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## Sensory and response contributions to visual awareness in extinction

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**Abstract.** Brain-damaged patients may extinguish contralesional stimuli when ipsilesional stimuli are presented simultaneously. Most theories of extinction postulate that stimuli compete for pathologically limited attentional resources with a bias to process ipsilesional over contralesional stimuli. Implicit in this view is the idea that responses follow the outcome of an earlier competition between inputs. In the current study of two patients, we used signal detection analyses to test the hypothesis that response criteria and response modalities also contribute to visual awareness. We found that identification was more sensitive than detection in uncovering deficits of contralesional awareness. Extinction was worse with bilateral stimuli when the ipsilesional stimulus was identical or similar to the target than when it was dissimilar. This diminished awareness was more likely to reflect a shift towards more conservative responses rather than diminished discrimination of contralesional stimuli. By contrast, one patient was better able to discriminate contralesional stimuli when using his contralesional limb to indicate awareness of targets than when using his ipsilesional limb. These data indicate that the nature of stimuli can modulate response criteria and the motor response can affect the sensory discriminability. Sensory discrimination and response output are not organized in a simple serial manner. Rather, input and output parameters interact in complicated ways to produce visual awareness. Visual awareness itself appears to be the outcome of two bottlenecks in processing, one having to do with sensory

processing that may be covert and the other having to do with decision making, which by definition is overt. Finally, we advocate the use of signal detection analyses in studies of extinction, a method that has been surprisingly neglected in this line of research.

**Keywords** Neglect · Visual attention · Consciousness · Signal detection theory

### Introduction

Patients with visual extinction are unaware of contralesional stimuli when ipsilesional stimuli are presented simultaneously. However, they can detect such contralesional stimuli when they are presented in isolation. This disorder is observed after unilateral brain lesions, more often with right than left hemisphere damage. Early theories (Bender 1952; Battersby et al. 1956) viewed extinction as a result of inadequate processing of contralesional sensory input to the damaged hemisphere. Although a mild sensory impairment might account for better detection of single stimuli than the more demanding condition of double stimuli presentations (Farah et al. 1991), sensory accounts do not explain many features of the disorder. The widely held view is that extinction reflects a lateralized disorder of spatial attention and/or representation (Bisiach and Vallar 1988; Heilman and Valenstein 1979; Kinsbourne 1993; di Pellegrino and De Renzi 1995; Smania et al. 1996). The attentional accounts mean that the impairment is subject to modulation. Extinction can be modulated by the orientation of spatial attention (Posner et al. 1987; Karnath 1988; di Pellegrino and De Renzi 1995), converging cross-modal inputs (Ladavas et al. 1998; Vaishnavi et al. 1999, 2001), task (Vuilleumier and Rafal 2000; Baylis et al. 2001) and response demands (Bisiach et al. 1989; Smania et al. 1996; Ricci et al. 2003).

Attentional accounts of extinction postulate a pathologically limited capacity to process multiple stimuli. These stimuli compete for limited attentional resources, and

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because of a bias to process ipsilesional stimuli preferentially over contralesional stimuli, the contralesional stimuli are extinguished. Implicit in this view is the idea that the subject simply reports whichever stimulus “wins” this competition to penetrate consciousness. The response phase of the behavior follows naturally from the outcome of the earlier limitations in processing.

For several reasons, a model of extinction in which response variables are not considered is likely to be incomplete. Single-cell neurophysiologic studies show that in the macaque, parietal attentional neurons are tightly linked to motor systems (Colby and Goldberg 1999; Graziano and Gross 1995). The intraparietal sulcus contains a mosaic of attentional cells that are especially responsive to stimuli when the eyes or limbs are moved towards them. Rizzolatti has long contended that spatial attentional mechanisms developed largely to select actions in space (Rizzolatti and Camarda 1987). In many patients with unilateral spatial neglect, the motor demands of a task affect their awareness of stimuli (Bisiach et al. 1990; Tegnér and Levander 1991; Na et al. 1998; Milner et al. 1993; Chatterjee 1998). Given these observations of the role of output systems on visual awareness, it seems plausible that the response demands of a task might also influence awareness of stimuli in extinction. In fact, we reported recently that tactile extinction was ameliorated when patients actively moved their fingers onto stimuli than when they received these stimuli passively (Vaishnavi et al. 2001).

Recently, we also raised another concern about response variables in theorizing about extinction (Olson et al. 2003). Most studies in extinction do not consider how biased response patterns might influence results. Despite the fact that methods of signal detection analyses (Green and Swets 1966; Snodgrass and Corwin 1988) have been around for almost a half century and extinction paradigms are essentially tests of signal detection, the extinction literature has made virtually no contact with signal detection theory. Signal detection analyses offer a way to disambiguate two parameters: one that quantifies the discriminability of a target from noise and another that identifies the criterion beyond which a subject judges the signal to be present. Our investigations of tactile extinction (Vaishnavi et al. 2000; Olson et al. 2003) suggest that signal detection analyses can offer insights into behavior that would otherwise be difficult to appreciate by simply comparing accuracy rates.

In the present study, we extended our use of signal detection analyses from tactile to visual extinction. We examined three variables that might modulate contralesional awareness. First was the perceptual characteristics of the stimuli themselves. How does the presence of and ease with which distractors can be discriminated from targets affect contralesional awareness? Second was the relevant attribute defining the target, that is shape or color as determined by the experiment. Does the salience of the distractor as determined in a “top-down” manner affect contralesional awareness? Third was the kind of response used to identify targets. Does responding by pointing

influence contralesional awareness? Since signal detection analyses have not been used much in extinction, our experiments are somewhat exploratory, and the predictions are relatively unrefined. A straightforward serial model of stimuli competing for limited attentional resources followed by a response indicating the “winner” would make the following predictions. The difficulty of discriminating target from distractors would most likely affect  $d'$ , since perceptually similar targets would presumably induce greater competition. By contrast, varying response modalities might simply affect  $c$ , the response criterion, if it had any effect at all. It is not clear if the salience of the stimuli as determined by the experimental condition would affect discriminability. A more interactive model in which responses influence input processing of stimuli would predict that the nature of responses might also influence discriminability.

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## Materials and methods

### Subjects

Two patients, EG and JD, with chronic unilateral lesions of the right and left hemisphere respectively participated in our investigations. The patients gave informed consent for this study which was approved by the Institutional Review Board in accordance with the ethical guidelines laid down by the 1964 Declaration of Helsinki. EG was a 62-year-old right handed man who had an ischemic stroke in the entire distribution of the right middle cerebral artery involving the frontal, parietal and temporal cortices. He had 18 years of education. At the time of testing he showed only mild evidence of neglect, scoring 138/146 on the Behavioral Inattention Test (BIT) (Wilson et al. 1987). JD was a 46-year-old right handed man with an ischemic stroke in the distribution of the posterior division of the left middle cerebral artery. He had a mild acquired dysgraphia, but otherwise did not have chronic language deficits. He had 14 years of education. At the time of testing, he did not have any evidence of neglect, scoring 144/146 on the BIT.

### Signal detection analysis

Signal detection analysis was used to determine the discriminability,  $d'$ , and the response criterion,  $c$ , adopted when reporting contralesional stimuli (Green and Swets 1966; Snodgrass and Corwin 1988).  $d'$  is an index of how easily the subject discriminates the target from background of noise or from the distractor. High values of  $d'$  mean better discriminability. The  $c$  value is an index of the criterion with which the subject gives his/her response. Positive  $c$  values indicate conservative response criteria, and negative  $c$  values indicate liberal criteria.  $d'$  and  $c$  for contralesional stimuli were derived from the conditions with an ipsilesional target and separately from the conditions with an ipsilesional distractor. Both subjects performed at ceiling at discriminating ipsilesional targets from distractors, and the parameters for these judgments are not reported. To test for differences between discriminability or response biases indices, the 95% confidence interval around the difference of  $d'$  values or  $c$  values was calculated respectively (Green and Swets 1966). The two signal detection parameters and relative statistics were derived in a standard manner; see Olson et al. (2003):

$$d' = Z_{FA*} - Z_{H*}$$

$$c = Z_{FA*} - d'/2 = 0.5(Z_{FA*} + Z_{H*})$$

As advocated by Snodgrass and Corwin (1988), we used corrected values for Hits and False Alarms to protect against situations in which hit rates might be 1.0 and false alarm rates might be 0, because the corresponding  $Z$  scores would be infinite. Accordingly,

$$FA* = (FA + 0.5)/(FA + CR + 1.0)$$

$$H* = (H + 0.5)/(H + M + 1.0)$$

## Experiment 1: simple detection

In this experiment we investigated the effects of the presence of an ipsilesional stimulus on awareness of the contralesional stimulus. This is a common way of testing for extinction. Subjects simply report the presence of a target in left, right, both or neither locations. In this and subsequent experiments we report conventional analyses by comparing the proportion of correct responses to unilateral contralesional and bilateral stimuli, in addition to signal detection analyses.

### Stimuli and procedure

Patients were presented with a red T ( $0.91^\circ$  by  $1.14^\circ$  of visual angle) which could appear on the left, right, both or neither sides of a fixation cross ( $0.34^\circ$  by  $0.34^\circ$  of visual angle). The distance between the stimulus and the central cross was  $10^\circ$  of visual angle. Stimuli were flashed for 50 ms on the black screen of a computer monitor, where the fixation cross was always present. Patients sat in front of the monitor, which was centered on their sagittal mid-plane. They were asked to verbally report the location of a red T. There were 50 trials for each condition. Trials were presented in a random order. Before the experimental session, 20 practice trials were administered. Patients were instructed to fixate the central cross from the beginning to the end of the stimulus presentation. The experimenter alerted the patient before delivering each trial by saying 'now'. Eye movements were monitored during stimulus presentation by one of the experimenters. Trials during which an obvious eye movement was detected were excluded from the analysis and rerun.

### Results

The patients' accuracy rates are reported in Table 1. EG did not have extinction as traditionally conceived. He did not make any errors. His discriminability ( $d'=5.16$ ) and unbiased response criterion ( $c=0.00$ ) reflected his ceiling performance.

By contrast, JD had an 83% overall accuracy rate. His ability to detect a contralesional target dropped significantly ( $p<0.05$ , test of proportion; Bruning and Kintz 1977) from 98% to 86% when this stimulus was presented simultaneously with an ipsilesional stimulus. Moreover,

**Table 1** Experiment 1. Detection task. Percent of patients' correct responses are reported for each condition. JD's contralesional errors were omissions in the bilateral and contralesional stimulus conditions, and false alarms in the no stimuli and ipsilesional stimulus conditions

	Bilateral stimuli	Contralesional stimulus	Ipsilesional stimulus	No stimuli
EG	100%	100%	100%	100%
JD	86%	98%	52%	96%

when presented with a single ipsilesional stimulus he also reported two stimuli (false alarms) on 48% of the trials. The presence of an ipsilesional stimulus significantly decreased ( $p<0.0001$ ) contralesional stimulus discriminability ( $d'$  diminished from 3.54 to 1.10).

### Comment

These findings, in one of our two patients, are consistent with the idea that ipsilesional stimuli compete with contralesional stimuli for limited attentional resources. The presence of an ipsilesional stimulus impaired JD's ability to detect the contralesional target. JD had an unusually high proportion of false alarms when there were no stimuli present. Despite this tendency, it was his ability to discriminate the contralesional stimulus that was impaired by the presence of a contralesional stimulus, as would be expected by biased competition models of extinction.

## Experiment 2: color identification

### Stimuli and procedure

Stimuli were red and green letters, in the form of T, X and L. In this task bilateral stimuli were always presented. Stimuli appearing on the screen could be: (1) both red, (2) red on the left and green on the right, (3) red on the right and green on the left, or (4) both green. Patients were told that red stimuli were targets and green stimuli distractors. They verbally reported the target location (i.e. both, left, right, neither). Within each of the four 'color conditions' stimuli could have 'same' (two T), 'similar' (TL on half of the trials and LT on the other half) or 'different' (TX or XT) shapes.

There were 300 trials for each color condition, for a total of 1,200 trials. Trials were presented with a random order within four different blocks. Procedure and stimuli parameters were the same as described for the detection task.

A pilot study on a group of ten normal subjects (five males and five females; mean age = 24 years, SD = 4.01) was performed (using our paradigm) to confirm that Ls are more difficult than Xs to discriminate from Ts. Stimuli were flashed on the screen with the same exposure time (50 ms) used for the patients' experiments. Stimuli could

**Table 2** Experiments 2 and 3. Identification tasks. Percent of patients' correct responses are reported for each condition. Contralesional errors were omissions in the bilateral and contralesional target conditions, and false alarms in the no target and ipsilesional target conditions

	Bilateral targets	Contralesional target	Ipsilesional target	No targets
<b>Color</b>				
EG	73%	100%	100%	73%
JD	1%	100%	100%	9%
<b>Shape</b>				
EG	75%	100%	100%	86%
JD	76%	90%	44%	42%

be two Ts (200 trials), one T on the left and one X on the right and vice versa (100 trials), one T on the left and one L on the right and vice versa (100 trials), for a total of 400 trials. Subjects had to press one key on the computer keyboard when stimuli were the same and another key when they were different. Normal subjects were significantly slower (Wilcoxon,  $p=0.013$ ) and less accurate (Wilcoxon  $p=0.008$ ) in judging the difference between Ts and Ls (RT = 583, SD = 67.37; accuracy = 96%) than Ts and Xs (RT = 563, SD = 62.38; accuracy = 99%).

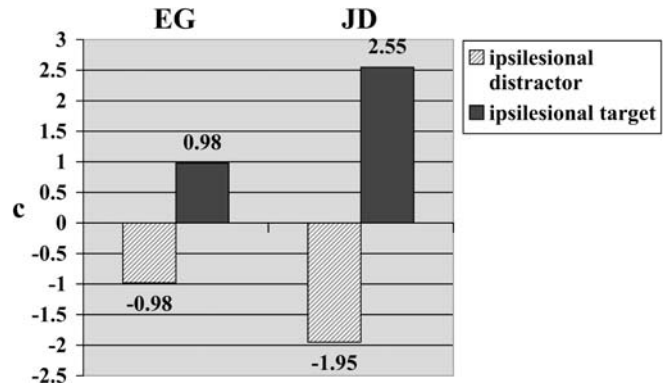
**Results**

Both patients were worse in this identification task than in the previous detection task. EG and JD were 87% and 53% correct respectively (see details in Table 2). When their data were analyzed in conventional ways, both patients' accuracy was significantly worse for bilateral targets than for unilateral contralesional targets (Bruning and Kintz 1977). EG went from 100% to 73% accuracy, and JD went from 100% to 1% accuracy. In both patients, conventional analyses did not reveal significant differences in performance for contralesional stimuli when an ipsilesional stimulus was a distractor versus when it was a target (unilateral left + neither vs. bilateral + unilateral right conditions).

By contrast, the nature of the ipsilesional stimulus (target or distractor) did affect performance when analyzed using signal detection analyses. The effect was on the criteria they used to report the contralesional target rather than contralesional discriminability. Specifically, both patients became more conservative ( $p<0.0001$ ) when the ipsilesional stimulus was a target (i.e. a red letter) than when it was a distractor (i.e. a green letter) (see Fig. 1). The shape of the ipsilesional stimulus (T, L or X), which was not relevant to the task, did not influence contralesional discriminability or response criterion.

**Comment**

Conditions in which bilateral stimuli were present in every trial and subjects made discriminations based on visual



**Fig. 1** Experiment 2. Color Identification Task: patients' response criteria (c) moved in a conservative direction when the ipsilesional stimulus was a target

attributes of stimuli were more sensitive in uncovering a lateralized attentional deficit than a simple detection task as is commonly used to assess extinction. Conventional analyses of performance also showed that performance worsened with bilateral presentation of stimuli. What could not be inferred from such conventional analyses is that the nature of the ipsilesional stimulus influenced both patients' response criteria and not their ability to discriminate contralesional targets from distractors. The nature of the distractor when not relevant to the task (shape) did not affect performance.

**Experiment 3: shape identification**

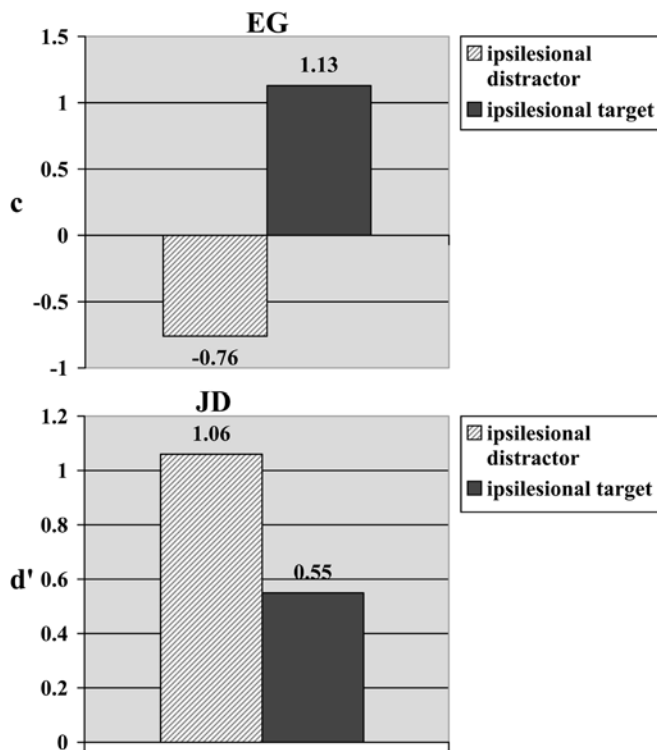
**Stimuli and procedure**

In this task, the target was defined by the shape of the stimulus and not by its color. Again bilateral red and green letters, in the form of T, X and L, were presented. Patients were asked to verbally report the location in which the letter T appeared (i.e. both, left, right, neither) and to ignore the letters X and L. The stimuli on the screen could be: (1) two Ts, (2) a T on the left and an X or an L on the right, (3) a T on the right and an X or an L on the left, or (4) two Xs or two Ls. Within each of the four 'shape conditions' the color could be the same (two red stimuli) or different (a red stimulus on the left and a green on the right or vice versa). There were 300 trials for each shape condition, for a total of 1,200 trials. For conditions 2, 3, and 4 the two possible stimuli combinations were balanced. Trials were presented in a random order within four different blocks. Procedure and stimuli parameters were the same as before.

**Results**

Again, both EG and JD were worse at this identification task than they were in the detection task. EG was 90% correct and JD 63% (see Table 2 for details). Again, when their data were analyzed in conventional ways, both





**Fig. 2** Experiment 3. Shape Identification Task: the presence of an ipsilesional target made EG's response criteria ( $c$ ) more conservative and diminished JD's contralesional discriminability ( $d'$ )

patients' accuracy was significantly worse (Bruning and Kintz 1977) for bilateral targets than for unilateral contralesional targets. EG went from 100% to 75% accuracy, and JD went from 90% to 76% accuracy. In both patients, conventional analyses did reveal significant differences in performance for contralesional stimuli when an ipsilesional stimulus was a distractor versus when it was a target (unilateral left + neither vs. bilateral + unilateral right conditions). EG's performance diminished from 93% to 88% accuracy, and JD's performance diminished from 66% to 60% accuracy.

JD's accuracy for single ipsilesional targets was low (43%) because he frequently reported bilateral targets. Thus, he had no difficulty detecting the ipsilesional target, but he made many false alarms with contralesional stimuli.

EG's contralesional discriminability was not affected by whether or not the ipsilesional stimulus was a target. However, his response criteria became more conservative ( $p < 0.0001$ ) when the ipsilesional stimulus was a target (see Fig. 2). The shape of the ipsilesional distractor, whether it was an L or an X, did not affect his contralesional discriminability or response criteria. The color of the ipsilesional stimulus, an irrelevant attribute, did not affect contralesional target discriminability or response criteria.

JD's behavior was more complicated. The presence of ipsilesional targets decreased ( $p = 0.002$ ) his contralesional target's discriminability (see Fig. 2). The shape of the ipsilesional distractor, whether it was an L or an X, did not affect his target discriminability but did affect his

contralesional response criteria. He was more conservative ( $p = 0.032$ ) with L distractors ( $-0.62$ ) than X distractors ( $-0.88$ ). When the ipsilesional stimulus was a target, its color, an irrelevant attribute, affected JD's contralesional response criterion. He was more conservative with the same ( $-0.25$ ) than with different colors ( $-0.50$ ). When the ipsilesional stimulus was a distractor (X or L) its color did not affect his contralesional discriminability or response criterion.

#### Comment

These experiments confirmed that identification tasks are more sensitive than detection tasks in eliciting deficits of contralesional awareness. Again, conventional analyses demonstrated extinction in both patients under these conditions. However, contralesional extinction was not exclusively accounted for by bottom-up competition as would be expected by sensory competition models for limited resources. Four conditions modulated contralesional awareness in JD and EG. These four conditions were the nature of the ipsilesional stimulus (target or distractor) for both JD and EG, the shape of the distractor (L or X) for JD, and the color of the ipsilesional stimulus when it was the target for EG. In three of these four conditions it was the response criteria and not the discriminability that was affected. Furthermore, the criteria shifts were consistent. The more similar the attribute of the ipsilesional stimulus and the contralesional target, the more conservative the response.

#### Experiment 4: response modality: pointing

In this experiment we wished to learn if the effects observed in the previous identification experiments specifically characterized patients' performance when they used a verbal response or if it would generalize to a motor response. Therefore, patients were asked to report target location by pointing towards it.

#### Stimuli and procedure

Stimuli were red Ts and Xs. The letter T was the target. Bilateral stimuli were always present. Stimuli appearing on the screen could be two Ts, two Xs, a T on the left and an X on the right and vice versa. There were 50 trials for each of the four conditions. Trials were given with a random order. Stimuli characteristics and procedure were the same used in the identification tasks of experiment 1.

Patients were asked to *point towards* the location (left, right, both) in which the target(s) appeared and to not point when targets were not present. EG could only perform the pointing task with his ipsilesional limb. JD used his contralesional first and then his ipsilesional limb.

**Table 3** Experiment 4. Shape Identification Task—Motor Response. Percent of patients' correct responses are reported for each condition. Contralesional errors were omissions in the bilateral and contralesional target conditions, and false alarms in the no target and ipsilesional target conditions. Patients performed the motor task using their ipsilesional limb (IL). JD was able to perform the task also with his contralesional limb (CL)

	Bilateral targets	Contralesional target	Ipsilesional target	No targets
EG (IL)	74%	100%	100%	78%
JD (IL)	48%	84%	64%	24%
JD (CL)	36%	90%	90%	64%

## Results

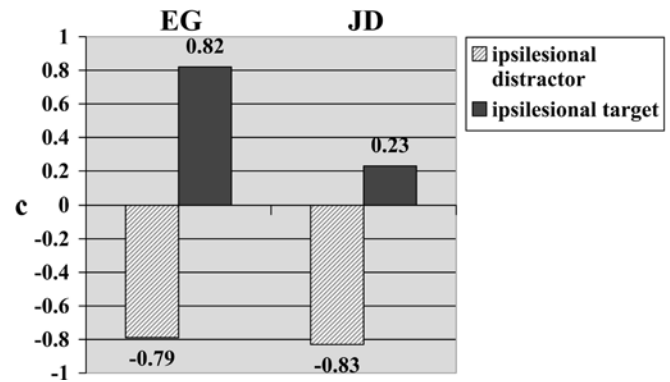
EG and JD were 88% and 55% correct respectively when they pointed with their ipsilesional limb. JD was 70% correct when he used his contralesional limb. The two patients' accuracy rates for the different target locations are reported in Table 3. When their data were analyzed in conventional ways, both patients' accuracy was significantly worse for bilateral targets than for unilateral contralesional targets (Bruning and Kintz 1977). When using their ipsilesional limb, EG went from 100% to 74% accuracy, and JD went from 84% to 48% accuracy. JD went from 90% to 36% when using his contralesional hand. JD's performance was not significantly different depending on whether he used his ipsilesional or contralesional hand to make his responses. In both patients, conventional analyses did not reveal significant differences in performance for contralesional stimuli when an ipsilesional stimulus was a distractor versus when it was a target (unilateral left + neither vs. bilateral + unilateral right conditions) and they used their ipsilesional hand. JD did show a significant effect when using his contralesional hand, such that his performance went from 80% with an ipsilesional target to 63% with an ipsilesional distractor.

When EG and JD pointed with their ipsilesional limb, the presence of an ipsilesional target did not affect their target discriminability. Instead it made both patients more conservative ( $p < 0.0001$ ) in their responses (see Fig. 3).

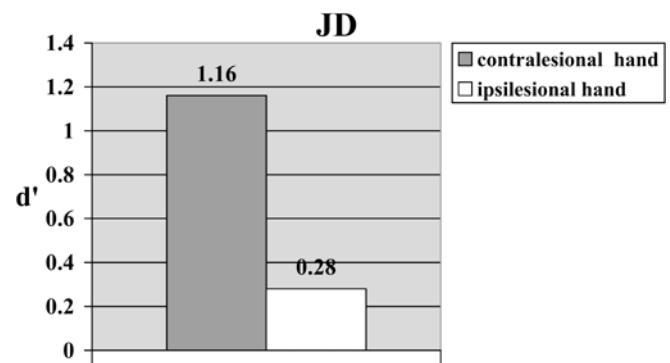
Overall, JD was better able ( $p = 0.0008$ ) to discriminate contralesional targets when pointing with his contralesional limb than when pointing with his ipsilesional limb (1.16 compared to 0.28) (see Fig. 4). When JD pointed with his contralesional limb, the presence of ipsilesional targets diminished ( $p = 0.039$ ) his contralesional discriminability (from 1.75 to 0.89).

## Comment

These results are in line with the results of experiment 2. Conventional analyses of our patients' data showed extinction in all of the conditions. Their performance was worse when targets were presented bilaterally than when presented unilaterally in contralesional space. Again,



**Fig. 3** Experiment 4. Shape Identification Task-Motor Response: when patients pointed towards targets with their ipsilesional limb, the presence of an ipsilesional target made their response criteria ( $c$ ) more conservative



**Fig. 4** Experiment 4. JD: pointing with the ipsilesional limb decreased contralesional target discriminability with respect to pointing with the contralesional limb

what would not have been evident from such analyses is the fact that the presence of an ipsilesional target influenced the patients' response criteria rather than their discriminability. They became more conservative when the ipsilesional stimulus was a target. JD could perform the task with both limbs. Conventional analyses failed to show a difference in his performance. However, using signal detection analyses it was evident that the limb he used to report stimuli affected sensory discriminability: pointing with the contralesional limb improved his ability to discriminate contralesional targets from distractors.

## Discussion

Patients with unilateral brain damage may extinguish awareness of contralesional stimuli when ipsilesional stimuli are presented simultaneously. Extinction is usually thought to reflect a limited capacity to process incoming stimuli, with a bias to process ipsilesional over contralesional stimuli (Duncan et al. 1997). In this study, we considered how input variables, such as target characteristics, and output variables, such as response modalities and response criteria, play a role in extinction. Furthermore, we used signal detection analysis to quantify

patients' performance, which has been used only rarely in the assessment of extinction (Vaishnavi et al. 2000; Olson et al. 2003). This analysis disambiguates discriminability and response criteria used by the patients to indicate their awareness of contralesional targets.

Our two patients were tested in detection and identification tasks. In detection, patients simply report where stimuli occurred. In identification, stimuli were always present bilaterally and patients reported the location of targets, which were defined by specific features (i.e. color or shape). One of the identification tasks was also repeated with the subjects pointing to the location of the target rather than reporting its location verbally.

EG performed normally on the detection task whereas JD demonstrated extinction. The presence of an ipsilesional stimulus diminished JD's ability to discriminate the presence or absence of a contralesional stimulus. Dampened discriminability of contralesional stimuli would be expected from a biased competition model in which incoming stimuli compete for limited resources.

Both patients were worse when they had to identify targets than when they simply had to detect them. EG's lateralized deficit was only evident on the identification task. Our data are in line with previous findings showing that increasing demands of a task can worsen extinction or neglect. Patients show greater extinction when they are asked not only to locate but also to identify stimuli among distractors (Vuilleumier and Rafal 2000; Baylis et al. 2001). Similarly, increasing the attentional load of a visual detection task worsens extinction (Mattingley et al. 2003). Furthermore, more stimuli were presented across trials in the identification than in the detection task. Increasing the number of stimuli can increase deficits of awareness in patients with neglect (Chatterjee et al. 1992, 1999; Rapcsak et al. 1989).

The idea that identifying a target in addition to detecting its spatial location places greater demands on attentional systems seems plausible. However, the effect of the ipsilesional stimulus on contralesional awareness, in our cases, seems rather specific. The similarity of the ipsilesional stimulus to the target diminished awareness of contralesional targets primarily by shifting our patients' response criteria rather than diminishing their contralesional sensory discriminability.

In experiment 3, we examined how attributes of the ipsilesional stimulus affected awareness of the contralesional target in greater detail. The conditions considered: (1) whether the ipsilesional stimulus was the same or different than the target, (2) when the ipsilesional stimulus was different than the target whether it was more or less similar to the target on the relevant dimension (shape) and (3) whether the ipsilesional stimulus was the same or different than the target on an irrelevant dimension (color).

The effect of an ipsilesional target on contralesional awareness differed in EG and JD. EG was more conservative in his judgment of whether the contralesional stimulus was a target when presented with an ipsilesional target than an ipsilesional distractor. By contrast, JD was less able to discriminate contralesional targets from

distractors when presented with an ipsilesional target. The attributes of the distractor, whether relevant or irrelevant, did not affect EG's contralesional awareness. When attributes of the ipsilesional distractor affected JD's contralesional awareness it did so by changing his response criterion. Perhaps irrelevant distractors come into play when uncertainty is high.

Two points about these observations are worth emphasizing. First, the effect of sensory attributes such as color or shape on response criteria and not discriminability would not be predicted by most models of biased competition. Second, the pattern of response criteria shifts was consistent. Ipsilesional stimuli that were more similar to contralesional targets produced more conservative responses. These results are reminiscent of previous findings, showing that patients' extinction is worse with targets that are similar to distractors than with targets that are dissimilar (Baylis et al. 1993; Vuilleumier and Rafal 2000). Recently, Rafal and colleagues (2002) reported that extinction was worse with competing items on bilateral trials when items were identical (e.g., "1" and "1") or when they shared meaning despite being perceptually quite different (e.g., "1" and "one"). From their observations, they infer that attention gates processing of stimuli at a relatively late stage, at the point of selecting a response. Our analyses, consistent with this view, demonstrate directly that worsening performance with distractors that are similar to targets is more likely to affect response criteria than contralesional target discriminability.

The general pattern of performance in which an ipsilesional target is more likely to affect response criteria was replicated when our patients used their limbs to indicate awareness of stimuli. Furthermore, JD was able to perform the task using either limb to indicate the presence of targets. If extinction is caused solely by biased competition between stimuli in their access to awareness, then the nature of the response downstream from this bottleneck should have no effect on target discriminability. However, we found that JD discriminated contralesional targets more easily when using his contra than his ipsilesional limb. This result is consistent with data from previous studies showing that contralesional movements can ameliorate neglect and extinction (Duhamel and Brouchon 1990; Robertson and North 1993; Robertson et al. 1994; Worthington 1996; Vaishnavi et al. 1999, 2001). One possibility is that these results occur because of a directional hypokinesia in which the ipsilesional limb is unlikely to move into contralesional space. Such a mechanism in its simplest form would be expected to change the response bias and not the sensory discriminability. However, our results are more specific in suggesting that this improvement occurs at the level of sensory discriminability. Visually guided reaching activates posterior parietal regions of the contralateral hemisphere (Grafton et al. 1992; Kawashima et al. 1994). Pointing with the contralesional hand may have improved contralesional discrimination by activating sensory-motor circuits within the damaged hemisphere.

What are we to infer from these patterns of performance in which competing stimuli can produce shifts in either discriminability or shifts in response criteria? The shifts in discriminability seem straightforward and well within the traditional view of extinction. This pattern is best exemplified in JD's performance in the first experiment. The presence of an ipsilesional stimulus impaired the detection of a contralesional stimulus by diminishing its discriminability. This is the predicted pattern of results for a model of extinction in which there is a limited capacity to process sensory information. Accordingly, a bias to process ipsilesional stimuli comes at a cost to the processing of contralesional stimuli. This initial bottleneck can be further modulated by the nature of the effectors used to indicate awareness. Thus, JD discriminated targets better when using his contralesional than his ipsilesional limb to indicate awareness, which we think follows from the tight sensory-motor attentional links within the damaged hemisphere.

The pattern of performance that is more interesting and also less straightforward is the one in which target attributes of ipsilesional stimuli, rather than impairing the ability to discriminate contralesional stimuli, make patients respond more conservatively. There are at least two possibilities for this pattern. One is that this pattern simply reflects individual variability. Under conditions of increasing uncertainty, perhaps some subjects become more conservative, and if we tested more subjects, we would find that others become more liberal. While this individual variability hypothesis is a logical possibility, we think that it is less likely (because of data from additional patients that we are currently gathering). Alternatively, these data may indicate that there are at least two "bottlenecks" of processing. The first, as we have already mentioned, is the level at which sensory processing competes for limited resources. Beyond that is a bottleneck of processing from which decisions emerge. A limited capacity to acknowledge targets and their attributes at this later level would shift responses in a conservative direction when such attributes are present in more than one stimulus. This later decision-making stage is an index of overt processing. By inference, the sensory bottleneck that occurs earlier reflects covert processing, since discriminability can remain unchanged despite changes in overt expressions of awareness.

From our observations, in addition to the conceptual elegance of signal detection analyses, there are several reasons to use this method in studies of extinction. Firstly, such analyses may be more sensitive at detecting differences in patterns of performance than conventional analyses. In this study, the difference in JD's ability to discriminate contralesional stimuli based on the limb he used to indicate awareness of targets would not have been captured by traditional analyses. Secondly, such analyses are able to incorporate false alarms by patients. Patients with neglect sometimes have contralesional productive symptoms (Bisiach 1999; Chatterjee 2002). JD made frequent "false alarms" often reporting targets in contralesional space when there were none. We do not know why JD and some patients make many false alarms. However, such productive or confabulatory responses often go unreported or unanalyzed in assessments of extinction.

Signal detection analyses can take account of negative and positive expressions of disrupted spatial awareness in extinction. Thirdly, and most importantly, such analyses disambiguate patients' abilities to discriminate contralesional stimuli and the criteria they use to judge the presence of a target. Here, we have shown that a class of conditions, in which ipsilesional stimuli are similar to targets, is more likely to affect response criteria than discriminability. More generally, these observations raise questions of many of the previous empirical observations in extinction. Are previous reports of modulation of awareness in extinction due to changes in discriminability or changes in response criteria?

In summary, we show that identification is more sensitive than detection in revealing deficits of contralesional awareness. However, worsening performance may reflect shifts in response criteria and not decreased discriminability as has been implicitly assumed in most discussions of extinction. Additionally, worsening extinction when presented with similar or identical targets on bilateral stimuli presentations is more likely to represent increasingly conservative responses than worsening contralesional target discrimination. The limb used to indicate awareness of targets may affect the discriminability of contralesional stimuli. These observations suggest that sensory discrimination and response output are not organized in a simple serial manner. Rather, visual attributes of ipsilesional stimuli can affect response criteria and laterality of motor responses can affect discriminability, suggesting that pre-motor intentional systems and sensory-attentional systems interact intimately to produce visual awareness. We also suggest that these patterns of performance reflect the presence of two bottlenecks in the cascade of processing in extinction. The first bottleneck represents the limited capacity to process incoming sensory stimuli. The processing of this bottleneck is likely to be covert. The second bottleneck represents a limited capacity to acknowledge target attributes. This level of processing is by definition overt. More generally, these observations raise questions of previous studies which report modulations of extinction. Were such modulations produced by changes in sensory discriminability or by shifts in response criteria?

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