

# Visual detection is gated by attending for action: Evidence from hemispatial neglect

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Edited by Michael I. Posner, University of Oregon, Eugene, OR, and approved September 6, 2002 (received for review May 22, 2002)

**We report observations in patients with visual extinction demonstrating that detection of visual events is gated by attention at the level of processing at which a stimulus is selected for action. In one experiment, three patients reported the identity of numerical words and digits presented either in the ipsilesional field, the contralesional field, or both fields. On the critical bilateral trials, extinction was greater when the competing items shared the same meaning and response, regardless of whether the items were visually different (e.g., ONE + 1), or identical (e.g., 1 + 1). A fourth patient was tested in a second experiment in which the competing items on bilateral trials were either different (e.g., ONE + TWO), identical (e.g., ONE + ONE) or homophones that were visually and semantically different but shared the same response (e.g., ONE + WON). Homophones and identical items caused similar extinction with less extinction occurring on different item trials.**

attention | consciousness | extinction | response selection

Our awareness of the visual environment is limited to only those parts of a scene to which we attend. An emerging view is that stimulus representations compete for processing (1), and for access to awareness. Neurobiological evidence indicates that attention biases this competition via selective enhancement and attenuation that can begin early in the visual pathway (2, 3), including primary visual cortex (4). Nevertheless, there is abundant evidence that unattended information is transmitted to later stages of processing, and that the identity of unattended items is registered outside of our awareness. Observations from masked priming studies in normal individuals (5) and neurological patients with the syndrome of hemispatial neglect (6, 7) have shown that this unattended information activates semantic representations; and indeed that it also activates motor responses relevant to the task at hand (8, 9). Thus, limitations in awareness are not attributable merely to a limitation in processing resources in sensory pathways. The open question is, at what stages of visuomotor processing do limitations for awareness arise?

We asked whether limitations for awareness might arise at the level of representations for action and response. We tested patients with visual extinction on their ability to explicitly detect contralesional visual targets, based on whether responses to the contralesional target were the same as or different from that of the ipsilesional one. We found that patients were less likely to detect a contralesional target when it required the same response as an ipsilesional target, suggesting that a competition for response processing determines the contents of awareness.

Patients with hemispatial neglect may be unaware of objects and events in the visual field contralateral to the lesion, even though sensory visual pathways are intact. Despite this dramatic exclusion from consciousness of contralesional stimuli, it has been shown that perceptual processing of these stimuli can proceed to the level of semantic classification (6, 7) and that preattentive vision parses the scene to extract figure from ground (10), group objects and define their primary axes (11), and prioritize, for subsequent orienting, the location of objects that are not perceived consciously (12). This evidence demonstrates that unawareness of contralesional stimuli cannot be entirely explained by attenuation of processing early in

the visual pathway; and that access to consciousness must be determined at a later stage of processing, after the identity of the extinguished item has been encoded. A common observation in bedside tests of patients with hemispatial neglect is that of extinction: patients can report the presence of a contralesional item presented alone, but fail to detect its presence when it appears together with a competing ipsilesional item. That is, the competing ipsilesional stimulus causes the presence of the contralesional item to be extinguished from awareness.

Our investigation is based on the simple clinical observation that there is less extinction when two competing objects are different than there is when they are the same (13). Baylis *et al.* (14) extended this clinical observation and demonstrated in five patients with extinction that the similarity of task relevant features determined whether the contralesional object was extinguished. On each trial, colored letters appeared either unilaterally or bilaterally and the patients were asked to report what they saw. Patients reported either the identity or color of letters in different blocks. Whereas there was a similar amount of extinction whether the stimuli were the same or different color in the letter naming block, in the color report blocks extinction was greater for the same color stimuli (when compared with the same stimuli in the letter report blocks or different colored stimuli in the color report block.) That is, extinction, the failure to report the presence of the contralesional item on bilateral presentations, occurred more frequently when the bilateral stimuli were the same on the attribute to be reported than when they were different on this attribute, and more frequently than when the stimuli were the same on the irrelevant attribute. These results demonstrate not only that information about shape and color of unattended objects is encoded, but also that awareness of the presence of this information is contingent on task goals.

In this earlier study, the patients' responses were determined solely on the basis of simple visual features (color or shape). Competition for awareness could therefore be due to competition either among objects sharing the relevant visual feature, or between objects sharing the same implications for response. The former could be implemented on the basis of competitive feature selection early in the visual pathway, whereas the latter implies preserved early visual processing and biased selection at a later level of semantics and/or response.

## Experiment 1

This experiment adapted the approach used in the study of Baylis *et al.* (14). However, here responses were based on the semantics of the items, and visual similarity between concurrently presented items was manipulated. If attention resolved competition at the level of perceptual features, then perceptual similarity should modulate the degree of extinction. If attention resolved competition at the level of the semantic meaning required for response selection, then visual similarity between the competing items should not influence extinction.

This paper was submitted directly (Track II) to the PNAS office.

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**Table 1. Patient and lesion details**

Patient	Age, years	Sex	Lesion	Neurological signs
JP	83	F	Frontal, temporal, parietal	Left proprioceptive loss, dressing apraxia
DG	82	M	Temporal, parietal	Left hemiparesis, tactile inattention
ML	59	F	Frontal, temporal, parietal	Left hemiplegia, tactile inattention
HH	89	M	Frontal, temporal, parietal	Left hemiplegia and hemisensory loss

F, female; M, male.

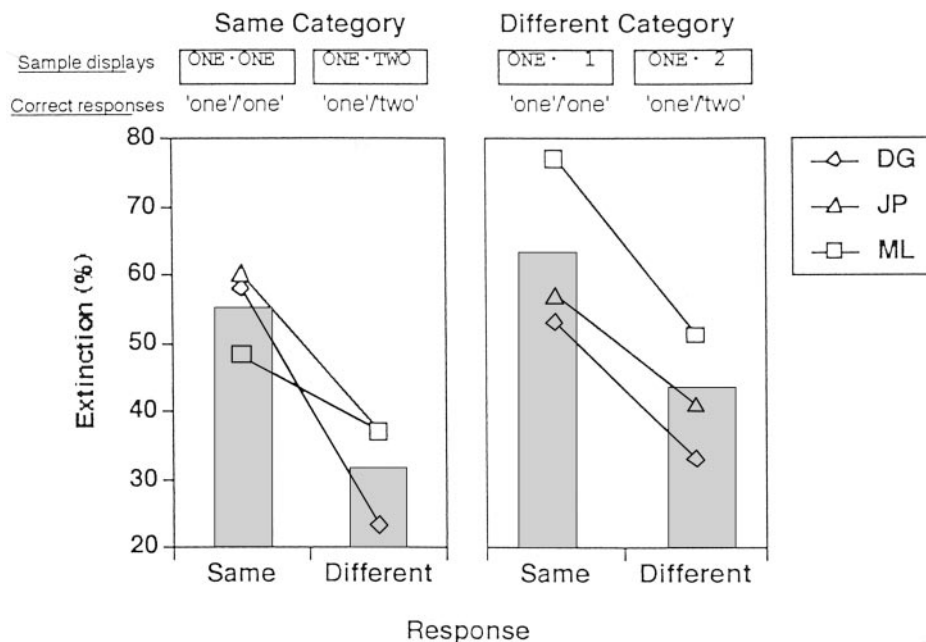
**Participants.** Three patients with visual extinction, caused by a recent stroke (within 6 weeks of testing) in the distribution of the right middle cerebral artery, were tested after obtaining informed consent under a protocol approved by both the University and National Health Service ethics committees. Each patient showed consistent visual extinction on confrontation testing at the bedside, but did not have a visual field deficit, so that they were able to report stimuli presented unilaterally in their contralesional fields. All showed signs of hemispatial neglect in social interaction and tasks of everyday life as well as on cancellation or line bisection tasks. Patient details, lesion location, and other neurological signs are summarized in Table 1.

**Procedure.** Each patient was tested in several sessions by using a laptop computer on which black stimuli were briefly presented on a white background. The stimuli were the words “ONE” and “TWO” and the numerals “1” and “2” (Helvetica 36) that appeared, randomly, in the left field (one-sixth of trials), the right field (one-sixth), or both fields (two-thirds of trials). The stimuli were centered on the vertical meridian at  $\approx 3^\circ$  eccentricity from a “+” sign at fixation that offset when the stimuli appeared. The patients were asked to read the item(s) and to report what was present in each visual field by responding “one” (indicating either the word “ONE” or the digit “1”), “two” (the word “TWO” or the digit “2”),

or “nothing.” Thus, responses were contingent on the semantic meaning of the stimulus (i.e., what it denotes in terms of numerosity), and independent of its visual features (i.e., whether a word or digit). Patients verbally reported the location and identity of the stimuli (e.g., “a one on the right and a two on the left”; “a one on the right and nothing on the left”), frequently pointing to the items in each field while naming them.

Because we were interested in the conditions determining the patients’ awareness of visual stimuli in their contralesional space, our primary dependent measure was the percentage of bilateral trials in which the patient reported that there was “nothing” in the left visual field. Misidentifying the contralesional stimulus would indicate that the patient was aware of some sort of visual stimulus, even though they were unable to correctly identify it. For this reason, misidentifications of the contralesional item (e.g., reporting “one” when the correct response was “two”) were scored as detections of the stimulus, and not as extinction trials.

On the critical bilateral trials, the items could: be identical (e.g., ONE + ONE or 2 + 2) and, thus, share the same visual features, meaning, and response; differ visually but share the same meaning and require the same response (e.g., 1 + ONE or TWO + 2); or differ both with regard to visual features, meaning and required response. This last condition included both trials in which the items came from the same category (e.g., 1 + 2) or from different categories (e.g., 1 + TWO; see examples in Fig. 1).



**Fig. 1.** Percentage of bilateral trials with extinction (i.e., the patients reported that “nothing” was present in the contralesional field) is shown for each patient in each condition (means in bar graph) in a task in which response was determined by the semantic meaning of the stimuli. Above each column is an example of a bilateral trial in which, from left to right, the competing items: (i) are identical in meaning, category, and visual features and require the same response; (ii) differ in meaning and visual features, and require different responses, but are from the same category; (iii) share the same meaning and response, but are from different categories and are visually dissimilar; or (iv) have different visual features and meaning, require different responses, and are from different categories.

**Table 2. Percent of targets missed, of those detected that were incorrectly identified for each patient in each condition of Experiment 1**

Example	DG		JP		ML	
	Misses, %	Errors, %	Misses, %	Errors, %	Misses, %	Errors, %
ONE 1	53 (19/36)	24 (4/17)	57 (23/40)	0 (0/17)	77 (37/48)	9 (1/11)
ONE 2	33 (12/36)	4 (1/24)	41 (16/39)	0 (0/23)	51 (24/47)	4 (1/23)
ONE ONE	58 (21/36)	27 (4/15)	60 (25/42)	12 (2/17)	48 (23/48)	24 (6/25)
ONE TWO	23 (8/35)	0 (0/27)	37 (15/41)	0 (0/26)	37 (18/48)	3 (1/30)
ONE –	0 (0/35)	14 (5/35)	37 (15/40)	4 (1/25)	27 (13/48)	3 (1/35)
– ONE	0 (0/34)	9 (3/34)	3 (1/39)	3 (1/38)	6 (3/48)	2 (1/45)

Numbers in parentheses indicate number of misses and number of errors out of total.

Training on the task was initiated by presenting the stimuli for several seconds and encouraging the patient to inspect each visual field and to report what item, if any, was present in each. When patients were reliably able to report both items on most trials with bilateral stimuli, a brief break was given and training resumed using a briefer exposure duration. This process continued until the patient began to manifest extinction on some trials. At this stage, the patients were encouraged to “guess,” if they thought they detected an item but were unsure of its identity. When the patient was comfortable with the procedure, the exposure duration was adjusted such that extinction occurred on  $\approx 30$ –70% of trials. Testing was then done in blocks (usually 48 trials): DG completed 215 trials with exposures of 500–1,000 ms; JP completed 246 trials with exposure durations of 2,500–2,750 ms; and ML completed 288 trials with a duration of 400 ms.

**Results.** Because our primary interest is in the conditions determining the patients’ detection of visual stimuli in contralesional space under conditions of competition, the chief dependent measure was the degree of extinction; i.e., errors in detecting the presence of any stimulus (reporting “nothing”) when a stimulus was, in fact, present. Misidentifications of an item (e.g., reporting “one” when the correct response was “two”) were scored as detections of the stimulus, because the patients had, in fact, detected the presence of a stimulus.

This approach also obviated a potential confound that might arise from a response bias in which a strategy was adopted to either use the same response used for the ipsilesional items or, conversely, to systematically select a different response under conditions of uncertainty. That is if, for example, on bilateral trials the patient detected a contralesional stimulus but was unsure of its identity, the patient could have adopted the strategy of reporting an identity different to that reported for the ipsilesional item. Such a guessing strategy could, if correct identification were the dependent measure, result in an artificial inflation of “correct” responses when the stimuli were different from when they were the same. Because, in our analyses, such incorrect identification of contralesional items on bilateral trials were scored as nonextinction trials, this type of strategy could not bias the results. Similarly, if the patient adopted a strategy, when he or she did not detect a contralesional item, of reporting that an item was present and guessing its identity, this strategy would affect scores on bilateral trials equally whether the items were same or different. Given task instructions and training, it was likely that that patients would, if a contralesional item had been detected but its identity uncertain, guess one of the two possible stimulus identities rather than guess that “nothing” had occurred. Our measure of extinction, therefore, may reasonably be assumed to accurately reflect a failure to detect the presence of any item, rather than the improbable alternative that patients systematically adopted a strategy to guess that “nothing” had been presented contralesionally when they had, in fact, detected an item but were uncertain of its identity.

Table 2 shows the number and percentage of misses (i.e., reporting “nothing” when a target had in fact been present), and the number and percentage of errors in identification on trials where the contralesional target was detected, for each patient in each condition. For all three patients, misses of right targets were very rare, both on unilateral right trials and on bilateral trials. Performance on unilateral left stimuli was more variable, though in each case better than left target detection on bilateral trials. For two of the patients, false alarms for left detections on unilateral right trials were very rare (JP, 3%, 1 of 39 trials; ML, 8%, 4 of 48 trials). The low false alarm rate for these two patients indicates that they did not adopt a strategy of reporting the presence of an item if they did not detect one. The third patient made a substantial number of false alarms in these displays (DG, 34%, 12 of 34 trials). These false alarms for patient DG indicate (i) a bias to report that a contralesional item was present under conditions of uncertainty and (ii) a bias to report the contralesional identity as different from the ipsilesional one (as seen on 8 of 12 false alarms). This set of response criteria deflates the overall magnitude of our extinction measure for DG, by making left detection on bilateral trials look artificially high. However, as discussed above, this bias in stimulus identification does not differentially affect our measure of primary interest, detection performance on same and different bilateral trials.

In those bilateral trials in which patients indicated there was an item in each field, they almost always indicated and reported the identity of the ipsilesional item first, and almost always looked at it and/or pointed toward its location. In those trials in which they also then reported the contralesional item, they also typically looked at and/or pointed to its location. In bilateral trials in which they reported that nothing was present in the contralesional field, they typically did not look toward that field.

Mean results for percent of extinction on bilateral trials are shown in Fig. 1 for all three patients. There was almost twice as much extinction when the items shared the same meaning and required the same response as when they required different responses,  $F[1,2] = 101.6, P = 0.01$ . This pattern of results was present and statistically reliable for all three patients: DG,  $\chi^2(1) = 11.01, P < 0.001$ ; JP,  $\chi^2(1) = 6.35, P = 0.02$ ; ML,  $\chi^2(1) = 6.42, P = 0.01$ . Post hoc testing revealed more extinction for same than different response conditions, both when items shared the same alphanumeric category,  $F(1,2) = 32.2, P = 0.03$ , and were in different categories,  $F(1,2) = 50.6, P < 0.02$ . Shared category did not significantly affect the degree of extinction,  $F(1,2) = 1.69, P = 0.32$ , nor did it interact with response,  $F(1,2) = 0.76, P = 0.48$ .

## Experiment 2

In the first experiment, response was based on semantics, and it is, therefore, unclear whether the degree of visual extinction was determined by similarity of semantics or similarity of the required response. A second experiment was conducted in a fourth patient, HH, in which the competing items were either ONE or

**Table 3. Percent of targets missed, and percent of those detected that were incorrectly identified for patient HH in each condition of Experiment 2**

Trials	Misses, %	Errors, %
Bilateral		
Different	34 (69/204)	1 (2/135)
Homophone	50 (51/101)	2 (1/50)
Identical	49 (50/103)	4 (2/53)
Unilateral		
Left	23 (24/104)	0 (0/80)
Right	2 (2/106)	0 (0/104)

Numbers in parentheses indicate number of misses and errors out of total.

TWO, or their homophones, WON and TOO. Thus, on the critical trials testing for extinction, the competing items could be, with equal probability, identical (e.g., ONE + ONE), different (e.g., ONE + TWO or WON + TWO), or could be homophones that were visually and semantically dissimilar but shared the same response (ONE + WON or TWO + TOO). (The three patients tested in the first experiment had either recovered or deteriorated and could no longer be tested.)

**Procedure and Results.** Table 3 shows that extinction was less when items were different than when they were identical  $\chi^2(1) = 6.25$ ,  $P < 0.0124$ ; or homophones,  $\chi^2(1) = 7.87$ ,  $P = 0.005$ . Thus, homophones that shared the same response but different meanings suffered as much extinction as items that were visually and semantically identical. Furthermore, differences in orthographic similarity did not modulate the degree of extinction. The rate of extinction for more orthographically similar pairs, i.e., TOO–TWO or TWO–TOO, was 45% (23 of 51) and was not greater  $\chi^2(1) = 1.2$ ,  $P > 0.2$ ) than the rate of extinction of the less orthographically similar pairs, i.e., ONE–WON or WON–ONE, 56% (28 of 50).

## Discussion

The current observations converge with other studies of hemispatial neglect in demonstrating that unattended items that are excluded from awareness may nevertheless be extensively analyzed at late stages of visual and semantic processing. If attention gated access to consciousness entirely by attenuating the processing of unattended stimuli early in the visual pathway, then visual extinction could not be influenced by the semantic meaning of the competing stimuli or by the task used to test for it. Extinction is, however, determined both by what the competing stimuli are, and by task demands. Whether or not a contralateral object is extinguished depends on (i) whether the competing item is the same, or different, on the dimension to be reported (14); (ii) whether the competing objects are grouped on the basis of Gestalt principles (15, 16); (iii) the task used to probe for extinction (counting, identification, or localization; ref. 17); and (iv) potential relevance, that is, real objects suffer less extinction than meaningless stimuli (18).

These previous findings demonstrate that, although attention may under some circumstances influence processing early in the visual pathway, this early filtering does not necessarily exclude unattended information from later stages of analysis, nor need it necessarily directly determine access to consciousness. The current observations go beyond these previous studies by demonstrating that attentional capture granting access to awareness of the presence of this information is gated at a stage at which the meaning of the visual stimulus is used in selecting it for action.

In considering the effect of stimulus similarity on extinction, Baylis *et al.* (14) speculated that the phenomenon might be

similar to that of “repetition blindness” that is observed in normal individuals. Usually demonstrated under conditions of rapid serial visual presentation, normal individuals omit reporting repeated items (19). Indeed, repetition blindness occurs not only for identical items but, as was the case in the current study, also for visually dissimilar items sharing the same meaning or phonology (20). However, important differences between repetition blindness and repetition effects in extinction have also been identified. To directly compare repetition blindness with the effects of stimulus repetition on visual extinction, a subsequent study (21) in healthy observers used masked stimuli in an experiment that replicated the conditions used in patients by Baylis *et al.* (14). That study was designed, like the current one, to obviate the possibility that repetition blindness could result simply from a reluctance to produce repeated responses (22). The results indicated a critical difference between repetition blindness in normal individuals and the effect of stimulus repetition in patients. Although repetition blindness induced in healthy observers did reduce the accuracy in discriminating items, it did not result in a failure to detect them. Moreover, repetition blindness does not require that the repeated items both be reported. For example, if subjects are asked to read a word such as “manager” presented one letter at a time, they frequently miss the second “a” and erroneously read “manger,” even though the task does not require reporting the individual letters (23). Kanwisher *et al.* (21) concluded that, unlike the effect of stimulus repetition on visual extinction in patients, repetition blindness reflects “a failure in binding the appropriate identity (type) to distinct object representations (tokens) when a type is repeated, rather than a complete failure to set up distinct tokens.” By contrast, extinction appears to reflect a fundamental difficulty in establishing object representations for action selection, a level of processing we suggest is crucial for explicit detection and visual awareness.

The emphasis here is on a distinction between the function that attention serves in perception (what it selects) and how this selection is implemented. We conclude that the function of attention is one of selection for action (24, 25). That is, attention selects late in the processing of visual information immediately before action selection. The concept of late selection, as used here, does not imply that attention cannot operate by modulating neural activity early in the visual pathway. Rather, selection can be implemented by biasing competition at various levels of neural processing; however, we propose that, given specified task goals, this competition is resolved at the level of the representation needed to select action. That is, if action is based on simple features such as location, shape, or color, competition is biased in visual cortical areas processing these features (2, 3, 14, 26, 27). If, on the other hand, action is based on semantics or phonology, as in the case of the current experiments, the competition is resolved at higher levels of representation, where this information is used to select action.

This view is consistent with a specific role for attention that has been posited recently as part of a dimensional–action model (28). Consistent with observations in normal individuals (8) and patients with hemispatial neglect (9) mentioned earlier, this model specifies that responses may be activated without attention. However, only those activated responses to which attention is deployed will reach “executive functions” that mediate goal-directed behavior.

Previous research in both normal individuals and in patients with hemispatial neglect have shown that visual signals that do not gain access to consciousness may “capture” attention, in the sense of producing an orienting bias reflected by a subsequent advantage in target detection at that location (12, 29) or the generation of a reflexive eye movement toward it (30, 31). The current study, however, has sought to elucidate the mechanisms determining whether attentional capture will not only bias

processing at a location, but will also lead to disengagement of attention from its current focus so that signals at that location are explicitly detected and accessible to processing by limited capacity systems for voluntary action.

Lesions of the temporo-parietal cortex junction causing visual extinction result in a deficit in disengaging attention (32). The current findings are consistent with a more general role for this region as a “circuit breaker” that enables disen-

gagement of attention when attention is captured by unattended task-relevant information (33). The findings reported here indicate that competition for access to this system is determined at a stage of processing immediately before response selection.

This work was supported by U.S. Public Health Service Grants RO1 MH41544 and RO1 DC00128 and the Wellcome Trust.

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