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Weighing the evidence for cross over in neglect

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Abstract

When patients with left-sided neglect are asked to bisect horizontal lines, they tend to place their marks to the right of the line's objective mid-point. However, when asked to bisect short lines they are either more accurate or paradoxically cross over and place their marks to the left of the objective mid-point. Previous explanations of the cross over phenomenon have considered specific aberrations of spatial attention. However, these explanations make no predictions about judgments of non-spatial stimuli. Two patients with right brain damage were asked to judge weights placed on both hands simultaneously. They were biased in reporting weights on the right as being heavier than those on the left. This rightward bias changed with lighter pairs of weights presented in the context of equal reference weights. In one patient the directional bias was eliminated and in the other the bias was reversed so that she was more likely to report the left weight as heavier than the right. These data suggest that a phenomenon analogous to cross over in line bisections also occurs with judgments of non-spatial stimuli. Representations of stimuli appear to be influenced by features of the stimuli encountered on-line and by memory traces of similar stimuli encountered previously. With an attentional deficit, memory traces influence the magnitude of the representation derived on-line disproportionately.

Keywords: Attention; Perception; Memory; Line bisection

1. Introduction

Over a decade ago, Halligan and Marshall described the 'cross over' phenomenon in patients with left spatial neglect [12]. Patients with left neglect generally bisect horizontal lines to the right of the objective mid-point. However, when confronted with short lines (usually less than 4 cm) they cross over and place their marks to the left. This behavior is observed in most patients with neglect [8,13] and resists easy explanation. Why should patients with an attentional or intentional bias to the right suddenly reverse the direction of their bias when faced with short lines? Why should a deficient left-sided representation produce a sudden shift in behavior with short lines? Below we review briefly explanations offered for the cross over phenomenon (see [21] for a detailed review of previous hypotheses), and raise questions about the adequacy of these explanations.

Explanations of the cross over phenomenon have relied on psychophysical, mathematical, and computational models. Marshall and Halligan [17] suggested initially that patients with neglect have abnormally large Weber fractions. The Weber fraction is the line segment within which one is unable to perceptually distinguish between the right and left segments of the transected lines and is proportional to the length of the line. Marshall and Halligan proposed that patients scan the lines from right to left and when they arrive at the right edge of the Weber fraction, they place their mark. However, when confronting short lines subsumed within foveal vision, the patients are postulated to cross over and place their marks at the left edge of the Weber fraction producing leftward bisec-

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tions. Exactly how and why stimuli within foveal vision should be approached differently is far from clear. Recently, Adair and co-workers [1] reported that a patient with apparent ipsilateral neglect on line bisections was demonstrating an exaggerated cross over effect on lines much longer than observed commonly. These stimuli extended beyond the confines of foveal vision, suggesting that in some cases cross over is not related to specific features of foveal processing.

More recently, based on a computational model of line bisection, Mozer along with Halligan and Marshall [22] suggested that patients are actually performing like normal subjects with short lines, since normal subjects frequently misbisect lines to the left of the true mid-position. This hypothesis is difficult to reconcile with empirical observations. First, older normal subjects that are matched to the ages of most patients with neglect are more likely to bisect lines to the right, rather than left, of the true mid-position, despite considerable variability in performance [19]. Second, neglect patients usually place their marks significantly on the left of short lines (occasionally even off the left edge of the line [24]) in ways that do not resemble bisections by young control subjects on shorter lines. In fact the degree of cross over seems to correlate with the severity of neglect [8].

We also relied on psychophysical models to interpret the cross over phenomenon. We used power function descriptions of line bisection performances and single word reading tasks and argued that how patients read short words might provide insight into how they were bisecting lines [6]. We found that patients tended to read short words as being longer than their objective lengths by adding letters to the left end of these words. By analogy, we proposed that patients were confabulating an extension past the left edge of short lines and were representing these lines as being longer than their objective extent. We speculated that a region of disinhibition at the left edge of a rightwardly restricted window of attention accounted for this representational completion or confabulation. Monaghan and Shillcock [21] reported a formal computational model incorporating opposing attentional vectors, and demonstrated the plausibility of this disinhibition hypothesis.

Anderson introduced a mathematical model and argued that traditional notions of hemispheric organization of spatial attention could account for the cross over phenomenon [2]. Heilman and colleagues [14] and Mesulam [20] had previously proposed that the left hemisphere directs a vector of attention contralaterally, whereas the right hemisphere directs attention bilaterally. Anderson showed that such an organization of spatial attention, if given specific hypothetical parameters, gives rise to a saliency function in which short lines placed at the mid-sagittal position are more salient on the left, and long lines are more salient on the right. This hypothesis invokes a specific warp in spatial attention close to the mid-line as underlying the cross over phenomenon. In one patient with left neglect, Anderson also showed that cross over like behavior generalizes to other tasks in which the patient made judgments of the left side of short horizontal segments [3].

Common in all these approaches to the cross over phenomenon is the focus on visual-spatial stimuli and explanations couched in terms of spatial attention. As such, they make no direct predictions about judgments of non-spatial stimuli, although some models are not confined in principle to addressing visual or spatial stimuli [21,23]. We recently reported that a patient with right brain damage under-estimated weights of objects on her left compared to those on her right [9]. We wished to learn if something analogous to the cross over phenomenon occurs with weight judgments. If a similar phenomenon occurs with weight judgments, then explanations of cross over would need to be expanded, modified or changed to encompass processing of non-spatial stimuli, assuming that theoretical parsimony is desirable. Cross over on line bisections might then be considered a specific instance of a more general aberration of stimuli processing following right brain damage.

2. Case descriptions and methods

2.1. Case 1

DC was a 67-year-old right-handed woman (with 10 years of education) who had a right hemisphere stroke. Initially, she demonstrated neglect on line bisection and cancellation tasks. She also had contralateral extinction to double simultaneous visual, auditory, and tactile stimulation. We previously reported that she had extinction on simultaneous weight judgment tasks [9]. Her neglect largely dissipated as assessed informally six months after her stroke and as evidenced by the Behavioral Inattention Test (BIT) performed one month before the experimental data presented here [26]. Contralesional tactile extinction remained (Table 1). She did not have left-sided weakness. Magnetic resonance imaging (MRI) scan showed a lesion involving the posterior insula, the posterior superior temporal gyrus, the supramarginal gyrus and anterior part of the angular gyrus. Primary sensory and motor cortex were spared. Data reported here were collected 45 months after her stroke.

2.2. Case 2

CG was a 58-year-old right-handed woman (with 12 years of education) who had a right hemisphere hemorrhagic stroke. She demonstrated neglect on line bisections and cancellation tasks based on the BIT (Table 1). She also had tactile extinction. She had significant left-sided weakness. Her magnetic resonance imaging scan showed a lesion involving most of the superior temporal gyrus and the supramarginal gyrus. The lesion also extended into the inferior portions of primary motor cortex. Data reported here were collected two months after her stroke.

3. Experiment 1: Judgment of weights

This experiment was designed to demonstrate a right directional bias in weight perception in patients with damage to the posterior right hemisphere. A bias to report right sided weights as heavier than left would be analogous to performances on line bisection in which the right side of lines are experienced as being longer than objectively equivalent left sided segments. Such a bias in DC would replicate earlier findings [9].

Two weights were placed simultaneously on the patients' hands. The patients' hands were kept flat with palms facing up on the table separated by approximately 33 cm. The patients were blind folded and were asked to report which weight was heavier in half the trials and which weight was lighter in the other half. These two response conditions alternated in an ABBA order. The trials within each condition followed a random order. Different numbers (from 1 to 11) of slotted weights (100 g each) placed on individual hangers (50 g) were placed on the left and right palms of the patients simultaneously. All combinations of 11 weights (150–1150 g), except for identical pairs, were given to both hands. The surface area of the hanger in contact with the patients' hands was identical regardless of how many weight slots were inserted. Each patient made a total of 110 judgements.

3.1. Results

Both patients were biased in reporting that weights on the right hand were heavier than those on the left hand. DC's tendency to judge the right weights as heavier than those on the left was significantly different than what would be expected without a directional bias (Fig. 1), $\chi^2 = 12.57$, $df = 1$, $P = 0.0004$. CG's bias was even more severe. She judged the right weight to be heavier than the left weight on every trial (Fig. 2). These dramatic biases cannot be attributed to a general rightward response bias [5]. In half the trials, subjects were more likely to respond 'left' when asked to report which side was lighter. Interestingly, the only trial in which DC mistakenly judged the left-sided weight to be heavier was with the lightest pairs of weights, 150 g on the left and 250 g on the right.

4. Experiment 2: 'Cross over' in judgments of weights

This experiment was designed to investigate whether a phenomenon analogous to the cross over on line bisections also occurs when patients judge weights. If such a phenomenon occurs, then with lighter weights the bias to report the right-sided weights as being heavier should be mitigated or even reversed. To investigate this possibility we introduced a reference pair of weights interspersed between each test trial since contextual effects may influence the cross over in line bisections [18].

The patients were asked to judge between four possible pairs of weights differing by 100 g (50 g vs 150 g, 350 g vs 450 g, 850 g vs 950 g and 1150 g vs 1250 g). The lighter weight was placed on the left hand in half of the trials, and on the right hand in the other half. Each possible combination was presented randomly within a block. There were 10 blocks for a total of 80 trials (10 blocks × 4 possible pairs × 2 sides). Again, there were two response conditions. In one, the patients reported which weight was heavier and in the other, which was lighter. These conditions proceeded in an ABBA order. Interspersed between each of the test trials, reference weights of 650 g each were placed on both hands simultaneously. The patients were told that these weights were identical. They were not asked to respond to these weights.

4.1. Results

Both patients had the same general directional bias observed in experiment 1. They tended to judge the right stimulus as heavier than the left (DC $\chi^2 = 7.72$, $df = 1$, $P = 0.006$; CG $\chi^2 = 4.75$, $df = 1$, $P = 0.029$). Of particular interest, both patients'

Table 1
Performances on the BIT

Patient	Line crossing	Line cancellation	Star cancellation	Figure shape copy	Line bisection	Drawing
DC	36/36	39/40	50/54[a]	3/4[a]	9/9	3/3
CG	17/36[a]	8/40[a]	12/54[a]	1/4[a]	3/9[a]	2/3[a]

[a] Abnormal performances.

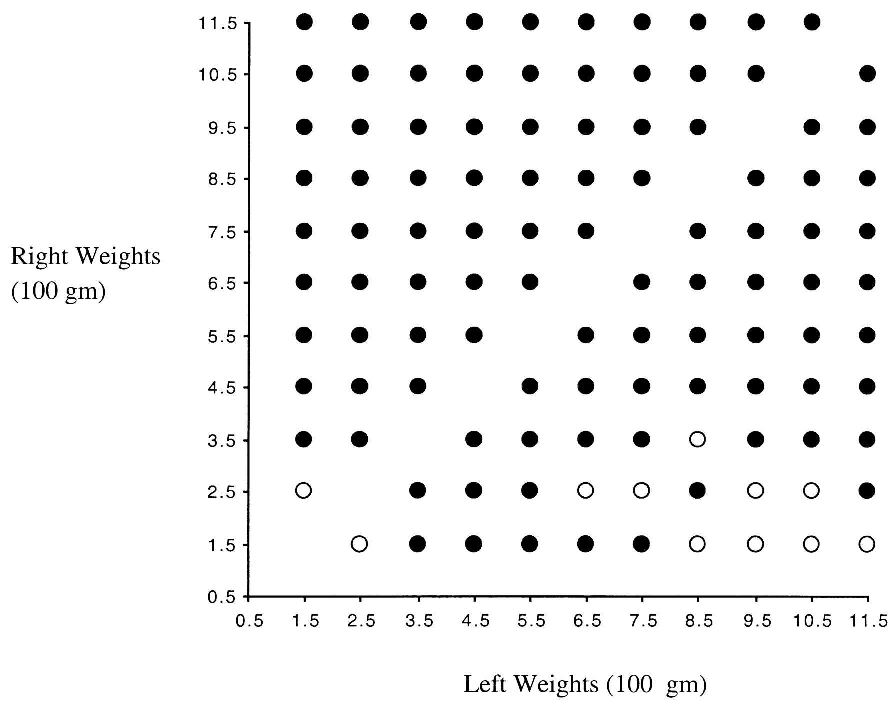

Fig. 1. DC's relative judgments of weights. Dark circles indicate pairs of weights in which she reported that the right weight was heavier and open circles refer to pairs of weights in which she reported that the left weight was heavier.

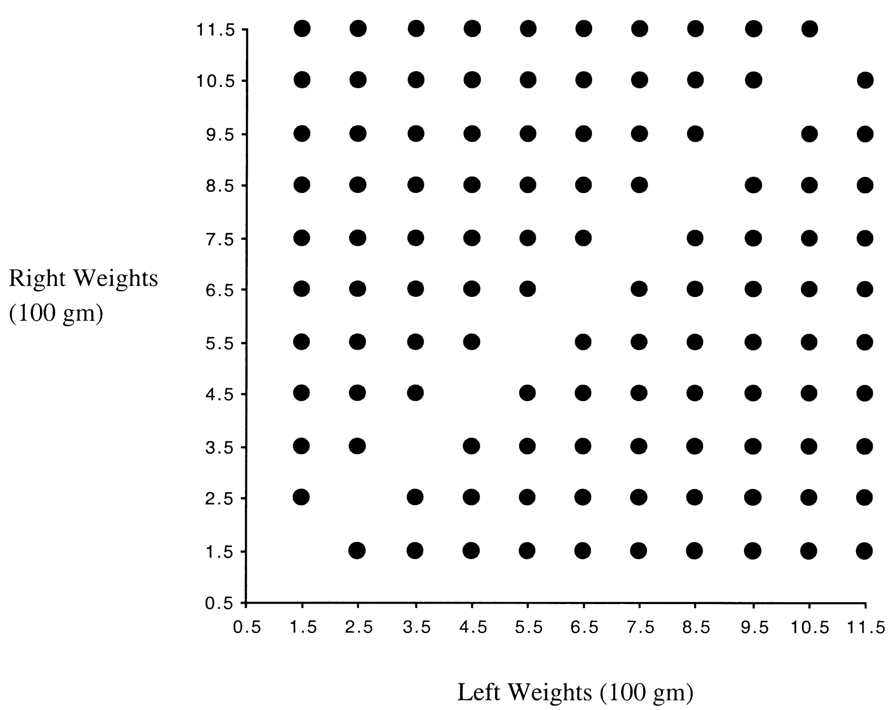

Fig. 2. CG's relative judgments of weights felt simultaneously. Dark circles indicate pairs of weights in which she reported that the right weight was heavier, which she did on every trial.

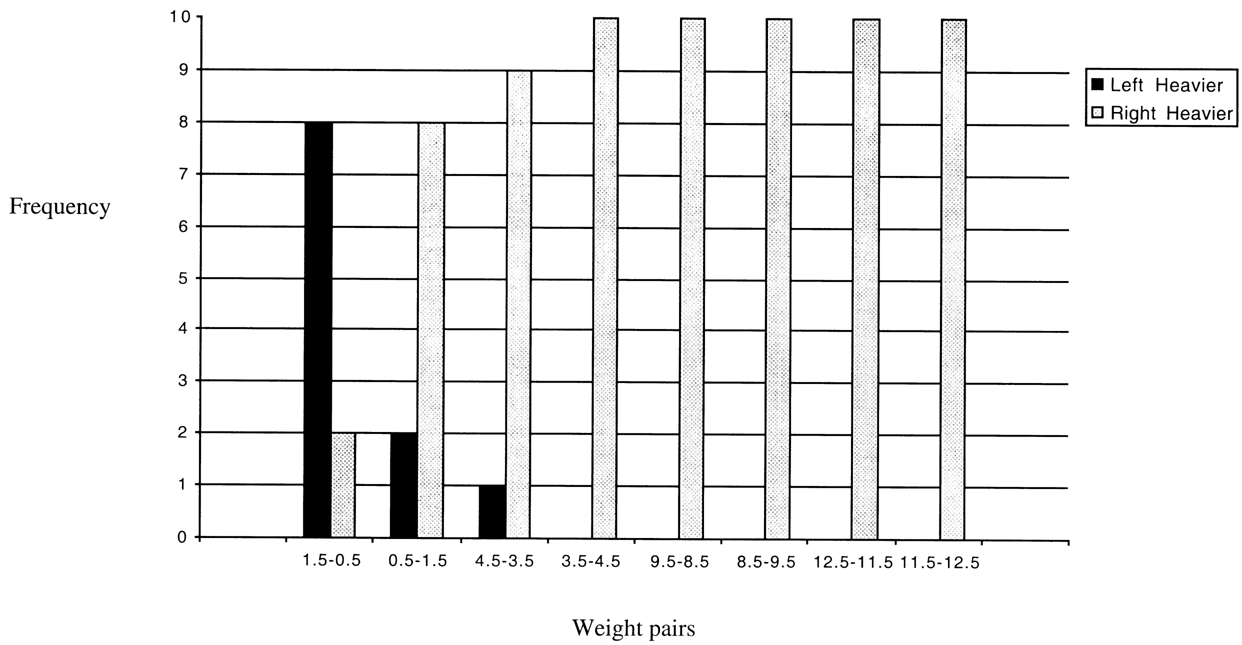

Fig. 3. DC's relative judgment of weight pairs. Light bars refer the frequency with which she reported that the right weight was heavier for a given pair of weights. Dark bars the frequency with which she reported that the left weight was heavier for a given pair of weights.

judgments on the lightest pairs of weights (50 g vs 150 g) changed. Although DC continued to make a few errors (20%) with this pairing, she no longer had a bias in judging right weights as heavier (Fig. 3). CG made more errors than DC at this pairing (40%). However, she was now biased to judge the left-sided weights as being heavier (Fig. 4).

Both patients' biases in judging weights changed when presented with the lightest pairs in this series in ways analogous to line bisection performances. DC no

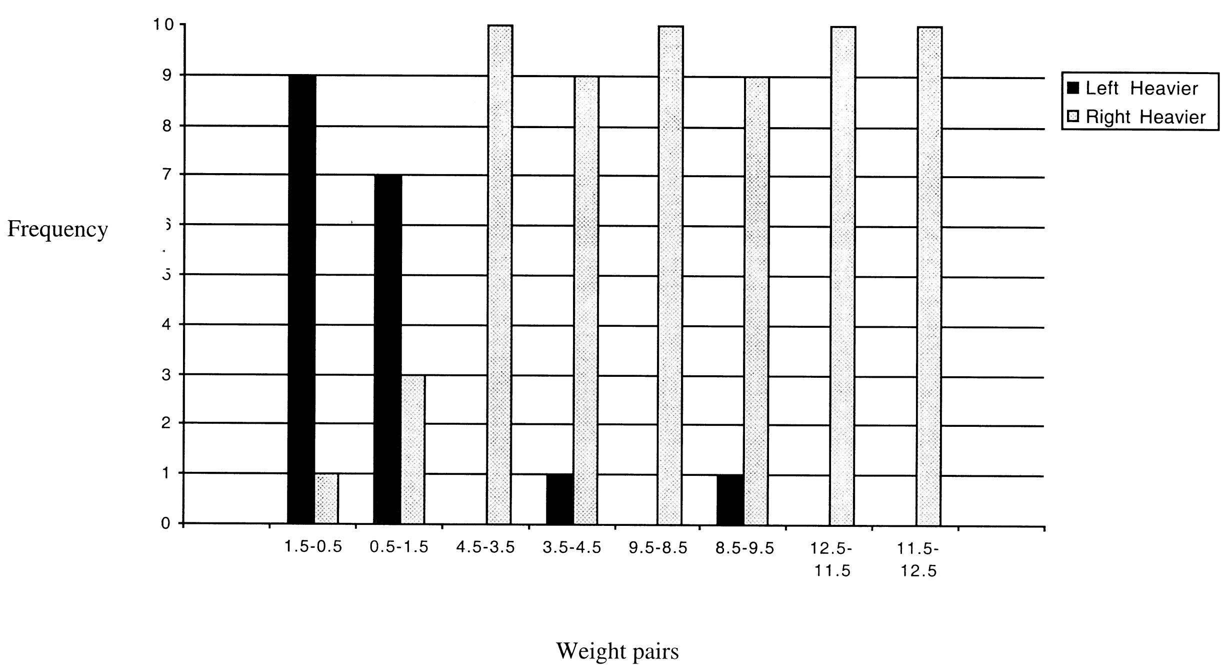

Fig. 4. CG's relative judgment of weight pairs. Light bars refer the frequency with which she reported that the right weight was heavier for a given pair of weights. Dark bars the frequency with which she reported that the left weight was heavier for a given pair of weights.

longer had a directional bias, similar to the fact that at some short line length patients with left neglect bisect lines very accurately. CG now had a bias to report the left weight as heavier, analogous to the cross over with short line bisections. Curiously, CG whose directional bias was more severe in experiment 1 had a greater reversal of this bias with lighter pairs than DC. This finding resembles the observations in line bisection that the degree of cross over generally correlates with the severity of neglect.

5. Discussion

Abnormalities of weight perception recognized half a century ago [4], have not received much recent scrutiny [9]. Consonant with this earlier literature, we found that patients with right temporal-parietal damage reported that weights on the right were heavier than those on the left. However, we also found that this bias changed when patients lift lighter weights. When weights were presented following equal reference weights, DC had no directional bias with the lightest pairs of weights, and CG judged the left weight to be heavier than the right. These findings are analogous to the behavior of neglect patients when bisecting lines. With longer lines, patients judge the right side of segments to be longer than the left side of segments. With short lines, this bias is eliminated or reversed. With heavier weights our patients judged right-sided weights to be heavier than left-sided weights. With lighter weights this bias was eliminated or reversed.

Perceptual psychologists have for some time been aware that contextual effects influence the processing of even simple stimuli [16]. In 1909, Hollingsworth [15] reported that the reproduction of horizontal lines by normal subjects was altered by the context in which they saw these lines. Subjects over-estimated short lines and under-estimated long lines when shown lines of varying lengths. However, they reproduced the same lines accurately when the lines were presented in isolation. Their reproductions of lines were modified by memory traces of similar stimuli encountered previously. These prescient ideas are echoed in recent line bisection studies.

Mennemeier and colleagues [19] reported that normal elderly subjects and patients with left brain damage also cross over when bisecting short lines, albeit to a lesser extent than right brain damaged subjects. Therefore, they argue that the cross over is a normal phenomenon that is exaggerated in patients with neglect. They suggest that normal subjects and patients represent short lines as longer and long lines as shorter than their objective counterparts, but these errors are exaggerated in neglect patients. They assume that neglect patients are anchored perceptually to the right end of the line. Patients place their marks to the left of true mid-position on short lines because they represent these lines as extending leftward past its objective end-point; an idea compatible with our earlier findings of completion and confabulation of similar stimuli [6].

Marshall and coworkers [18] reported that neglect patients bisections of a given line are influenced by the length of the line that preceded it. When a longer line preceded the target line, patients placed their marks further leftward. When a shorter line preceded a target line, they placed their marks further rightward. They suggest that such contextual effects contribute to the cross over phenomenon when neglect patients bisect lines in a series, since longer lines always precede the shortest line in a series.

These ideas of mis-estimation of lines based on their length, and contextual effects on these mis-estimations also apply to weight perception. The psychophysical principle that seems to underlie both kinds of cross over is that an individual stimulus is apprehended and influenced by the context of stimuli that precede it. Smallest stimuli are perceived as larger than expected from their objective magnitudes

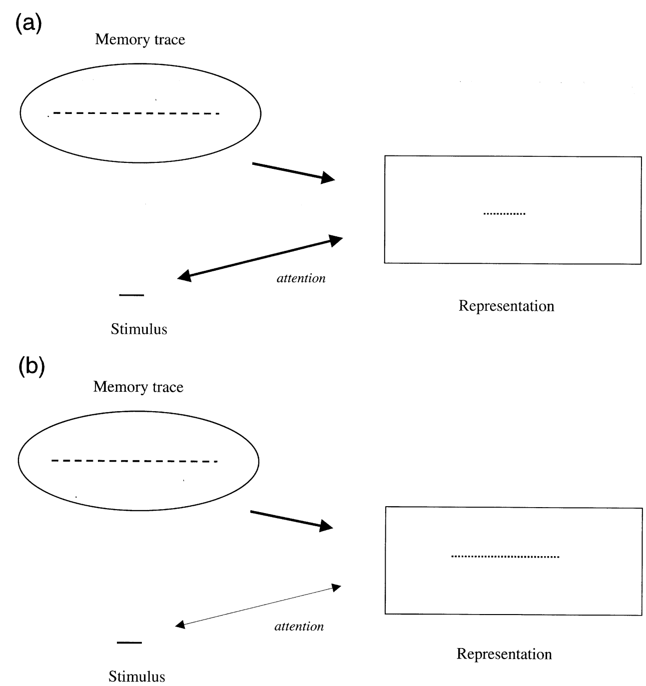

Fig. 5. (a) Normal model of stimulus representation influenced by features of the stimulus itself as well as the memory trace of similar stimuli encountered previously. Lines are used as an example, but the model applies to weights as well. For purposes of the example the line encountered previously is longer than the stimulus. Therefore the stimulus is pulled to being represented as longer than expected from its objective measure. (b) With attention to the stimulus attenuated following brain damage, the memory trace has a disproportionate influence, resulting in an exaggerated overestimation of the representation compared to normal contextual effects.

and largest stimuli are perceived as smaller than expected from their objective magnitudes. This is not to say that contextual effects (in the narrow sense of the context of stimuli apprehended immediately before the target stimuli) entirely explain the cross over effect. Absolute magnitudes of stimuli may also play a role, but the magnitudes of stimuli representations are clearly modulated contextually.

Our patients offer additional insight into the mechanisms underlying this psychophysical principle. In comparing weights across both hands, several factors operate simultaneously. Each weight is compared to the weight in the other hand. In addition, the perception of each weight is influenced by the weights lifted previously. The general psychophysical phenomenon of larger weights being estimated as lighter and lighter weights as heavier applies to both hands. If the over and under estimation errors were similar (monotonically related) on both sides, then the directional bias would not change for lighter pairs of weights. The shift in directional bias means that this over and underestimation is greater on the left than on the right[1]. Contextual effects must have a greater influence on the formation of left-sided representations in these patients with a left-sided attentional deficit.

Attention must normally mitigate contextual effects on the formation of stimuli representations. These representations seem to be pulled in at least two directions (Fig. 5a). The first is by the stimulus itself and the second is by the context in which this stimulus is encountered. Normally, attention to the stimulus forces the representation to adhere closely to its objective counterpart. Released from attentional restraint following brain damage, these representations are disproportionately susceptible to contextual effects produced by memory traces of previous stimuli (Fig. 5b). This general model would account for the observation that severity of neglect in general correlates with the degree of cross over. Presumably patients with more severe neglect have a greater contralesional attentional disturbance. Therefore, memory traces of lines viewed previously would have a greater influence on contralesional representations in these patients than in patients with mild neglect.

The nature and dynamics of the influence of memory traces warrant further investigation. They may in fact decay quite quickly [11], and may have different effects on the analog structure than on the content of the representation. Our previous observations in neglect dyslexia [6] suggest these traces modulate the *magnitude* of stimuli represented on-line. But the *content* of the stimuli represented on-line is susceptible to contralesional confabulations. Finally, our claim that we are observing a generalizable psychophysical phenomenon does not necessarily mean that cross over like behavior will be seen in all tasks in every patient. Given that neglect can fractionate across different tasks, modalities and reference frames [7], it is likely that the degree of cross over, or influence of memory traces, would also fractionate along similar lines.

In summary, we suggest that the cross over phenomenon on line bisections by neglect patients represents a specific instance of a more general psychophysical phenomenon which also occurs in weight judgments. Representations are constrained both by features of the stimulus encountered on-line and by memory traces of similar stimuli encountered previously. With an attentional deficit, memory traces have a disproportionate influence on the structure of the representation that is itself derived from on-line stimuli.

[1] We have been emphasizing that the stimuli in these experiments are not extended in space. However, the patients themselves do have a spatial deficit; their processing is *directionally* biased. This bias may be related to somatotopic space [10,25]. The deficit is on the patients' left, not evidenced on the left of the stimuli.

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