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Research Report

Selection for action and selection for awareness: Evidence from hemispatial neglect

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ABSTRACT

In bedside testing of patients with hemispatial neglect, we have found that extinction for contralesional stimuli is less when the contralesional and ipsilesional items are different on the dimension to be reported relative to when they are the same. Importantly, a study that investigated this observation found that similarity on visual features that are not necessary for response does not impact the amount of extinction. These findings suggest that response requirements may determine what stimuli will and what stimuli will not gain access to awareness. In a related study, we found that extinction of contralesional stimuli was not determined by perceptual similarity of the ipsilesional and contralesional items but by whether they shared the same semantics (e.g., ONE + 1) or the same response (e.g., ONE = WON). Here, we report a single case study in which extinction was determined by whether the competing items shared the same response, regardless of whether they shared or differed in their visual features or semantics. When asked to read the item in each field, there was equivalent extinction in the conditions (ONE + ONE) and (ONE + 1) but less extinction in the condition (ONE + TWO). By contrast, when asked to count the number of characters in each field, there was more extinction in the condition (ONE + TWO) than (ONE + 1). When asked to categorize each item as either a word or digit, the degree of extinction was determined both by whether the items shared the same semantics and by whether they required the same response. The results are consistent with a biased competition model in which competition for selection is resolved flexibly depending on response requirements. Furthermore, the data provide evidence that unattended stimuli are processed to the level of response.

1. Introduction

The patient shown in Fig. 1 had suffered a stroke involving the right parietal lobe 10 days before this video (with thanks to Sharon Posner and Perpetua Productions) was made. When the examiner's finger was wiggled in his left (i.e., contralesional) visual field he detected it—so he is not blind in that field. However, when a finger was wiggled simultaneously in his right visual field, this competing stimulus captured his attention, and he failed to detect the contralesional stimulus (Fig. 1). That is, the competing stimulus in the ipsilesional field causes the contralesional stimulus to be extinguished from his awareness.

Under conditions like this, in which a simple visual feature must be detected and the competing stimuli are in opposite visual fields (i.e., not within the same receptive fields of

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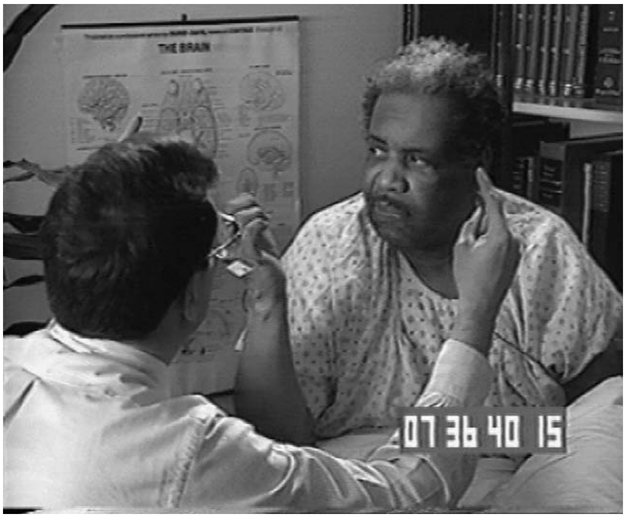

Fig. 1 – Conventional bedside test demonstrating visual extinction. (See text).

neurons in the early visual pathway), attenuation of processing for the unattended stimulus occurs very early in visual pathway. Such evidence is often interpreted to support 'early selection' accounts of attention.

1.1. *Early versus late selection*

Does 'early selection' determine whether a visual signal will gain access to consciousness? Vuilleumier and Rafal, (2000) measured vocal reaction times in four patients in a simple visual extinction task like that shown in Fig. 1. Stimuli were presented in the left visual field, the right visual field, or both simultaneously; and the patients were asked to report 'left', 'right', or 'both'. Exposure duration of the stimuli were adjusted such that, for each patient, extinction occurred (i.e., 'right' reported) on about 50% of bilateral trials (where the correct response should have been 'both'). Not surprisingly, on unilateral trials, vocal RTs were longer for left than for right stimuli. On bilateral trials where the patients reported 'both', vocal RT was, again unsurprisingly, about the same as on unilateral left trials; i.e., response latency was determined by the stimulus requiring the most time to process. The interesting finding in this experiment was the vocal RTs on extinction trials, i.e., bilateral trials where the patient reported 'right'. If inattention on these trials had caused gating from awareness at the earliest levels of the visual pathway, such that no further processing of the left stimulus had occurred before a response was made, then one might expect RT s to be the same as for a 'right' response on unilateral right trials (which were phenomenally the same as extinction trials). This was not the case, however: RTs on these trials was actually the same as for bilateral trials where both targets were detected. It seems, then, that extinguished left stimuli took as much time to process as detected left stimuli, before being gated from awareness. In this sense, extinction might be construed as something more like denial than as an attenuation of perceptual processing due to early attentional selection.

The current communication reports a single case study of a patient with visual extinction. It tests the hypothesis that one function of attention is selection for action. We proceeded from the perspective that attentional selection is needed, not only because of limitations in perceptual processing capacity, but also because we are limited in the number of actions that we can initiate simultaneously. We provide evidence that visual information is selected for, or excluded from, awareness and guidance of goal directed responses at the level of response selection, immediately prior to action.

1.2. *Extinction and stimulus repetition*

In bedside tests of extinction, we have found that when patients are asked to identify visually presented objects, there is less extinction when two competing objects are different, than when are the same (Rafal, 1994). In Fig. 2, for example, when the patient is shown two different objects (top), he reports the identity of both of them. By contrast, when shown two forks (bottom), he only reports the identity of the one on the right. One way of thinking about this effect of stimulus repetition is that when there are two different items present, both are 'singletons'; and this may be viewed as a special case of singleton 'popout' that occurs in visual search tasks in healthy observers (Folk et al., 1992). Note, however, that in Fig. 2, each fork is of a different color. Why didn't this difference attract attention and prevent extinction? The reason, as it turns out, is that, in this task, the patient was asked to report the identity of the stimulus and not its color. Would the patient have been more likely to detect both forks if the task had been to report the colors of the stimuli?

An experimental investigation (Baylis et al., 1993) examined this question in five patients (including the patient shown in Fig. 1), and confirmed that only the similarity of response relevant features determined whether the contralesional object was extinguished. Since this paradigm is the same as that used in the current case study, it will be described in some detail here. All the patients had recently demonstrated visual extinction at the bedside. On each trial, colored letters appeared either unilaterally or bilaterally and the patients were asked to report what they saw in each field. Exposure duration of stimuli was adjusted such that extinction occurred on approximately 1/3–1/2 of trials with bilateral items. Patients reported either the identity or color of letters in different blocks. Whereas there was a similar amount of extinction whether the stimuli were the same or different color in the letter naming block, in the color report blocks extinction was greater for the same color stimuli (when compared to the same stimuli in the letter report blocks or different colored stimuli in the color report block). That is, extinction–failure to report the presence of the contralesional item on bilateral presentations–occurred more frequently when the bilateral stimuli were the same on the attribute to be reported than when they were different on this attribute, and more frequently than when the stimuli were the same on the irrelevant attribute. These results demonstrate not only that information about shape and color of unattended objects is encoded, but also that awareness of the presence of this information is contingent upon task goals.

Notice, that in that study, the patients' responses were determined solely on the basis of simple visual features (color or shape). Competition for awareness could therefore have been due either to competition among objects sharing the

Fig. 2 – Extinction and the effect of stimulus similarity. (See text).

relevant visual feature, or between objects sharing the same implications for response. The former could be implemented on the basis of competitive feature selection early in the visual pathway and/or response, while the latter implies biased selection at a later level of semantics and/or response.

Another study, which leads to the current work, attempted to determine the level at which selection takes place (Rafal et al., 2002). In the first experiment of this study, responses were based on the semantics of the items, while visual similarity between concurrently presented items was manipulated. The stimuli were the words "ONE" and "TWO" and the numerals "1" and "2" that appeared, randomly, in the left field (one-sixth of trials), the right field (one-sixth), or both fields (two-thirds of trials). The patients were asked to read the item(s) and to report what was present *in each* visual field by responding "one" (indicating either the word "ONE" or the digit "1"), "two" (the word "TWO" or the digit "2"), or "nothing". Thus, responses were contingent upon the semantic meaning of the stimulus (i.e., what it denotes in terms of numerosity), and independent of its visual features (i.e., whether a word or digit). Patients verbally reported the location and identity of the stimuli (e.g., 'a one on the right and a two on the left'; 'a one on the right and nothing on the left'), frequently pointing to the items in each field while naming them. On the critical bilateral trials, the items could: be identical (e.g., ONE + ONE; or 2 + 2) and, thus, share the same visual features, meaning and response; differ visually but share the same meaning and require the same response (e.g., 1 + ONE; or TWO + 2); or differ both with regard to visual features, meaning, and required response. This last condition included both trials in which the items came from the same category (e.g., 1 + 2) or from different categories (e.g., 1 + TWO). If attention resolved competition at the level of perceptual features, then perceptual similarity should modulate the degree of extinction. If attention resolved competition at the level of the semantic meaning required for response selection, then visual similarity between the competing items should not influence extinction.

The results of this experiment demonstrated that, for all three patients, competing items that were identical (e.g., ONE + ONE, or 2 + 2) resulted in higher rates of extinction than did competing items that had different meanings and required different responses (e.g., ONE + TWO, 1 + 2, or ONE + 2). However, there was just as much extinction in the condition (ONE + 1) as in the condition (ONE + ONE), even though in the case of the first pair, the competing items were not physically similar. The data from that experiment for Patient JP, investigated in the current report, are shown in Table 1 and Fig. 4A. Thus, in this task that required semantic processing to produce a correct response, there was no evidence that differences in visual similarity influenced awareness. Rather, selection in this experiment was dependent upon whether the items shared the same meaning and response.

Table 1 – Percent of targets missed, and percent of those detected that were incorrectly identified for Patient JP in each condition of Experiment 1 reported by Rafal et al., (2002) and Experiment 1 and 2 of the current report

Example	Read items ("One" or "Two") (Rafal et al., 2002)		Categorize ("Word" or "Digit") Experiment 1		Count ("One" or "Three") Experiment 2	
	Misses	Errors	Misses	Errors	Misses	Errors
ONE 1	57% (23/40)	0% (0/17)	42% (16/38)	0% (0/22)	20% (21/107)	26% (22/86)
ONE 2	41% (16/39)	0% (0/23)	26% (10/38)	11% (3/28)	27% (26/95)	29% (20/69)
ONE ONE	60% (25/42)	12% (2/17)	69% (27/39)	17% (2/12)	35% (37/107)	37% (26/70)
ONE TWO	37% (15/41)	0% (0/26)	47% (18/38)	0% (0/20)	35% (34/96)	34% (21/62)
ONE –	37% (15/40)	4% (1/25)	0% (0/32)	6% (2/32)	1% (1/106)	12% (13/105)
– ONE	3% (1/39)	3% (1/38)	5% (2/38)	8% (3/36)	0% (105/105)	11% (12/105)

A second experiment reported by Rafal et al., (2002) examined whether selection for action could determine awareness independent of semantics. A fourth patient was tested in an experiment that examined competition between homophones that shared the same response (based on phonology) but that were different in terms of both visual features and semantics. The results showed that there was just as much extinction when the competing items required the same response (e.g., ONE + WON, or TOO + TWO), even though they differed in semantics and visual features, as when they were identical (e.g., ONE + ONE, WON + WON, TOO + TOO, or TWO + TWO).

Here, we report two further experiments in a single case study of Patient JP, who was one of the participants in the study reported by Rafal et al., (2002). Our purpose was twofold. First, we sought further evidence that the effect of stimulus similarity on extinction was determined at the level of response selection. Further, we wanted to specifically test whether attentional selection could be biased at several levels of processing under conditions where more than one level of processing could be relevant to selecting a correct response. In the first experiment, JP was shown the same stimuli she had been tested with in the study by Rafal et al., (2002). However, instead of being asked to read each item, she was asked to classify it and report whether it was a "Word" or Digit". In the second experiment, she was asked only to report the number of characters presented on each side (i.e., to respond 'three' if there was a word, or 'one' if there was a digit).

1.3. *Case report*

JP was 81 years old when she suffered a stroke in September 2000. She had previously been in good health and living independently. The stroke involved most of the cortex in right middle cerebral artery territory: parts of lateral frontal cortex (including the frontal eye field), temporal lobe (including the temporo-parietal junction), and inferior and superior parietal lobes (Fig. 3). Very fortunately, it spared the primary motor cortex and subcortical region of the internal capsule. Right arm weakness recovered completely, but she was left with left hemispatial neglect, mild sensory impairment in the left hand and arm and dressing apraxia. She remained fully lucid and socially engaged. She was able to return home to live alone, with supervision by her family, and was independent in everyday activities at the time of testing, 5 months after her stroke.

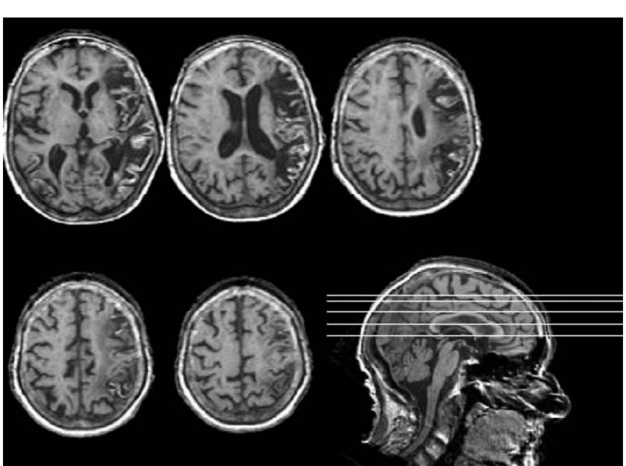

Fig. 3 – T1-weighted MRI scan of patient JP.

2. Experiment 1

2.1. *Procedure*

The apparatus and stimuli were identical to those used by Rafal et al., (2002). The task, instead of reading the items, was to report for each visual field, whether there was a "word" a "digit" or "nothing". A laptop computer was used on which black stimuli were briefly presented on a white background. The stimuli were the words "ONE" and "TWO" and the numerals "1" and "2" (Helvetica 36) that appeared, randomly, in the left field (one-sixth of trials), the right field (one-sixth), or both fields simultaneously (two-thirds of trials). The stimuli were centered on the vertical meridian at approximately 3° eccentricity from a + sign at fixation which offset when the stimuli appeared.

Training on the task was initiated by presenting the stimuli for several seconds and encouraging the patient to inspect each visual field and to report what item, if any, was present in each. When JP was reliably able to report both items on most trials with bilateral stimuli, a brief break was given and training resumed using a briefer exposure duration. This process continued until she began to manifest extinction on some trials. At this stage, she was encouraged to 'guess', if she thought she detected an item but was unsure of its identify. After training, JP was tested in 5 sessions comprising 240 trials. Exposure durations across blocks ranged from 2250 to 2500 ms in order to maintain a rate of extinction between 1/3 and 1/2 of bilateral trials.

2.2. *Analysis*

Because our main interest is in the conditions determining the patient's detection of visual stimuli in contralesional space under conditions of competition, the primary dependent measure was the degree of extinction: i.e., errors in detecting the presence of *any* stimulus (i.e., reporting "nothing") when a stimulus was, in fact, present. Misidentifications of an item (e.g., reporting 'word' when the correct response was 'digit') were scored as detections of the stimulus, because the patients had in fact detected the stimulus. This approach also obviated a potential confound that might arise from a response bias in which a strategy was adopted to either use the same response used for the ipsilesional items or, conversely, to systematically select a different response under conditions of uncertainty. That is if, for example, on bilateral trials the patient detected a contralesional stimulus but was unsure of its identity, the patient could have adopted the strategy of reporting an identity different to that reported for the ipsilesional item. Such a guessing strategy could, if correct identification were the dependent measure, result in an artificial inflation of 'correct' responses when the stimuli were different than when they were the same. Since, in our analyses, such incorrect identification of contralesional items on bilateral trials were scored as non-extinction trials, a strategy of this type would not bias the results. Similarly, if JP adopted a strategy, when she did not detect a contralesional item, of reporting that an item was present and guessing its identity, this strategy would affect scores on bilateral trials equally whether the items were same or different. Given task instructions and training, it was likely that JP would, if a contralesional item had been detected but its identity uncertain, guess one of the two possible stimulus identities rather than guess that 'nothing' had occurred. Our measure of extinction, therefore, may reasonably be assumed to accurately reflect a failure to detect the presence of any item, rather than the improbable alternative that patient systematically adopted a strategy to guess that 'nothing' had been presented contralesionally when she had, in fact, detected an item but were uncertain of its identity.

2.3. Results

Table 1 reports the data for this experiment, and includes the number and percentage of misses (i.e., reporting 'nothing' when a target had in fact been present), and the number and percentage of errors in identification on trials where the contralesional target was detected, in each condition. For comparison purposes, Table 1 also shows the data for Patient JP reported by Rafal et al., (2002) when her task was to read the item on each side.

Fig. 4B shows that, in this experiment, there was an effect of category [$\chi^2(1) = 9.03$, $P = 0.0027$]. That is, pairs of items that required the same response showed more extinction than those requiring different responses, regardless of perceptual or semantic similarity. Note, however, that there was also an independent effect of semantics [$\chi^2(1) = 5.55$, $P < 0.02$]. Thus, attentional selection gated access to awareness at both the level of semantics and the level of response selection. However, on these findings, we cannot conclude that attentional selection at the level of semantics is automatic and obligatory since, in this experiment, semantics could be used in determining the correct response, e.g., patients might read the stimuli as a step in determining their category.

3. Experiment 2

This experiment examined whether selection on the basis of semantics is obligatory and occurs when semantic access is not only unnecessary, but detrimental to response selection. JP was asked to report the number of characters on each side: the correct response for words was "3" since each word contained three letters and for digits "1". Exposure durations ranged from 600 to 2750 ms over 16 blocks comprising 768 trials. The word ONE was replaced, in this experiment, by the word SIX and the numeral 1 by 6. With this stimulus set, not only is the semantic meaning of the items irrelevant to response selection, but simple reading of the items would compete with generation of a correct response, since neither "Two" nor "Six" was ever a correct response. Thus, the task not only made semantic analysis of the stimuli irrelevant, but required that reading of the items be inhibited in order to prevent them from competing with the correct response.

The results (Table 1 and Fig. 4C) showed that extinction occurred more frequently [$\chi^2(1) = 7.82$, $P = 0.0052$] when the competing items required the same response (73/203, 36%) than when they required different responses (47/202, 23%). There was no effect [$\chi^2(1) = .910$, $P > 0.3$] of semantic (word vs. digit) similarity: same = 27%, different = 31%.

4. Discussion

Our awareness of the visual environment is limited to only those parts of a scene to which we attend. An emerging view is that stimulus representations compete for processing (Duncan et al., 1997), and for access to awareness. Neurobiological evidence indicates that attention biases this competition via selective enhancement and attenuation that can begin early in the visual pathway (Heinze et al., 1994; Moran and Desimone, 1985), including primary visual cortex (Vuilleumier et al., 2001), and as early as the lateral geniculate (O'Connor et al., 2002).

Nevertheless, there is abundant evidence that unattended information is transmitted to later stages of processing, and that the identity of unattended items is registered outside of our awareness. Masked priming studies in normal individuals (Marcel, 1980) have shown that this unattended information activates semantic representations; and indeed that it also activates motor responses relevant to the task at hand (Cohen et al., 1995; Dehaene et al., 1998). Priming experiments in neurological patients with the syndrome of hemispatial neglect (Berti and Rizzolatti, 1992; McGlinchey-Berroth et al., 1993) offer some of the most compelling evidence that information outside of awareness undergoes processing at least to a semantic level of representation. Thus, limitations in awareness are not attributable merely to a limitation in processing resources in sensory pathways.

The current observations converge with these studies of semantic priming, and extend earlier work in our laboratory showing an effect of stimulus repetition on visual extinction (Baylis et al., 1993; Rafal et al., 2002). They extend the earlier work by showing that, given the same stimuli, the degree of extinction is determined by the task at hand; and, specifically, that the degree of extinction can be modulated by whether the competing stimuli require the same response. Thus, the reading task, in which response was determined by semantics (ONE + 1), resulted in more extinction than (ONE + TWO); whereas the opposite pattern of performance was observed when the task was counting the number of characters or categorizing each stimulus as a word or digit.

These experiments examined the level of processing at which attentional set influences detection. They should not be interpreted to mean that attentional set is the only factor determining the detectability of signals, or that sensory factors, such as the size or brightness of stimuli do not have their own independent affects on target detectability. Regardless of task, it would be expected, for example, that (ONE + 1) would result in less extinction than (1 + ONE). We conducted these analyses and, though the effect did not reach statistical significance in any of the three experiments, when averaged across all three experiments, the difference in extinction between Digit-Word versus Word-Digit pairs was statistically reliable [$\chi^2(1) = 5.3$, $P < 0.025$]. This raises the question of whether the advantage for different items might have derived only from those trials in which the larger item was in the contralesional field. This could have been the case in the semantic (reading) task in which, for example, there was a trend for more extinction between (1 + ONE) than (ONE + ONE). However, this could not have accounted for the opposite result with these same pairs in the categorizing or counting tasks. It also cannot account for the observations that homophones (ONE + WON) result in as much extinction as items that are also semantically and physically identical (ONE + ONE) (Rafal et al., 2002).

If attention gated access to consciousness entirely by attenuating the processing of unattended stimuli early in the visual pathway, then visual extinction could not be influenced by the semantic meaning of the competing stimuli or, as demonstrated here and in our previous work (Rafal et al., 2002), by the task used to test for it. Extinction is, however, determined both by what the competing stimuli are, and by task demands. Whether or not a contralesional object is extinguished is dependent upon: (1) whether the competing objects are grouped on the basis of Gestalt principles (Mattingley et al., 1997; Ward et al., 1994); (2) whether the competing item is the same, or different, on the dimension to be reported (Baylis et al., 1993; Rafal et al., 2002); (3) the task used to probe for extinction—counting, identification, or localization (Vuilleumier and Rafal, 2000); and (4) potential relevance—that is, real objects suffer less extinction than meaningless stimuli (Ward and Goodrich, 1996), and the degree of extinction is modulated by the social relevance and emotional valence of the stimuli (Vuilleumier, 2000; Vuilleumier and Schwartz, 2001a,b,c).

Previous research in both normal individuals, and in patients with hemispatial neglect, have shown that visual signals that do not gain access to consciousness may 'capture' attention in the sense that they confer a subsequent advantage in target detection at that location (Danziger et al., 1998; McCormick, 1997), or summon a reflexive eye movement toward it (Ladavas et al., 1997; Theeuwes et al., 1998). The observations in JP reveal the mechanisms underlying attentional capture that not only bias processing at a location, but that also lead to disengagement of attention from its current focus so that signals at that location are explicitly detected and accessible to processing by limited capacity systems for voluntary action. They provide further evidence that attentional capture is contingent upon attentional control settings and suggest that attention can grant or deny access to the gates of consciousness at a stage of processing at which

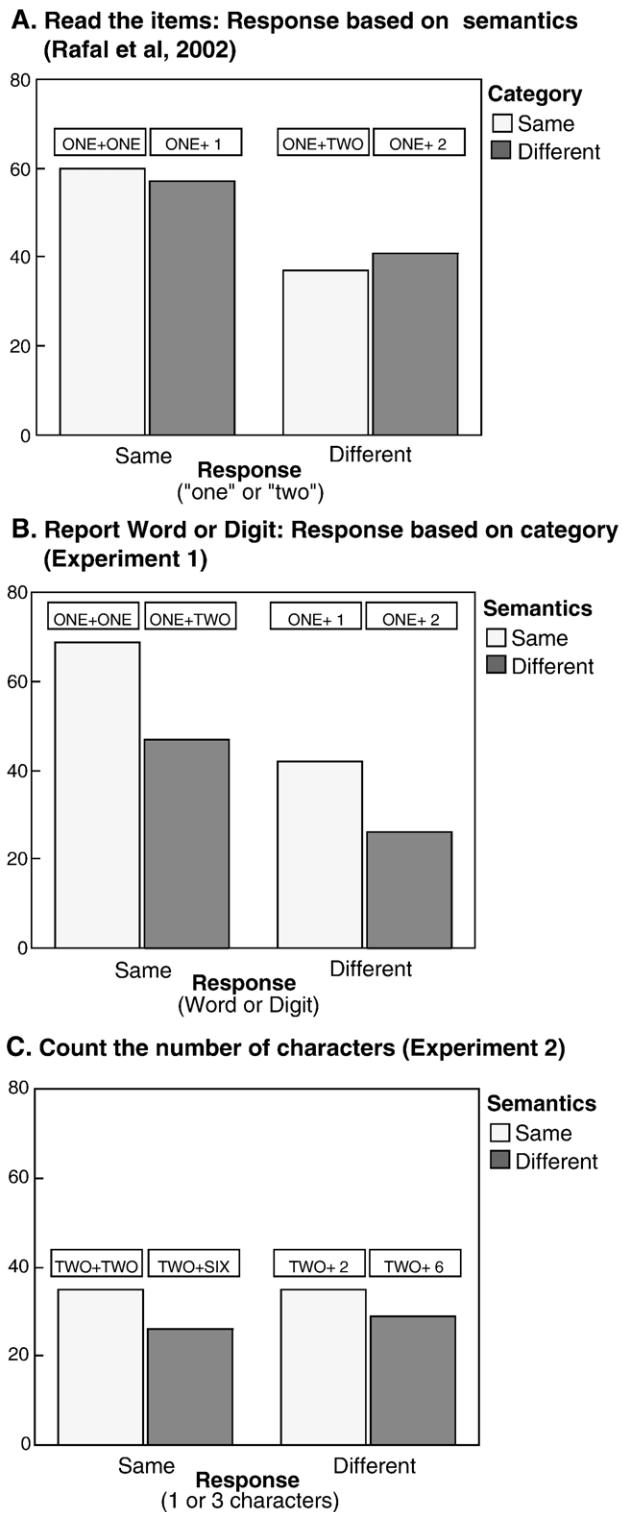

Fig. 4 – (A) Mean percent of bilateral trials with extinction, for Patient JP, in a task in which she was asked to read the item in each field and, therefore, in which response was determined by the semantic meaning of the stimuli (from Rafal et al., 2002). Above each column is an example of a bilateral trial in which, from left to right, the competing items: (a) share the same meaning and response, but are from different categories and are visually dissimilar; (b) are identical in meaning, category, visual features, and response; (c) have different meaning and responses and are from different categories; (d) are different in meaning, visual features but are from the same category. (B) Mean percent of bilateral trials with extinction, for Patient JP, in a task (Experiment 1) in which she was asked to categorize the item on each side as a 'word' or 'digit'. (C) Percent of bilateral trials with extinction for patient JP in a task (Experiment 2) in which required response was to 'count' the number of characters

the meaning of the visual stimulus is utilized in selecting it for action.

Our results show that the exclusion from awareness observed in visual extinction is based on similarity of the attributes relevant for response. When patients can respond based on a simple visual feature, for example, report the color or shape (Baylis et al., 1993), or size (Experiment 2 here), then unselected items may be excluded from awareness early in processing. When the response must be determined by semantics, as in reading each item, there is just as much extinction between (ONE + 1) or (1 + ONE) as between (ONE + ONE) or (1 + 1). Thus, in this situation where physical features cannot be used to choose a response, attentional selection does not appear to occur as early in visual processing (Rafal et al., 2002). Indeed, since in a reading task there is as much extinction between homophones (ONE + WON) as physically and semantically related items (ONE + ONE), attentional selection may be implemented even after semantic processing, at a level of representation immediately prior to response (Rafal et al., 2002). Nevertheless, when semantic processing was beneficial for choosing the correct response in the categorization task (Experiment 1 here), attentional selection occurred at both the level of semantics and the level of response. Our findings are consistent with a framework in which competition for selection and awareness occurs at many levels of processing from sensation to action. Exclusion from awareness can arise at any level (or levels) of processing relevant for response selection.

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