Exp Brain Res (2003) 151:15–23
DOI 10.1007/s00221-003-1428-2

RESEARCH ARTICLE

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Evidence for a unimodal somatosensory attention system

Received: 8 June 2002 / Accepted: 25 January 2003 / Published online: 9 May 2003

Abstract Extinction is generally viewed as a disorder of selective attention for spatial locations. Recent physiologic, behavioral and lesion studies view spatial locations as a complex construct in which multiple modalities and motor systems are integrated. Accordingly, cross-modal and sensory-motor conditions often modify extinction. In a patient with tactile extinction, we tested the hypothesis that attentional deficits can also be confined to a specific sensory modality. Using objectively and subjectively balanced tactile stimuli and signal detection analysis, we found that our patient's contralesional tactile discrimination was not modulated by proprioceptive or visual input or by movement. By contrast, increasing the salience of the contralesional tactile stimuli did improve her contralesional tactile discrimination, consistent with our hypothesis that she suffered from a modality-specific attentional deficit. Additionally, she did not have any evidence of visual extinction, again bolstering our claim that her extinction was confined to touch. These data suggest that in addition to polymodal and sensory-motor attentional systems, spatial attention also operates on specific sensations. We also advocate the use of signal detection analysis, a method that has been surprisingly neglected in extinction research.

Keywords Neglect · Extinction · Cross-modal integration · Tactile attention · Awareness

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Introduction

Early studies of extinction viewed the disorder as a bias to process specific sensory input. These studies discussed mechanisms, such as reciprocal inhibition (Nathan 1946; Reider 1946; Kinsbourne 1970), delayed sensory processing and interference (Birch et al. 1967), perceptual rivalry (Denny-Brown et al. 1952) and limited attentional capacities (Heilman and Valenstein 1979). These mechanisms were framed in the context of specific sensations such as touch or vision or audition. Thus, when a patient was biased to be aware of an ipsilesional touch over a contralesional touch, the question was how inhibition or interference or selection operated on spatial locations within the somatosensory system.

Recent physiologic and behavioral studies give rise to a more complex notion of spatial locations and what might be extinguished in patients with extinction (Marzi et al. 2001). On this view, space is a mental construct in which information from different sensory modalities and motor systems is integrated (Chatterjee 2003). Neurons within the macaque posterior parietal cortex and parts of dorsolateral prefrontal cortex are responsive to cross-modal (visual and tactile) stimuli and are linked to motor systems, such as those controlling eye or limb movements (Andersen 1995; Graziano and Gross 1995; Gross and Graziano 1995; Colby and Duhamel 1996; Colby and Goldberg 1999). Behavioral studies in normal subjects show that input from one modality can aid processing of information in another modality when these inputs emanate from the same spatial location (Driver and Spence 1998; Spence and Driver 1998).

In parallel with these observations in monkeys and normal human subjects, recent studies in extinction have incorporated the more complex notion of spatial locations by considering the contributions of cross-modal and sensory-motor variables to awareness. We reported that extinction can occur for weight perception, a judgment which combines somatosensory, proprioceptive and kinesthetic input (Chatterjee and Thompson 1998; Chatterjee et al. 2000). di Pellegrino and colleagues (di Pellegrino and Ladavas 1997) and Mattingley and colleagues (Mattingley et al. 1997) found that ipsilesional visual stimuli can interfere with processing of contralesional tactile information (although for contrary evidence, see Inhoff et al. 1992). Ladavas and colleagues (di Pellegrino and Ladavas 1997; Ladavas et al. 1998) reported that contralesional visual input can improve contralesional tactile awareness. Similarly, we reported that gaze direction or intentional movement also improved contralesional tactile awareness (Vaishnavi et al. 1999, 2001).

From these and other studies the following view of extinction emerges. Extinction is an example of a bias in selective attention for an ipsilesional spatial location. The phenomenon is evident when information from more than one spatial location competes for pathologically limited resources (Marzi et al. 2001). Information from more than one sensory modality at the same location or movement to that location increases that location's salience and consequently improves awareness. The selection bias is for a cross-modal or sensory-motor representation, rather than a modality specific sensation.

In this report, we revisit the question of whether extinction can be confined to a specific sensory modality. Earlier large group studies have shown dissociations between auditory and visual extinction (De Renzi et al. 1984) and visual and tactile extinction (Vallar et al. 1994). However, these studies used relatively coarse bedside assessments such as the examiner moving their fingers in the subjects' visual fields or touching the subjects lightly, leaving open the possibility of relative differences in deficits across modalities. Also, these studies did not look for modulation of awareness in one modality by input from another modality or by volitional movement. In our earlier group study, while the effects for cross-modal integration between vision and touch were clearly evident, not every patient showed this effect (Vaishnavi et al. 2001). Additionally, one patient did not improve when movement was coupled with touch. It is therefore possible that in some patients the selection bias is not directed at cross-modal or sensory-motor representations, but instead is directed at specific sensations.

Here, we present a patient with tactile extinction in whom we tested the hypothesis that attention may be confined to a specific sensory modality. In our analysis, we use signal detection parameters. The use of signal detection theory to analyze tactile extinction is surprisingly rare in extinction studies (Vaishnavi et al. 2000; Ricci et al. 2002) despite its obvious relevance to these paradigms. Signal detection approaches allow one to separate the ability of a subject's perceptual system to detect the difference between the signal and noise from the likelihood that the subject will report the presence of signal plus noise or noise alone (Green and Swets 1966). When patients with extinction improve, the implicit assumption is often that the ability to detect the contralesional stimulus has improved. However, we have shown in some cases "improvement" may reflect a shift in subjects' response criteria rather than improved discriminability (Vaishnavi et al. 2000). More germane here, signal detection analyses offer a sensitive way to test for modulation of sensory awareness that takes into consideration the difference between sensory discrimination and response biases. Furthermore, as we will demonstrate here, it offers insight into the data that would not otherwise be evident in traditional analyses, which compare unilateral and bilateral stimulation conditions.

Materials and methods

Subject

The subject, CE, is a 78-year-old right-handed woman. She sustained a right hemisphere stroke involving the right parietal cortex. Her lesion involved Brodmann's areas 39 and 40 and parts of posterior 22 (see Fig. 1) as determined by the standard templates (Damasio and Damasio 1989). She had received 12 years of education. Her visual acuity was 20/25 for each eye. There was some indication that CE experienced neglect in her daily living. She broke her left wrist/ hand after her stroke because she was "ignoring her left leg" and failed to pick it up over a curb and fell. However, at the time of testing she did not evidence extrapersonal neglect on line bisection or cancellation tasks. She had some trouble fully extending the fingers in her left hand, but otherwise was not compromised in her daily activities. She remained very active in Church activities.

CE gave informed consent prior to participating in the study. The Institutional Review Board of the University of Pennsylvania approved the study.

The tactile stimuli were administered via Semmes-Weinstein Microfilaments (Stoelting Co., IL). These filaments, similar to Von Frey hairs, assess tactile sensitivity by exerting a constant pressure on the patient's skin. The units of pressure mentioned in each experiment are those on the probes, which represent a linear scale of perceived force, but a logarithmic scale of actual force [unit = log (10×force in milligrams)] (Stoelting 1996).

For all experiments CE was seated at a table with her trunk and head facing forward. Her arms rested on foam pads on the table, placed equidistant to the midline of the subject's body with her hands and fingers curled over the edge of the foam pads so that she could not see her fingertips. Touch was administered randomly to either the right index finger, the left index finger, neither finger, or both fingers in equal numbers of trial types. The subject's task was to report the location of the touch, either "left," "right," "neither," or "both."

For each condition two sets of signal detection analysis parameters, d'—discriminability and c—response criterion, were calculated. The parameters referred to CE's ability to discriminate

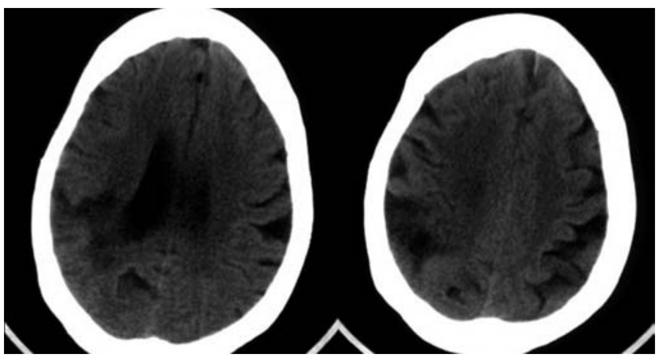

Fig. 1 Computerized tomographic scan showing CE's posterior parietal stroke

Table 1 General framework for assessing hits, false alarms, rejections and errors when calculating d' and c parameters for CE's left hand in the competitive and the non-competitive conditions $d'=Z_{FA*}-Z_H$; $c=Z_{FA*}-d'/2=0.5(Z_{FA*}+Z_{H*})$ As advocated by Snodgrass and Corwin (1988), we used the 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, $FA* = (FA+0.5)/(FA+CR+1.0)$ $H* = (H+0.5)/(H+M+1.0)$

	Competitive	Non-competitive
Hit (H)	Touched bilateral Says left or bilateral	Touched left Says left or bilateral
False alarm (FA)	Touched right Says left or bilateral	Touched neither Says left or bilateral
Correct rejection (CR)	Touched right Says right or neither	Touched neither Says right or neither
Miss (M)	Touched bilateral Says right or neither	Touched left Says right or neither

and her tendency to report when she was touched on the left. These parameters were determined for when she was also touched on the right (bilateral touch versus the unilateral right touch), which we refer to as the "competitive" trials, and for when she was not touched on the right (unilateral left touch versus neither touch), which we refer to as the "non-competitive" trials.

Table 1 shows the general framework used to determine the signal detection parameters for the competitive and the non-competitive conditions. Note that these parameters are being determined for the discriminability and response criterion for her left side. In this case we are interested in the modulation of her left-sided awareness.

Experiment 1: modulation of extinction using objectively balanced stimuli

In these experiments, extinction was tested using conventional methods. Tactile stimuli were applied with filaments of equal pressure (5.46) on both sides.

Experiment 1a

Assessment of extinction

Sixty trials were presented in a random order. CE was blindfolded for this assessment.

Results

CE had tactile extinction on the standard tactile extinction assessment. She was 100% accurate on right unilateral trials, 93% on left unilateral trials, and 0% on bilateral trials.

Experiment 1b

Proprioception and touch

This experiment assessed the effect of limb position on tactile extinction. In this experiment there were two conditions: one in which CE's arms were apart, and another in which they were crossed; these were presented in a blocked, ABBA design. Two hundred trials were presented, 100 in each condition (arms apart/arms crossed), and within each condition 25 of each type (left, right, neither, or both). She was blindfolded for this experiment.

Results

CE did not identify bilateral trials accurately in either the arms crossed (0% correct) or arms apart (0% correct) conditions. For the signal detection analysis, the d' and c values for the hands crossed or hands apart were not different in the competitive or the non-competitive conditions, analyzed separately (Tables 2, 3). The competitive trials dampened her discriminability on the left when compared to the non-competitive trials (d' = 2.70 vs. 0.44, p=0.001, one tailed).

Experiment 1c

Vision and touch

This experiment assessed whether visual input from the area of tactile extinction improves the perception of touch. CE was instructed to look at either the right or the left hand (in a blocked, ABBA design). Two hundred trials were presented, 100 in each condition (look left/look right). CE could not directly see the point at which

Table 2 Discriminability indices (d') for experiment 1, in which objectively balanced tactile stimuli were used

	Apart	Crossed	Look left	Look right	Passive	Active
Non-competitive	2.41	3.01	1.91	2.25	2.52	3.01
Competitive	0.00	0.50	0.00	0.50	0.77	0.98

Table 3 Response criteria indices (c) for experiment 1, in which objectively balanced tactile stimuli were used. Significant differences (<0.05) are indicated by an *asterisk*

	Apart	Crossed	Look left	Look right	Passive	Active
Non-competitive	0.10	0.56	–0.15	–0.45	–0.32*	0.56*
Competitive	2.07	1.82	2.07	1.82	1.69	1.59

her fingers were being touched because of the position of her fingers over the foam rests. We did not want her to be able to determine if she was touched by visually observing whether the tactile probe produced a slight dent in her skin. However, she could see the examiner's hand move towards her own hand on each trial. The examiner made similar movements even in conditions in which CE was not touched.

Results

CE did not identify bilateral trials accurately in either the look right (0% correct) or look left (0% correct) conditions. For the signal detection analysis, the d' and c values for the look left or look right conditions were not different in either the competitive or the non-competitive conditions (Tables 2, 3). The competitive trials dampened her discriminability on the left when compared to the non-competitive trials (d' = 2.11 vs. 0.44, $p<0.01$, one tailed).

Experiment 1d

Movement and touch

This experiment was designed to assess the effect of CE's intentional movement on her tactile awareness. There were two conditions: one in which CE's hands remained still and she passively received touch, and another in which she actively moved her fingers into the probe by extending her fingers; these were presented in a blocked, ABBA design.

Results

The number of times that CE correctly identified bilateral trials was not significantly different between the passive (1 correct) and the active (0 correct) conditions. For the signal detection analysis the d' values for the passive and active trials were not different in either the competitive or the non-competitive conditions (Tables 2, 3). There was no significant difference between the values of c in the competitive trials; however, her response criteria were more conservative in the active than passive trials (active = 0.56, passive = −0.32, $p<0.05$) in the non-competitive trials. The competitive trials dampened her discriminability on the left when compared to the non-competitive trials (d' = 2.59 vs. 1.10, $p=0.01$, one tailed).

To confirm that CE had a lateralized deficit, we combined the data for all of the experiments with objectively balanced stimuli in the competitive conditions and found that she discriminated right sided stimuli better than left sided stimuli (d' = 3.27 vs. 1.22, $p<0.0005$).

Summary

CE clearly had left-sided tactile extinction. However, her tactile discriminability on the left was not modulated by proprioceptive or visual input or by active movement. In these experiments, the stimuli were balanced objectively. Since CE might have had a higher sensory threshold on the left it is possible that subjectively she was receiving less input on the left than on the right. Perhaps the lack of modulation of tactile awareness was due to a "floor effect" of somatosensory processing on the left. To address this concern, we repeated the experiments after establishing sensory thresholds for unilateral touches on each hand.

Experiment 2: modulation of extinction using subjectively balanced stimuli

The threshold filament weights were determined using the following procedure. The experimenter used increasing intensity filaments to touch the back of the CE's finger in an ascending and then descending manner. Either hand was touched randomly. The thresholded value used for each hand was the filament strength at which she consistently reported feeling the touch on that hand. As expected, her threshold on the left (4.17) was higher than her threshold on the right (3.22). The subsequent experiments were conducted in the same manner as before, except that the tactile stimuli were now subjectively rather than objectively balanced.

Experiment 2a

Proprioception and touch

In this experiment there were two conditions: one in which the subject's arms were apart, and another in which they were crossed. CE was blindfolded.

Results

CE did not identify bilateral trials accurately in either the arms crossed (0% correct) or arms apart (0% correct) conditions. For the SD analysis the d' and c values for the hands crossed or hands apart were not different in either the competitive or the non-competitive conditions (Tables 4, 5). The competitive trials dampened her discriminabil-

Table 4 Discriminability indices (d') for experiment 2, in which subjectively balanced tactile stimuli were used. Significant differences (<0.05) are indicated by an *asterisk*

	Apart	Crossed	Look left	Look right	Passive	Active
Non-competitive	1.48	2.25	1.01	1.45	1.86	1.02
Competitive	−0.46	0.13	0.97	−0.20	1.13	1.13

Table 5 Response criteria indices (c) for experiment 2, in which objectively balanced tactile stimuli were used. Significant differences (<0.05) are indicated by an *asterisk*

	Apart	Crossed	Look left	Look right	Passive	Active
Non-competitive	0.06	0.45	–0.05	–0.38	0.37*	1.06*
Competitive	1.34	0.74	1.59	1.20	1.51	1.51

ity on the left when compared to the non-competitive trials (d' = 1.83 vs –0.08, p<0.001, one tailed).

Experiment 2b

Vision and touch

This experiment assessed the effects of visual input on tactile extinction. Again, CE looked at either the right or the left hand.

Results

CE's ability to identify bilateral trials accurately was not different if she looked to the right (1 correct) or looked to the left (1 correct). For SD analysis, the d' and c values for the look left or look right conditions were not different in either the competitive or the non-competitive conditions (Tables 4, 5). The competitive trials dampened her discriminability on the left when compared to the non-competitive trials (d' = 1.22 vs 0.25, p=0.01, one tailed).

Experiment 2c

Movement and touch

This experiment assessed the effect of CE's intentional movement on her tactile awareness. There were two conditions: one in which CE's hands remained still and she passively received touch on the back of the hand, and another in which she actively moved her hands into the probe by extending her fingers.

Results

The number of times that CE correctly identified bilateral trials was not significantly different between the passive (0% correct) and the active (0% correct) conditions. For the SD analysis: the d' values for the passive and active trials were not different in either the competitive or the non-competitive conditions (Tables 2, 3). There was no significant difference between the values of c in the competitive condition; however, her response criteria were more conservative in the active than passive trials (active = 1.07, passive = 0.37, p<0.05) in the non-competitive condition. The competitive trials did not dampen her discriminability on the left when compared to the non-competitive trials (d' = 1.49 vs. 1.37). However, her response criteria were more conservative in the competitive trials (c = 0.76 vs 1.65, p<0.01).

To again confirm that CE had a lateralized deficit, we combined the data for all of the experiments with subjectively balanced stimuli in the competitive conditions and found that she discriminated right sided stimuli better than left sided stimuli (d' = 1.95 vs. 0.33, p<0.0001).

Summary

These experiments using subjectively balanced stimuli replicated the findings of the previous experiments in which objectively balanced stimuli were used. Again, CE's ability to discriminate touch from non-touch on the left was not modulated by proprioceptive or visual input or by movement.

Experiment 3: varying tactile salience

Our experiments thus far did not reveal any modulation of CE's discriminability of touch on the left by cross-modal or sensory-motor conditions. If her attentional deficit was confined to the somatosensory system, then we hypothesized that varying the relative tactile salience on the left and right hand would modify her contralesional tactile awareness.

The contrasting stimuli were determined as follows. First, her sensory thresholds were established as in the previous experiment. Her thresholds in both hands were slightly higher than in the previous experiment, 3.61 on the right and 4.31 on the left. In the left suprathreshold (LST) trials the filament used on the right hand (3.61) was at threshold, while the filament used on the left hand was (6.65) 1.5 times the threshold for that hand. In the right suprathreshold (RST) trials, the filament used on the left hand (4.31) is the threshold filament, while the filament used on the right hand was (5.88) 1.6 times the threshold for that hand. The experiment was conducted as before with a total of 200 trials, with each condition (LST and RST) presented in an ABBA manner. CE was blindfolded.

Results

CE correctly identified bilateral trials more often in the LST (5 correct) than the RST (0 correct) trials (X^2=5.56, one-tailed Fisher Test exact p<0.05). For her SD analysis her discriminability d' in the competitive trials was

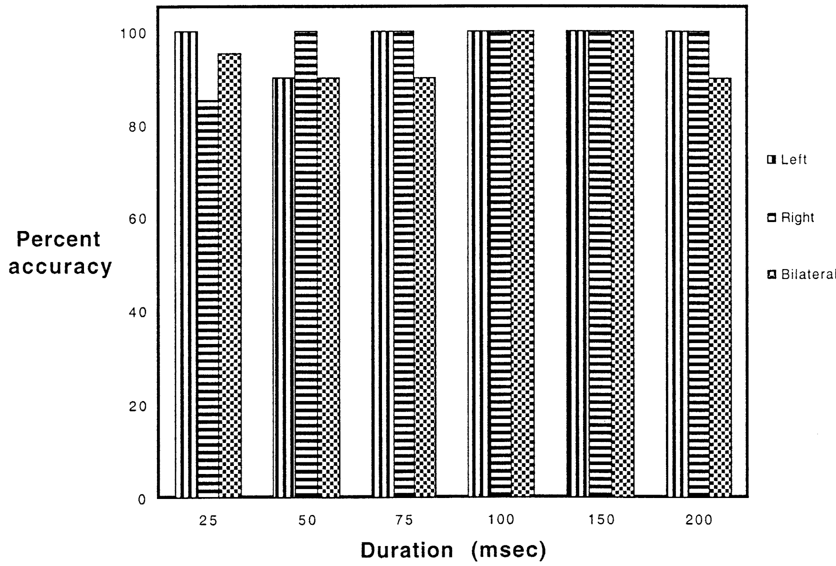

Fig. 2 Percent accuracy for left, right and bilateral visual stimuli on the visual extinction paradigm

Table 6 Signal detection parameters for experiment 3, in which LST refers to left suprathreshold and RST refers to right suprathreshold stimuli. Significant differences (<0.05) are indicated by an *asterisk*. N/A refers to non-applicable comparisons for c, because the discriminability indices were significantly different

	LST (d')	RST (d')	LST (c)	RST(c)
Non-competitive	4.14	4.14	0.00	0.00
Competitive	2.02*	0.00*	N/A	N/A

significantly different (LST = 2.02, RST = 0.0000; one-tailed $p<0.05$). There were no differences between the values of d' in the non-competitive condition, which were at ceiling (LST = 4.13, RST = 4.13). There were no differences between the values of c in the non-competitive condition (Table 6).

Experiment 4: visual extinction

The goal of this experiment was to gather further evidence in support for our hypothesis that CE had a modality specific attentional disturbance. Therefore, we tested her in a paradigm to assess visual extinction. If she had visual extinction, it would still be possible that she had a modality-specific attentional disturbance. She might have modality-specific deficits in two distinct sensory modalities, touch and vision. However, if she did not have visual extinction, then our hypothesis that she had an attentional deficit confined to the somatosensory system would be bolstered.

CE sat before a computer monitor and gazed at a central fixation cross. To the left and right of the fixation cross a box "place-holder" was always present separated by 7° visual angle. After a warning tone (100 ms), an asterisk appeared (following 500 ms) in the left, the right, or both boxes. CE reported whether she thought the asterisk appeared in the left, the right or both boxes. Each trial was initiated after her response. The duration that the asterisks remained on the screen varied between 200 and 25 ms in blocks. There were 30 trials each for 200-, 150-, 100- and 75-ms durations and 60 trials each for 50- and 25-ms durations for a total of 240 trials, with an even number of left, right and bilateral trials.

Results

CE did not have any evidence of visual extinction (see Fig. 2). She made occasional errors on bilateral trials (5/80), of which three were omissions on the left and two on the right.

Experiment 5: visual extinction with masked stimuli

The goal of this experiment was to further test the hypothesis that CE did not have visual extinction. CE's performance was close to ceiling in the previous experiment and the argument could be made that a lateralized deficit might emerge if tested under more stringent conditions. In this experiment we used visual masks with stimuli of various exposure times. In addition, the data were analyzed using SDT parameters as in the tactile experiments.

CE sat before a computer monitor and gazed at a central fixation cross. To the left and right of the fixation cross a box "place-holder" was always present separated by 7° visual angle. After a warning tone (100 ms), an asterisk appeared (following 500 ms) in the left, the right, both, or neither boxes. Before and after the asterisk appeared, the place holder boxes had a visual mask consisting of hatched lines. The mask was identical in both boxes and remained in place after offset of the asterisk until CE responded. CE reported whether she thought the asterisk appeared in the left, the right, both or

Table 7 Discriminability indices (d') for experiment 5 using masked visual stimuli. None of the left-right comparisons was significantly different

	Left (500 ms)	Right (500 ms)	Left (750 ms)	Right (750 ms)	Left (1250 ms)	Right (1250 ms)
Non-competitive	0.55	0.88	1.38	1.41	2.00	1.72
Competitive	1.08	1.55	1.91	1.69	2.10	2.24

Table 8 Response criteria indices (c) for experiment 5, using masked visual stimuli. None of the left-right comparisons was significantly different

	Left (500 ms)	Right (500 ms)	Left (750 ms)	Right (750 ms)	Left (1250 ms)	Right (1250 ms)
Non-competitive	–0.61	–0.27	–0.65	0.74	–0.58	–0.30
Competitive	–0.07	–0.16	0.29	0.24	0.04	0.04

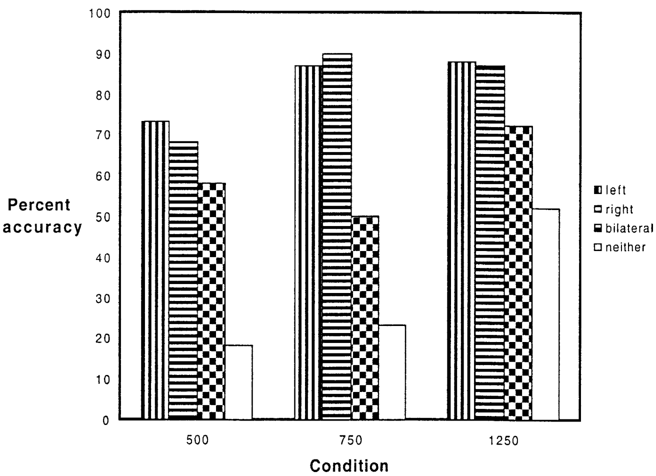

Fig. 3 Percent accuracy for left, right, bilateral and neither stimuli for masked visual stimuli extinction paradigm

neither boxes. Each new trial was initiated after her response. The asterisks were present for 500, 750 or 1250 ms in separate blocks. Each block consisted of 80 trials, equally divided between the right, left, both and neither conditions, which were presented randomly. There were 3 blocks for each stimulus duration for a total of 720 trials (80 trials × 3 durations × 3 blocks). The order of blocks was as follows: 1250, 750, 500, 750, 500, 1250, 500, 1250 and 750 ms.

Results

As can be seen from Fig. 3, with masked stimuli, CE makes considerable errors. In general, as would be expected, her performance improves with longer stimulus durations and is worse with bilateral than with unilateral conditions. Even when her performance breaks down with unilateral conditions her accuracy is not any better in the right than in the left. This impression from the accuracy data is confirmed by the signal detection analysis of her data (Tables 7, 8). There are no left-right differences in her discriminability or her response criteria for the three exposure durations. In addition to the lack of a lateralized deficit, surprisingly, CE performed better in the competitive than in the non-competitive condition. When combining the data from left and right stimuli and across the three exposure durations, CE was better able to discriminate stimuli in the competitive than the non-competitive conditions (d', 1.74 vs. 1.29, respectively, p=0.003).

Discussion

We present a patient CE, with tactile extinction following damage to her right inferior parietal lobule. Her ability to detect touch on the left was not influenced by proprioceptive or visual input. It was also not influenced by intentional movements. These observations were true regardless of whether stimuli were objectively or subjectively balanced for intensity. Unlike many other patients with tactile extinction, CE's selection bias appeared confined to the somatosensory system.

We are sensitive to the truism that the absence of evidence (in this case cross-modal or sensory-motor modulation) does not necessarily constitute evidence of absence. However, three lines of evidence converge to support the claim that CE's attentional disorder was specific to touch. First, her discriminability for left-sided touch was influenced by whether or not she was also touched on the right, demonstrating the effects of biased competition within the somatosensory system. Second, varying the tactile salience on the left did influence her left-sided discriminability, demonstrating that her left-sided tactile awareness was modifiable by touch even though it was not by proprioception or vision. One could argue that the simultaneous visual input in our paradigm was not of sufficient intensity to modulate her tactile awareness. However, we have found previously that these methods do modulate tactile awareness in *most* patients with tactile extinction (Vaishnavi et al. 1999, 2001). Third, she did not have visual extinction. This was true with stimuli exposures as brief as 25 ms and in a more demanding task with visual masks. With masked visual stimuli exposed for durations at which our patient was no longer performing at ceiling, CE did not have a lateralized visual processing deficit. Furthermore, she did not have extinction. If anything, her ability to discriminate stimuli on either side was marginally better with than without competing stimuli. The reason for this counterintuitive finding is not clear. It may be that the presence of more stimuli served to increase her general arousal and improved performance. Alternatively, she may have the rare phenomenon of "anti-extinction" (Goodrich and Ward 1997) in vision despite her lateralized extinction in touch. Anti-extinction is not well understood and the use of signal detection analysis may be useful in its assessment.

In an early study of cross-modal influences on extinction in three patients, Inhoff and colleagues (Inhoff et al. 1992) reported that ipsilesional stimuli did not interfere with processing of contralesional stimuli in the other modality, even though each patient had extinction in touch and vision when tested with competing stimuli from the same modality. Although relatively coarse bedside measures were used (examiner moving their fingers or finger lightly touching the subjects), these authors also argue for modality-specific attentional systems. However, none of their cases had extinction confined to touch and not vision.

Signal detection analysis offers a way to dissect the effects of perceptual discriminability from shifts of response criteria (Green and Swets 1966). Virtually nothing about the response criterion in extinction is known. CE's response criterion was higher in the active condition than in the passive condition.[1] We simply do not know if this conservative response on active trials is idiosyncratic to her, or would generalize to other patients or is related to the location of patients' lesions. We have shown previously that response criterion shifts may offer insight into otherwise puzzling behavior. In a previous case study we reported that a patient was more accurate with bilateral stimuli than with unilateral contralesional stimuli. It turned out that this "improved" performance on bilateral stimulation was a reflection of a more liberal response criterion and not indicative of better sensory detection of contralesional stimuli on bilateral than unilateral trials (Vaishnavi et al. 2000).

A final note can be made about CE's lesion. Her lesion involved Brodmann's areas 40 and parts of 39 and 22. Although animal physiological and functional neuroimaging studies show that input from different sensory modalities converge into the posterior inferior parietal cortex (see review in Chatterjee 2003), our observations suggest that damage within this region in humans can produce remarkably selective deficits. Based on data from a clinical-anatomic study of 159 patients with right brain damage, Vallar et al. (1994) emphasized the importance of ascending white matter tracts in extinction. Consistent with their claims, CE's lesion involved the white matter anteriorly, which was more likely to interrupt ascending somatosensory than visual fibers.

In summary, we suggest that CE had tactile extinction that was confined to the somatosensory system. These results suggest that spatial attention can be directed within the somatosensory system. Thus, in addition to polymodal and sensory-motor attentional systems, spatial attention also operates at the level of specific sensations. Further, we advocate the use of signal detection methods in extinction paradigms. These methods, surprisingly neglected in extinction studies, provide additional insights into sensory processing and response biases, which are central concerns in the neuropsychology of neglect and related disorders.

Acknowledgments This research was supported by NIH grant RO1NS37539. We also thank Ashley Wilson for help with data collection.

[1] Additionally, in the active condition there was no difference in her ability to discriminate contralesional touch between the competitive and non-competitive conditions. The reason for this lack of extinction is not clear. In normal subjects tactile thresholds increase with simultaneous movement. Simultaneous movement may have produced a floor effect, disproportionately affecting the non-competitive condition.

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