# Visuomotor links in awareness: evidence from extinction

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In patients with extinction, ipsilesional stimuli may abolish awareness of contralesional stimuli. Explanations of extinction often assume a serial model of processing in which sensory competition and identification precedes the selection of responses. We tested the adequacy of this assumption by examining the effects of response variables on visual awareness in six patients using signal detection analysis. Ipsilesional stimuli modulated patients' response criteria in deciding whether a contralesional stimulus was a target, and response modality (verbal or motor) modulated patients' abilities to discriminate between contralesional targets and distractors. This pattern of input variables modulating response criteria and output variables modulating discriminability indicates the extent to which attentional and intentional systems are tightly intertwined, with bi-directional effects in producing visual awareness. *NeuroReport* 16:843–847 © 2005 Lippincott Williams & Wilkins.

**Key words**: Consciousness; Neglect; Signal detection theory; Visual attention

## INTRODUCTION

Patients with unilateral brain lesions may extinguish contralesional stimuli when ipsilesional stimuli are presented simultaneously. Because nonsensory factors, such as the orientation of attention [1,2], cross-modal interactions [3,4] and task demands [5], modulate this phenomenon, theories of extinction emphasize a lateralized disorder of spatial attention and/or representation [2,6–9]. These theories generally posit a pathologically limited capacity of attentional resources with a bias to process ipsilesional over contralesional stimuli [10]. An implicit assumption in these theories is that information is processed serially. Sensations are apprehended and compete for processing to the level of awareness before an action indicating this awareness is generated. Missing from these accounts is the possibility that patients' responses themselves might have an impact on awareness of stimuli.

Motor behavior (i.e. 'directional hypokinesia') can affect spatial attention as emphasized in motor theories of neglect [11,12]. However, studies of extinction have only rarely considered the effects of response variables. Bisiach and colleagues [13] found that the response modality could modulate contralesional detection of visual stimuli in right brain-damaged patients (better with verbal than with ipsilesional limb motor response). Also, Smania and colleagues [9], in a single case study, showed modulation of extinction by verbal and eye movement responses, again suggesting that output systems influence awareness.

Distinct from the influence of the response modality on awareness is the role of response criteria in extinction. The notion of response criteria derives from signal detection theory [14] in which awareness of a stimulus is reflected by two parameters, $d'$ or discriminability and $c$ or response criterion. $d'$ indicates how easily the stimulus is distinguished from background noise and $c$ refers to the threshold at which the study participant reports the presence of a stimulus. Even though studies of extinction are essentially signal detection experiments, these quantitative methods are not widely used [15–18].

Signal detection analyses can be more sensitive and informative in describing extinction deficits than conventional methods [15,17,18]. It allows the examination of interactions of input and output variables in awareness of stimuli. A straightforward model in which multiple stimuli compete for limited attentional resources would predict that the nature of ipsilesional targets and distractors would affect discriminability of contralesional targets. Similarly, changing the response modality should not influence discriminability but might alter response criteria. However, in an earlier study, we found that properties of ipsilesional stimulus altered patients' response criteria [18] rather than discriminability. Here, we attempt to replicate this finding and also test the hypothesis that response modality might influence discriminability.

## MATERIALS AND METHODS

*Study participants:* Six patients with unilateral right and left hemisphere lesions participated in this study (see Table 1 for patient information). Unilateral neglect was

**Table I.** Patients' demographic and clinical data.

| Patient | Sex | Age | Education (years) | Length of illness (months) | Lesion (CT scan) | Etiology | Line bisection | Diller |
|---|---|---|---|---|---|---|---|---|
| S.F. (RHL) | M | 75 | 5 | 4 | O P | I | + 15.00 | 4 |
| M.D.G. (RHL) | F | 75 | 4 | 3 | cr | I | − 1.20 | 1 |
| V.C. (RHL) | M | 74 | 8 | 77 | P | I | + 19.80 | 1 |
| A.B. (RHL) | F | 79 | 5 | 27 | ins P T | I | + 1.40 | 4 |
| G.R. (LHL) | M | 55 | 8 | 5 | ci th | H | −5.60 | 0 |
| A.C. (LHL) | F | 78 | 12 | 97 | bg th | H | −2.33 | 1 |

F=frontal, O=occipital, P=parietal, T=temporal, bg=basal ganglia, ci=capsula interna, cr=corona radiata, ins=insula, th=thalamus; H=haemorrhage, I=infarction; line bisection: error in millimeters, positive values index a rightwards bias and negative values a leftwards bias; Diller: contralesional minus ipsilesional omissions.

assessed using the Diller cancellation task [19] and five 180-mm-long line-bisection tasks. None of the patients with left hemisphere lesion had oral or reading language deficits at the time of testing. Patients gave informed consent for this study, which was approved by the local Ethics Committee.

***Signal detection analysis:*** Signal detection analysis was used to calculate the discriminability, $d'$, and the response criterion, $c$, for reporting contralesional stimuli from the conditions with an ipsilesional target and separately from the conditions with an ipsilesional distractor. High values of $d'$ reflect ease of discriminability. Positive and negative values of $c$ indicate conservative and liberal criteria, respectively. To test for significant differences in these parameters, the 95% confidence interval around the difference of $d'$ values or $c$ values was calculated [14].

## EXPERIMENT 1: DETECTION STIMULI AND PROCEDURES

Patients were presented with a red T (0.91° by 1.14° of visual angle), which could appear on the left, right, both sides or neither side of a fixation cross (0.34° by 0.34° of visual angle). The distance between the stimulus and the central cross was 10° of visual angle. Stimuli were flashed for 50 msec on the black screen of a computer monitor on which the fixation cross was always present. Patients sat in front of the monitor, which was centered on their sagittal mid-plane. They had to report the location of the red T. Fifty trials for each condition were presented in a random order, preceded by 20 practice trials. Patients were instructed to gaze at the central cross from the beginning to the end of stimulus presentation. The experimenter alerted the patient before delivering each trial by saying 'now'. Eye movements were monitored during stimulus presentation, and trials during which an obvious movement was detected were rerun.

In the motor condition, patients pointed with their ipsilesional limb towards the location(s) in which the stimulus(i) appeared. No response was required when no stimuli were presented. In the verbal condition, they reported target location verbally (left, right, both, neither). The two response modalities were administered in an ABBA order, counterbalanced across patients.

## RESULTS

Only one patient (S.F) extinguished contralesional stimuli in both motor and verbal tasks: his ability to detect a contralesional target decreased ($p<0.05$, test of proportion) when an ipsilesional stimulus was presented simultaneously (for both modalities from 96% to 0%). Signal detection analysis showed that the presence of an ipsilesional stimulus decreased ($p<0.0001$) his contralesional discriminability for both response modalities (motor: from 3.98 to 0; verbal: from 3.99 to 0).

The other five patients did not have visual extinction on this task. Individual analyses did not show significant differences in any of the signal detection parameters. However, group analysis revealed a subtle effect of response modality. Discriminability decreased (Wilcoxon test $p=0.028$) when patients used the ipsilesional limb (3.73, range 1.99–4.45) as compared with when they reported stimuli verbally (3.94, range 2.00–4.67). When accurate with bilateral stimuli, patients tended to point to the ipsilesional stimulus before the contralesional stimulus, but this order was not recorded systematically.

## EXPERIMENT 2: IDENTIFICATION

Identification can be more sensitive than detection in uncovering contralesional deficits [17]. Because five of six patients had ceiling performances in the detection experiment, we proceeded with an identification task.

## STIMULI AND PROCEDURE

Stimuli were red Ts and Xs. The letter T was the target. Bilateral stimuli were always present. They could be two Ts, two Xs, a T on the left and an X on the right and vice versa. Patients performed the task using verbal and motor response. Stimuli characteristics and procedure were the same as in Experiment 1.

## RESULTS

Patients' accuracy rates and signal detection results are reported in Tables 2 and 3, respectively. When accurate with bilateral stimuli, patients tended to point to the ipsilesional stimulus before the contralesional stimulus, but this order was not recorded systematically.

S.F. had a floor performance. He extinguished the contralesional stimulus regardless of whether it was a target or a distractor. In the other five patients, tests for differences between proportions ($p<0.05$) showed that V.C., A.B. and G.R. were significantly less accurate in identifying the contralesional targets when an ipsilesional target was present in both the verbal and the motor condition, whereas this pattern was significant in M.D.G. and A.C. only in the verbal condition.

At a group level, no significant differences were detected between the accuracy of motor and verbal responses. Single case analyses showed that G.R. identified contralesional

**Table 2.** Experiment 2: Identification Task: Percent of patients' correct responses (hits for the bilateral and contralesional target conditions, and correct rejections for the ipsilesional target and no targets conditions).

| | Bilateral targets | Contralesional target | Ipsilesional target | No target |
|---|---|---|---|---|
| S.F. | *V*=0% | *V*=0% | *V*=100% | *V*=100% |
| | *M*=0% | *M*=0% | *M*=100% | *M*=100% |
| M.D.G. | *V*=88% | *V*=100% | *V*=100% | *V*=100% |
| | *M*=91% | *M*=98% | *M*=96% | *M*=98% |
| V.C. | *V*=30% | *V*=100% | *V*=100% | *V*=46% |
| | *M*=31% | *M*=96% | *M*=100% | *M*=49% |
| A.B. | *V*=4% | *V*=100% | *V*=96% | *V*=4% |
| | *M*=6% | *M*=100% | *M*=100% | *M*=2% |
| G.R. | *V*=92% | *V*=100% | *V*=100% | *V*=96% |
| | *M*=69% | *M*=98% | *M*=92% | *M*=92% |
| A.C. | *V*=90% | *V*=100% | *V*=82% | *V*=38% |
| | *M*=92% | *M*=94% | *M*=82% | *M*=38% |

targets more often when using a verbal (97%) than when using a motor (88%) response. Many of these patients also made false alarms when no contralesional targets were presented. It should be noted that such observations are not usually incorporated in conventional analyses of extinction, but are critical data in signal detection analysis.

For both motor and verbal tasks, when analyzed as a group, the presence of an ipsilesional target did not affect the patients' contralesional discriminability. An ipsilesional target as compared with a distractor did make the response criteria for contralesional targets more conservative [motor: from −0.30 (range −2.09–2.33) to 1.00 (range −0.23–2.33); verbal: from −0.42 (range −1.97–2.33) to 1.05 (range −0.22–2.33); Wilcoxon $p<0.05$]. When analyzed individually, this pattern was true for V.C., A.B., G.R. and A.C. in the verbal condition and for V. C. and A.B. in the motor condition.

For the group of patients, contralesional discriminability decreased (Wilcoxon $p<0.05$) when they used a motor (1.71, range 0.00–3.71) rather than a verbal (2.27, range 0.00–4.67) response when the ipsilesional stimulus was a distractor. Response modalities did not produce consistent differences in discriminability when the ipsilesional stimulus was a target.

In summary, identification was more sensitive than detection in revealing contralesional deficits. Patients identified targets better in the verbal than in the pointing condition, specifically when the ipsilesional stimulus was a distractor. Ipsilesional targets, as compared with distractors, were more likely to modulate response criteria than affect discriminability.

## EXPERIMENT 3: IPSILESIONAL VERSUS CONTRALESIONAL MOTOR RESPONSE

Responding with an ipsilesional limb worsened contralesional discriminability as compared with responding verbally. This might be explained by the fact that the motor task itself was more difficult for patients than responding verbally. Alternatively, ipsilesional responses might be more likely to activate the intact hemisphere and exaggerate hemispheric imbalances. To disambiguate these possibilities, we tested the one patient (A.C.) who could use her contralesional (right) limb to point. If worsening performance was due to intrinsic properties of the motor task, then she would continue to perform less well also when using her contralesional limb. Alternatively, if use of her contralesional limb activated her damaged hemisphere, then performance should be better than with her ipsilesional limb. Furthermore, if visuomotor systems are more tightly linked than visuoverbal systems, then she should perform better with her contralesional limb than when she responded verbally.

## STIMULI AND PROCEDURE

A.C. performed the same detection and identification tasks as before using verbal and motor responses. This time she pointed to stimuli with her contralesional limb.

## RESULTS

For the detection task, A.C. had a ceiling performance. In the identification task, her accuracy was significantly higher ($p<0.05$) when pointing with the contralesional (91%) than with the ipsilesional limb (75%). Pointing with the contralesional limb significantly increased ($p=0.004$) contralesional sensory discriminability (from 1.68 to 2.68).

A.C. was also more accurate ($p<0.05$) when she pointed with her contralesional hand (91%) than when she used a verbal response (81%). She discriminated contralesional targets better ($p=0.02$) when pointing with her contralesional limb (2.68) than when responding verbally (1.88).

## DISCUSSION

Extinction is usually explained as resulting from a limited capacity to process stimuli, with an additional bias to process ipsilesional over contralesional stimuli [9,10]. Often a serial model of processing is implicitly assumed in which sensory competition and identification precedes the selection of responses. Here we tested this assumption by examining the effects of response variables on the visual awareness of six brain-damaged patients when they performed detection and identification tasks.

Two kinds of response variables were considered: the response modality (verbal or motor) and the response criteria derived from signal detection analyses. Serial models of sensory competition resulting in extinction would predict that manipulating the sensory qualities of the task would affect discriminability and manipulating response modalities would affect response criteria.

In accordance with previous findings [18], we observed that patients who did not show extinction on traditional detection tasks had deficits of contralesional awareness on identification tasks. Importantly, on these tasks, the presence of an ipsilesional target was more likely to affect performance by producing conservative shifts in response criteria, than by influencing target discrimination. Additionally, altering the response modality by which patients indicated their awareness was more likely to affect their target discriminability. Patients as a group were better able to detect or identify contralesional targets when responding verbally than when pointing with their ipsilesional limb in the detection tasks and when the ipsilesional stimulus was a distractor in the identification task. The results challenge serial models of visual extinction and are in accord with more general motor theories of neglect [11,12].

**Table 3.** Experiment 2: Patients' $d'$ and $c$ for the contralesional stimulus.

| | *Verbal modality* | | *Motor modality* | |
|---|---|---|---|---|
| | Ipsilesional target | Ipsilesional distractor | Ipsilesional target | Ipsilesional distractor |
| S.F. | $d'$=0.00 | $d'$=0.00 | $d'$=0.00 | $d'$=0.00 |
| | $c$=2.33 | $c$=2.33 | $c$=2.33 | $c$=2.33 |
| M.D.G. | $d'$=3.43 | $d'$=4.67 | $d'$=2.95 | $d'$=3.71 |
| | $c$=0.60 | $c$=0.00 | $c$=0.18 | $c$=−0.02 |
| V.C. | $d'$=1.81 | $d'$=2.23 | $d'$=1.83 | $d'$=1.61 |
| | $c$=1.42** | $c$=−1.22** | $c$=1.41** | $c$=−0.83** |
| A.B. | $d'$=0.00 | $d'$=0.70 | $d'$=0.84 | $d'$=0.47 |
| | $c$=1.64** | $c$=−1.97** | $c$=1.88** | $c$=−2.09** |
| G.R. | $d'$=3.66 | $d'$=3.97 | $d'$=1.83** | $d'$=3.22** |
| | $c$=0.50** | $c$=−0.34** | $c$=0.44 | $c$=−0.28 |
| A.C. | $d'$=2.22 | $d'$=2.03 | $d'$=2.21* | $d'$=1.19* |
| | $c$=−0.22** | $c$=−1.32** | $c$=−0.23 | $c$=−0.89 |

Asterisks indicate, for each patient and within each response modality, significant differences (*$p<0.05$, **$p<0.01$) in $d'$ or c values between ipsilesional target and ipsilesional distractor conditions.

Two possibilities exist for why patients' motor responses might interfere with contralesional sensory processing more than verbal tasks. Specific aspects of motor responses themselves might in some way account for differences. For example, in our study, having to make two distinct responses on bilateral stimulation, single responses on single stimulation and no responses when no targets are present might be more complex than generating a verbal response. Alternatively, the use of an ipsilesional limb might further activate the contralesional hemisphere. If the lateralized attentional bias is affected by relative degrees of hemispheric activation [8], then activation of the intact hemisphere by motor use of the ipsilesional limb would increase this bias and result in worse performance. It should be noted that a verbal response by engaging language systems would also activate the intact hemisphere in right brain-damaged patients. However, these effects would be less pronounced than those of motor activations if visual attention is more tightly linked to motor than to verbal systems.

These competing hypotheses were tested in A.C., who could use either limb to indicate her awareness of stimuli. If the better performance with verbal than with motor responses was produced by intrinsic differences in these tasks, then we would observe the same results regardless of which limb was used. By contrast, the hemispheric activation hypothesis would predict that performance would improve when she used her contralesional limb. Our results were consistent with the hemispheric activation account. A.C. discriminated contralesional stimuli better when pointing with her contralesional limb than when responding verbally or when using her ipsilesional limb.

Beyond the hemispheric activation account, our data generate the hypothesis that visuomotor systems are linked more tightly than visuoverbal systems. Contralesional limb movements can improve performance in patients with neglect [20]. We extend these observations by showing that contralesional movement can specifically improve target identification. Because visually guided reaching engages posterior parietal regions of the contralateral hemisphere [21], enhanced contralesional discrimination might be explained by activation of sensory–motor circuits induced by the ipsilesional limb pointing within the damaged hemisphere. Neurophysiological studies show that in the macaque, parietal attentional neurons are tightly linked to motor systems [22]. Attentional cells in the intraparietal sulcus are highly responsive to visual stimuli when the eyes or the limbs are moved towards them [23]. These observations suggest that visuospatial attention is designed to engage the environment motorically [24]. Because A.C. had left brain damage, presumably both verbal and right arm responses activated her damaged left hemisphere. Again, consistent with the group data, despite the fact that language may be linked to visuospatial systems [25], these results suggest a tighter link between visuospatial and motor processing. Testing in additional patients will be needed to adequately test the hypothesis that visuomotor systems are linked more tightly than visuoverbal systems.

## CONCLUSION

Signal detection analysis has greater sensitivity in detecting deficits of contralesional awareness in patients with unilateral brain lesion and may reveal counterintuitive interactions. Our results, in which input variables modulate patients' response criteria and response modalities modulate target discriminability, challenge serial models of visual extinction. The pattern of results underscores the extent to which attention and intention interact and modulate each other to produce awareness of stimuli and generates the hypothesis that visuomotor systems are more tightly linked than visuoverbal systems.

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