended targets or ignored distractors (Miller & Desimone, 1994; Fahy, Riches, & Brown, 1993). In keeping with this, PET and fMRI studies in humans demonstrated that stimulus repetition can be associated with reduced activation of ventral temporal regions involved in object processing, relative to the first presentation of the same item (Koutstaal et al., 2001; Buckner et al., 1998; Squire et al., 1992). In parietal patients with neglect, such areas in the inferior temporal and fusiform cortex are not only structurally intact, but recent fMRI and ERP studies show they can still exhibit category-specific activation in response to extinguished stimuli (Driver et al., 2001; Vuilleumier, Sagiv, et al., 2001; Rees et al., 2000). In our patients, it is possible that similar covert activation of the ventral temporal areas, elicited by extinguished objects during the study phase, might mediate implicit memory and a subsequent facilitation of identification for the same objects during the test phase.

On the other hand, a second important finding of our study was that implicit memory was not entirely immune to the conditions of attention or awareness at study. Although identification of extinguished objects benefited from significant implicit learning as compared to new items, objects that had been consciously seen produced still greater learning effects in the indirect test, irrespective of whether the patients actually remembered or forgot that they had already seen these items. This provides a new evidence that awareness and attention during study may also affect implicit memory, not solely explicit memory (Crabb & Dark, 1999; Bentin et al., 1998; MacDonald & MacLeod, 1998). Recent imaging results show that neural activation in intact visual areas of parietal patients is stronger when contralesional stimuli are consciously perceived as opposed to extinguished (Vuilleumier, Sagiv, et al., 2001), similar to the normal effects of attention (e.g., Rees, Russell, Frith, & Driver, 1999; Kastner, De Weerd, Desimone, & Ungerleider, 1998; Corbetta, Meizin, Dobmeyer, Shulman, & Petersen, 1990). Such increases during study might give rise to enhanced implicit repetition effects when the previously exposed objects recur.

Another aspect of our results also indicates that indirect and direct memory tests may be differentially sensitive to the degree of attention and awareness at encoding. We found that explicit recognition was better for objects seen unilaterally in the RVF as opposed to the LVF (although both of these were correctly reported in the study phase), whereas implicit performance in the fragment identification task did not differ between the two fields. Although unilateral left stimuli did not suffer extinction by concurrent right stimuli, they might be detected slightly later and processed less fully than unilateral right stimuli, given their brief duration and the patients' spontaneous ipsilesional bias in attention. This result exemplifies the high sensitivity of explicit memory to processing depth at encoding (see Ganor-Stern et al., 1998; MacDonald & MacLeod, 1998; Jacoby & Kelley, 1991; Craik & Lockhart, 1972). Similar deficits of explicit memory for contralesional stimuli were described for words heard in the left ear in a right parietal patient with neglect (Heilman, Watson, & Schulman, 1974) and for objects on the left side of a page in another case with pure representational neglect in mental imagery (Beschin, Cocchini, DellaSala, & Logie, 1997, p. 14). Moreover, we also found here that explicit recall for objects presented in the normal RVF was decreased when concurrent stimuli in the LVF were perceived as opposed to extinguished, that is, on bilateral trials where the patients reported two stimuli instead of just one. Again, implicit memory was unaffected.

We note finally that, in contrast to our findings, Bisiach, Ricci, Sialni, Cossa, and Crespi (1999) recently suggested that patients who neglect visual stimuli may later remember some of these items in an explicit yes/no recognition task, more often than new items. However, except in one case (patient L. L.), their study may have overestimated the rate of explicit recognition due to the small number of stimuli they used.[1] Other studies are needed to establish whether such ''hypermnesia'' for unseen stimuli can occur in some patients and not in others. It is worth noting that enhanced fluency due to implicit memory may sometimes induce subjective feelings of familiarity, which can be used to judge an item as ''old'' in explicit recognition tests (Jacoby & Kelley, 1991; Johnston, Hawley, & Elliott, 1991). However, despite the fact that implicit learning led to improved identification of fragmented pictures in our patients, there was no increase in their likelihood of judging an extinguished object as ''old'' in comparison with ''new'' objects. Enhanced fluency due to implicit memory thus does not seem to inevitably bias explicit judgements (see also Wagner, Gabrieli, & Verfaellie, 1997).

Our findings show that implicit learning effects are not only relevant to the study of memory, but can also provide a new tool to investigate both preserved and defective aspects of residual processing in neglect and extinction. It is thought that implicit memory traces can be formed at distinct levels of processing, reflecting whatever information has been extracted from the stimulus up to that stage (Mulligan & Hornstein, 2000; Ganor-Stern et al., 1998; Moscovitch et al., 1993; Tulving & Schacter, 1990). It remains to be determined how far residual processing of extinguished stimuli can proceed along the anatomically intact ventral temporal stream in patients with parietal damage and how comparable or different it is with respect to normal processing of consciously seen stimuli (Driver & Vuilleumier, 2001; Driver et al., 2001; Vuilleumier, Sagiv, et al., 2001). Future studies could use learning procedures to investigate to what extent implicit memory for extinguished stimuli is dependent on particular stimulus or task characteristics (e.g., Gabrieli et al., 1999; Cooper, Schacter, Ballesteros, & Moore, 1992) and whether it can be usefully exploited in rehabilitation. The present results do indicate that neglect patients with visual extinction are able to learn about stimuli that escape their awareness, albeit without realizing that they are doing so.

## METHODS

The four patients (S. V., C. W., M. M., and V. K.) had a single right hemisphere stroke (Figure 1) and left neglect during the acute stage. All had intact visual fields on both sides but severe left extinction on double visual stimulation, with mild chronic neglect on clinical tests in three of them at the time of our investigation (Table 1). They were examined on two separate sessions (same day in S. V., C. W., and V. K. and 1 week apart in M. M.), each including two phases.

Phase 1 (''study'') was a visual extinction task (Figure 2A). All stimuli ($\sim$3–4°) were taken from Snodgrass et al. (1988). Each trial began with a fixation cross at the center of the screen (1 sec), followed by an object briefly shown in the RVF, LVF, or both fields ($\sim$7–8° of eccentricity). Stimulus duration was determined in each individual patient using a practice block with a different set of stimuli, so as to obtain left extinction on bilateral trials but reliable performance on unilateral left trials (75 msec in V. K., 200 msec in S. V., 300 msec in M. M., and 400 msec in C. W.); this duration was then kept constant in each patient. In each session, there were 18 unilateral stimuli (9 different objects in RVF and LVF) and 18 bilateral stimuli (total of 54 different objects). All objects were presented only once in the study phase. Trial order (unilateral right, left, or bilateral) was randomized.

On Phase 1 of Session 1, patients were asked to report the name and location of each of the objects, but not informed that memory for the stimuli would be tested later.

Phase 2 (''test'') was a visual identification task and followed Phase 1 after a short break. Fragmented object pictures were shown according to a progressive clarification procedure, beginning with an extremely fragmented version, then followed by increasingly completed versions, until patients correctly identified the object (Figure 2B). Fragmentation systematically varied along eight levels using previously described stimuli (Snodgrass et al., 1988, 1990). The objects included the same 54 ''old'' items used in the preceding extinction ''study'' phase and 20 ''new'' items. Each object was shown alone in either the RVF or LVF, with all fragmented versions of a given item successively presented on the same side. "Old" objects were tested in the same field as in the study phase; half of "new" objects were presented in LVF and half in RVF. Each trial began with a central fixation cross (1 sec), followed by the test stimulus, which then remained on the screen until response. Stimulus size and position were as in the study phase (~3–4° of visual angle, ~7–8° away from fixation). The trial order (old vs. new, left vs. right) was randomized. Care was taken to ensure that each of these trial categories included items with matched identification thresholds according to available norms (see Koch, Abbey, & Schmidt, 1995; Snodgrass & Corwin, 1988), and the assignment of items to the different conditions was counterbalanced across patients.

Finally, once a given object was identified, the complete picture of this object was then shown for an unlimited time (on the same side of the screen as previously), and the patient was asked whether he remembered having seen this item during the study phase (yes/no).

This whole procedure was repeated on Session 2, using different objects. During Phase 1, the patients were again shown objects in the right, left, or both fields, but now asked not only to name and locate them, but also to judge whether these were usually encountered indoor or outdoor, thus ensuring deep semantic processing. In addition, they were informed that their memory would be tested in the following "test" phase and explicitly instructed to learn as many items as possible. Phase 2 was identical to that in Session 1 in all respects, except for the different set of objects used.


### Acknowledgments

Thanks to Bob Rafal and Mick Rugg for helpful discussions and suggestions. This work was supported by grants from the Medical Research Council and McDonnell Foundation (J. D., P. V., and K. C.), the Wellcome Trust (M. H.), and the Swiss National Science Foundation (P. V. and S. S.).



Reprint requests should be sent to Dr. P. Vuilleumier, Institute of Cognitive Neuroscience, University College London, Alexandra House, 17 Queen Square, London WC1N 3AR, UK, or via e-mail: p.vuilleumier@ucl.ac.uk.


### Note

1. Although Bisiach et al. (1999) included more patients, the apparent discrepancy between the two studies is unlikely to result from a small sample size or lack of power here. We had twice as many neglected items in terms of cumulative data across patients (i.e., comparable to the procedure used in their analysis). Their pooled analysis may have overestimated the rate of explicit memory (since correct recognition judgment for a single neglected item scored as 100% recall in some cases) and it is unsure whether these recognition judgments reliably differed from the rate of false alarms on novel items.

## REFERENCES


Baylis, G. C., Rolls, E. T., & Leonard, C. M. (1985). Selectivity between faces in the responses of a population of neurons in the cortex in the superior temporal sulcus of the monkey. *Brain Research, 342,* 91–102.

Bentin, S., Moscovitch, M., & Nirhod, O. (1998). Levels of processing and selective attention effects on encoding in memory. *Acta Psychologica, 98,* 311–341.

Berti, A., & Rizzolatti, G. (1992). Visual processing without awareness: Evidence from unilateral neglect. *Journal of Cognitive Neuroscience, 4,* 345–351.

Beschin, N., Cocchini, G., DellaSala, S., & Logie, R. (1997). What the eyes perceive, the brain ignores: A case of pure unilateral representational neglect. *Cortex, 33,* 3–26.

Bisiach, E., Ricci, R., Silani, G., Cossa, F. M., & Crespi, M. G. (1999). Hypermnesia in unilateral neglect. *Cortex, 35,* 701–711.

Bowers, J. S., & Schacter, D. L. (1990). Implicit memory and test awareness. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 16,* 404–416.

Brown, M. W., Wilson, F. A., & Riches, I. P. (1987). Neuronal evidence that inferomedial temporal cortex is more important than hippocampus in certain processes underlying recognition memory. *Brain Research, 409,* 158–162.

Buckner, R. L., Goodman, J., Burock, M., Rotte, M., Koutstaal, W., Schacter, D., Rosen, B., & Dale, A. M. (1998). Functional–anatomic correlates of object priming in humans revealed by rapid presentation event-related fMRI. *Neuron, 20,* 285–296.

Cermak, L. S., Talbot, N., Chandler, K., & Wolbarst, L. R. (1985). The perceptual priming phenomenon in amnesia. *Neuropsychologia, 23,* 615–622.

Cooper, L. A., Schacter, D. L., Ballesteros, S., & Moore, C. (1992). Priming and recognition of transformed three-dimensional objects: Effects of size and reflection. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 18,* 43–57.

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.

Crabb, B. T., & Dark, V. J. (1999). Perceptual implicit memory requires attentional encoding. *Memory and Cognition, 27,* 267–275.

Craik, F. I. M., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior, 11,* 671–684.

Desimone, R. (1996). Neural mechanisms for visual memory and their role in attention. *Proceedings of the National Academy of Sciences, U.S.A., 93,* 13494–13499.

Driver, J., & Vuilleumier, P. (2001). Perceptual awareness and its loss in unilateral neglect and extinction. *Cognition, 79,* 39–88.

Driver, J., Vuilleumier, P., Eimer, M., & Rees, G. (2001). Functional MRI and evoked potential correlates of conscious and unconscious vision in parietal extinction patients. *Neuroimage, 14,* S68–S75.

Drysdale, K. A., Finlay, D. C., & Fulham, W. R. (1995). An event-related potential examination of attended and unattended stimuli in visual selection using bilateral stimulus presentation. *Biological Psychology, 39,* 115–129.

Fahy, F. L., Riches, I. P., & Brown, M. W. (1993). Neuronal activity related to visual recognition memory. *Experimental Brain Research, 96,* 457–472.

Gabrieli, J. D., Vaidya, C. J., Stone, M., Francis, W. S., Thompson-Schill, S. L., Fleischman, D. A., Tinklenberg, J. R., Yesavage, J. A., & Wilson, R. S. (1999). Convergent behavioral and neuropsychological evidence for a distinction between identification and production forms of repetition priming. *Journal of Experimental Psychology. General, 128,* 479–498.

Ganor-Stern, D., Seamon, J. G., & Carrasco, M. (1998). The role of attention and study time in explicit and implicit memory for unfamiliar visual stimuli. *Memory and Cognition, 26,* 1187–1195.

Heilman, K. M., Watson, R. T., & Schulman, H. M. (1974). A unilateral memory defect. *Journal of Neurology, Neurosurgery and Psychiatry, 37,* 790–793.

Heilman, K. M., Watson, R. T., & Valenstein, E. (1993). Neglect and related disorders. In K. M. Heilman & E. Valenstein (Eds.), *Clinical neuropsychology* (3rd ed., pp. 279–336). New York: Oxford University Press.

Jacoby, L. L., & Kelley, C. M. (1991). Unconscious influences of memory: Dissociations and automaticity. In A. D. Milner & M. D. Rugg (Eds.), *The neuropsychology of consciousness* (pp. 201–233). London: Academic Press.

Johnston, W. A., Hawley, K. J., & Elliott, J. M. (1991). Contribution of perceptual fluency to recognition judgments. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 17,* 210–223.

Kastner, S., De Weerd, P., Desimone, R., & Ungerleider, L. G. (1998). Mechanisms of directed attention in the human extrastriate cortex as revealed by functional fMRI. *Science, 282,* 108–111.

Koch, C., Abbey, L., & Schmidt, S. (1995). Reexamining the Snodgrass and Corwin 1988 picture identification norms. *Perceptual and Motor Skills, 81,* 763–769.

Koutstaal, W., Wagner, A. D., Rotte, M., Maril, A., Buckner, R. L., & Schacter, D. L. (2001). Perceptual specificity in visual object priming: Functional magnetic resonance imaging evidence for a laterality difference in fusiform cortex. *Neuropsychologia, 39,* 184–199.

Ladavas, E., Paladini, R., & Cubelli, R. (1993). Implicit associative priming in a patient with left visual neglect. *Neuropsychologia, 31,* 1307–1320.

MacDonald, P. A., & MacLeod, C. M. (1998). The influence of attention at encoding on direct and indirect remembering. *Acta Psychologica, 98,* 291–310.

McGlinchey-Berroth, R., Milberg, W. P., Verfaellie, M., Alexander, M., & Kilduff, P. T. (1993). Semantic processing in the neglected visual field: Evidence from a lexical decision task. *Cognitive Neuropsychology, 10,* 79–108.

Miller, E. K., & Desimone, R. (1994). Parallel neuronal mechanisms for short-term memory. *Science, 263,* 520–522.

Moscovitch, M., Vriezen, E. R., & Goshen-Gottstein, J. (1993). Implicit tests of memory in patients with focal lesions pr degenerative brain disorders. In F. Boller & J. Grafman (Eds.), *Handbook of neuropsychology* (vol. 8, pp. 133–173). Amsterdam: Elsevier.

Mulligan, N. W., & Hornstein, S. L. (2000). Attention and perceptual priming in the perceptual identification task. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 26,* 626–637.

Otten, L. J., Rugg, M. D., & Doyle, M. C. (1993). Modulation of event-related potentials by word repetition: The role of visual selective attention. *Psychophysiology, 30,* 559–571.

Parkin, A. J., Reid, T. K., & Russo, R. (1990). On the differential nature of implicit and explicit memory. *Memory and Cognition, 18,* 507–514.

Rees, G., Russell, C., Frith, C. D., & Driver, J. (1999). Inattentional blindness versus inattentional amnesia for fixated but ignored words. *Science, 286,* 2504–2507.

Rees, G., Wojciulik, E., Clarke, K., Husain, M., Frith, C. D., & Driver, J. (2000). Unconscious activation of visual cortex in the damaged right hemisphere of a parietal patient with extinction. *Brain, 123,* 1624–1633.

Rugg, M. D. (1995). Memory and consciousness: A selective review of issues and data. *Neuropsychologia, 33,* 1131–1141.

Rugg, M. D., Mark, R. E., Walla, P., Schloerscheidt, A. M., Birch, C. S., & Allan, K. (1998). Dissociation of the neural correlates of implicit and explicit memory. *Nature, 392,* 595–598.

Schacter, D. L. (1992). Understanding implicit memory. A cognitive neuroscience approach. *American Psychologist, 47,* 559–569.

Schmitter-Edgecombe, M. (1996). The effects of divided attention on implicit and explicit memory performance. *Journal of the International Neuropsychological Society, 2,* 111–125.

Snodgrass, J. G., & Corwin, J. (1988). Perceptual identification thresholds for 150 fragmented pictures from the Snodgrass and Vanderwart picture set. *Perceptual and Motor Skills, 67,* 3–36.

Snodgrass, J. G., & Feenan, K. (1990). Priming effects in picture fragment completion: Support for the perceptual closure hypothesis. *Journal of Experimental Psychology, 119,* 276–296.

Squire, L. R., Ojemann, J. G., Miezin, F. M., Petersen, S. E., Videen, T. O., & Raichle, M. E. (1992). Activation of the hippocampus in normal humans: A functional anatomical study of memory. *Proceedings of the National Academy of Sciences, U.S.A., 89,* 1837–1841.

Suzuki, W. A., Miller, E. K., & Desimone, R. (1997). Object and place memory in the macaque entorhinal cortex. *Journal of Neurophysiology, 78,* 1062–1081.

Szymanski, K. F., & MacLeod, C. M. (1996). Manipulation of attention at study affects an explicit but not an implicit test of memory. *Consciousness and Cognition, 5,* 165–175.

Tulving, E., & Schacter, D. L. (1990). Priming and human memory systems. *Science, 247,* 301–306.

Vaidya, C. J., Gabrieli, J. D., Verfaellie, M., Fleischman, D., & Askari, N. (1998). Font-specific priming following global amnesia and occipital lobe damage. *Neuropsychology, 12,* 183–192.

Vuilleumier, P., & Sagiv, N. (2001). Two eyes make a pair: Facial organization and perceptual learning reduce visual extinction. *Neuropsychologia, 39,* 1144–1149.

Vuilleumier, P., Sagiv, N., Hazeltine, E., Poldrack, R., Rafal, R., & Gabrieli, J. (2001). The neural fate of seen and unseen faces in visuospatial neglect: A combined event-related fMRI and ERP study of visual extinction. *Proceedings of the National Academy of Sciences, U.S.A., 98,* 3495–3500.

Vuilleumier, P., Valenza, N., & Landis, T. (2001). Explicit and implicit perception of illusory contours in unilateral spatial neglect: Behavioural and anatomical correlates of preattentive grouping mechanisms. *Neuropsychologia, 39,* 597–610.

Wagner, A. D., Gabrieli, J. D., & Verfaellie, M. (1997). Dissociations between familiarity processes in explicit recognition and implicit perceptual memory. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 23,* 305–323.

Warrington, E. K., & Weiskrantz, L. (1968). New method of testing long-term retention with special reference to amnesic patients. *Nature, 217,* 972–974.

Wiggs, C. L., & Martin, A. (1998). Properties and mechanisms of perceptual priming. *Current Opinion in Neurobiology, 8,* 227–233.

Yamagata, S., Yamaguchi, S., & Kobayashi, S. (2000). Event-related evoked potential study of repetition priming to attended and unattended words. *Brain Research, Cognitive Brain Research, 10,* 167–171.