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Impaired search for orientation but not color in hemi-spatial neglect

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Running head: feature search in neglect

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ABSTRACT

Patients with hemi-spatial neglect have trouble finding targets defined by a conjunction of visual features. The problem is widely believed to stem from a high-level deficit in attentional deployment, which in turn has led to disagreement over whether the detection of basic features is also disrupted. If one assumes that the detection of salient visual features can be based on the output of spared 'preattentive' processes (Treisman and Gelade, 1980), then feature detection should remain intact. However, if one assumes that all forms of detection require at least a modicum of focused attention (Duncan and Humphreys, 1992), then all forms of search will be disrupted to some degree. Here we measured the detection of feature targets that were defined by either a unique color or orientation. Comparable detection rates were observed in non-neglected space, which indicated that both forms of search placed similar demands on attention. For either of the above accounts to be true, the two targets should therefore be detected with equal efficiency in the neglected field. We found that while the detection rate for color was normal in four of our five patients, all showed an increased reaction time and/or error rate for orientation. This result points to a selective deficit in orientation discrimination, and implies that neglect disrupts specific feature representations. That is, the effects of neglect on visual search are not only attentional but also perceptual.

Key words: unilateral neglect, feature detection, attention, perception

INTRODUCTION

Hemi-spatial neglect, or ‘neglect’ for short, is a relatively common and disabling disorder usually acquired after damage to the right hemisphere (Karnath et al., 2004). The disorder is associated with a variety of clinical symptoms, the most striking of which is a lateralized spatial bias in which patients fail to acknowledge or report information falling on the contralesional side of space. This may lead them to bump into things on the affected side, eat from only one side of their plate or ignore words on one side of a page when reading. In its most extreme form, the bias may even induce ipsilesional rotation of gaze and trunk. The extent to which the symptoms of neglect can be attributed to attentional as opposed to perceptual impairment remains a matter of debate, and is the focus of the current study.

The idea that neglect involves some kind of attentional dysfunction is based on several observations: (1) neglect can occur in the absence of primary motor or sensory loss, (2) the severity of neglect does not correlate with any field cut, (3) it cannot be eliminated by replacing a motor response with a verbal one, (4) it can be overcome by prompting a patient towards their neglected field by either a salient exogenous cue or verbal command and, (5) patients with more mild symptoms may show good detection of contralesional stimuli in the absence of ipsilesional competition, indicating that basic sensory encoding and orienting are intact. Beyond this first approximation, however, controversy reigns over the precise nature of impairment.

Some insights have been gained from the study of visual search behavior. In a conventional search task, participants are asked to report the presence/absence of a pre-defined target amongst distractor items. By measuring the effects of distractor number on the speed and accuracy of target detection, one can compare, albeit imperfectly, the attentional cost associated with finding different kinds of target. In healthy controls, search for targets defined by a conjunction of

features, such as a red X amongst green Xs and red Os, is slowed by at least 30msec for every extra distractor that is added (e.g. Treisman and Gelade, 1980). This has been taken to indicate an effortful mode of search in which attention is moved serially from one location to another until the target is found (Wolfe, 1994). Simpler targets such as those defined by a unique feature can be found in a relatively effortless manner and typically generate very small set size effects (<5msec per item).

The interpretation of these search patterns falls into two camps. Some have argued that the large differences between feature and conjunction search reflect the operation of two qualitatively distinct processing stages; an initial ‘preattentive’ stage in which basic visual features are recovered in a spatially parallel manner, followed by a second ‘attentional’ stage in which features are spatially bound into coherent objects under the serial spotlight of attention (Wolfe, 1994). According to this account, if neglect is an attentional disorder then features that can be detected under little or no attention should remain detectable in the neglected field. In support of this, a study conducted in our laboratory found that ‘effortless’ search for a Q amongst Os produced negligible slopes in patients and controls alike (<9msec per item), while ‘effortful’ search for an O amongst Qs tended to produce slopes in left visual field that were twice as steep as those seen in healthy, age-matched controls (Esterman et al., 2000). A similar result was reported by Riddoch and Humphreys (1987) who had patients search for either an inverted T amongst heterogeneously oriented Ts or a red circle among green circles. While strong set size effects were observed for the T stimuli, none of the patients showed significant linear effects in either their error or reaction time data for the simpler color search. This led the authors to suggest that “patients can manifest parallel processing of stimuli on the neglected side of space’ (p. 166-7).

Other models of visual attention make different predictions about search behavior in neglect. According to Biased Competition Theory (Desimone and Duncan, 1995; Duncan and Humphreys, 1992), there is no qualitative distinction between any form of search. Rather, search efficiency falls along a continuum and is determined by both target-distractor and inter-distractor similarity. A key premise is that all forms of search are deemed to require at least some attention (see also Joseph et al., 1997). If one accepts that neglect is at least partly an attentional disorder then it follows that all forms of search will be disrupted to some degree. In support of this, and contrary to the study conducted in our laboratory, two separate studies have shown that patients have difficulty finding a Q amongst Os (Behrmann et al., 2004; Egly et al., 1994). The findings of Behrmann et al. (2004) are especially persuasive because a relatively large sample size (26 patients) was used, and the experiment was designed in such a way that the potential effects of visual field loss and more general right hemisphere damage could be discounted. Two additional studies indicate that the basic encoding of color and orientation may also be compromised. Contrary to Riddoch and Humphreys (1997), Egly and colleagues found that search for a left-sided red dot among yellow and blue distractors was three-times as slow for patients compared to healthy controls (Egly et al., 1989). In another study, Pavlovskaya and colleagues asked three patients to report the presence/absence of a 45° oriented bar amongst a field of vertical distractors (Pavlovskaya et al., 2002). Unlike the healthy controls, patients found targets increasingly hard to find at more leftward locations.

In sum, it would appear that neglect can interfere with the detection of salient visual features, although the findings from both our laboratory (Esterman et al., 2000) and Riddoch and Humphreys (1987) suggest that this is not inevitable. Taken together, these studies raise an interesting question about the nature of impairment in neglect. While the particulars of any one

account differ, the standard view maintains that neglect stems from a failure to orient attention into the contralesional hemispace (see Heilman et al., 1985; Kinsbourne, 1977; Rizzolatti and Berti, 1993). This implies that basic visual processes that place little demand on attention will continue to operate in the neglected field. In the absence of distracting ipsilesional stimuli, it is proposed that these basic processes can signal the presence of very salient stimuli and overcome the spatial bias of neglect. From this standpoint, one can account for instances of impaired feature search by assuming that the explicit detection, but not necessarily the initial encoding, of features requires focused attention.

The purpose of the current study was to further test this attentional hypothesis by comparing patients' abilities to detect qualitatively different visual features. If neglect is solely attentional then the level of impairment should vary as function of the amount of attention needed to find the target. In particular, searches that place a similar demand on attention in non-neglected space should be disrupted to a similar degree in neglected space, regardless of feature type. By contrast, if neglect affects lower, perceptual levels of processing then differences in feature detection should emerge when attentional load is equated. Since no neglect study has yet compared the detection rates of different features within a single group of patients, this hypothesis has yet to be tested.

Here we examined the abilities of five neglect patients to search for targets defined by either a unique color or orientation¹. In the color experiment, participants searched for a red bar amongst green distractors. In the orientation experiment, they searched for a white, vertical bar amongst white, horizontal distractors in displays that were otherwise identical to those used in the other experiment. When performed in patients' ipsilesional fields or in either field of our healthy controls, both kinds of search placed a similar demand on attention, as indexed by the

effect of distractor number on reaction time and accuracy. We chose targets defined by these properties to increase the chances of finding a selective impairment; deficits in orientation discrimination tend to occur following damage to those peri-sylvian structures that are often affected by neglect (Riddoch et al., 2004), while problems in color perception tend to follow from more ventral damage (Meadows, 1974).

To recapitulate, we considered three theoretical positions, each of which predicts a different pattern of performance in the neglected field: (1) If responses can be based on spared 'preattentive' processes then regardless of any attentional deficit, both forms of feature search will be normal (e.g. Riddoch and Humphreys, 1987), (2) If neglect is attentional and all forms of search require at least a modicum of attention then both color and orientation detection will be slightly affected (e.g. Behrmann et al., 2004). Critically, when the attentional demands of these two searches are equated in non-neglected space, both should be affected to a similar degree, (3) If neglect can disrupt specific feature representations then one form of search may be disproportionately affected when attentional demands are equated.

METHODS

Phase 1: Assessment of Neglect

To be included in the study, patients had to show neglect on two separate tasks from our Standard Comprehensive Assessment of Neglect (SCAN) (McGlinchey et al., 1996). This includes line bisection, letter and symbol cancellation, line crossing and complex figure and scene copy. Impairment is inferred if a patient bisects more than 80% of lines 0.5cm to the right of midpoint, fails to cross-off a greater number of targets on the left compared to right in the cancellation and line crossing tasks, or when drawing omits either more objects or object parts on the left compared to right. As a further test of neglect, patients also performed two computerized tasks involving lateralized picture discrimination and dot detection under double simultaneous presentation. These are briefly described next.

In the discrimination task, two line drawings taken from the Snodgrass and Vanderwart Set (Snodgrass and Vanderwart, 1980) appeared simultaneously 9^o left and right of central fixation for 500msec. After a brief delay one of these reappeared at either the top-middle or bottom-middle of the screen, along with a foil. Patients indicated which of the two drawings was the target by pressing one of two vertically aligned response buttons. Left-sided impairment was inferred if a significantly greater number of left- compared to right-sided pictures were mistaken with the foil.

In the extinction task, patients were presented with asterisks that blinked for two 150msec periods that were spaced 500msec apart. On unilateral trials, the asterisks appeared on one side of the screen in either one or both corners. On bilateral trials, the asterisks appeared on both sides of the screen and were either both at the top or bottom, or diagonally opposite. Patients indicated

the location of dots by verbal response. Left-sided impairment was inferred if a significantly greater number of left-sided targets were missed in either the unilateral or bilateral trials.

Phase 2: Experimental Procedures

Participants

On the basis of the screening measures described above, six patients were recruited for the study. All had suffered unilateral lesions to the right hemisphere (see Figure 1), were free of previous neurological or psychiatric disorder, and did not show evidence of aphasia or any other major intellectual deterioration. Twelve healthy control participants took part in the orientation feature search, and a separate group of eleven healthy controls took part in the color feature search. All participants were right-handed, as determined by self-report. Demographic information and other patient information can be found in Table 1.

Figure 1 and Table 1 about here

Apparatus

All computerized tests were conducted on a Macintosh G4 laptop computer and administered using PsychLab software (Gum, 2003). Participants made their responses via a CMU button box with the buttons vertically aligned to prevent any spatial incompatibility effects. All experiments were conducted in a quiet, dimly lit room and participants sat approximately 60cm from the screen.

Stimuli

Stimuli appeared on a black background and subtended an area of 1° by 1° . In the orientation task, the target appeared as a vertical, white bar, amongst horizontal, white distractor bars (see Figure 2). In the color task, the target appeared as a horizontal red (CIE 1976 chromaticity co-

ordinates; $x= 0.65$, $y= 0.34$) bar amongst horizontal, green ($x= 0.32$, $y= 0.60$) distractor bars. Stimuli were arranged on the perimeter of an imaginary elliptical array that was positioned in the center of the display and subtended 26° across and 14° high. At the largest set-size, each position in the elliptical array was occupied. The spatial extent of search arrays was equated so that the eccentricity of the left- and right-most stimuli at set sizes 2 and 16 were the same. Stimuli were always arranged in a symmetrical pattern with the same number of stimuli appearing left and right of center.

Figure 2 about here

Procedure

Targets were present in half of all trials and appeared the same number of times in each possible stimulus location. Displays contained a target and 1, 3, 7 or 15 distractors (present trials) or no target and 2, 4, 8 or 16 distractors (absent trials). To ensure central fixation at the start of each trial, participants were instructed to read aloud a random succession of 2 to 4 digits that appeared at the center of the computer screen. These appeared for 750msec followed by a 500msec ISI, except for the final digit which was followed by a 16msec ISI and then the search array. Participants rested their right index and middle finger on the response buttons, and pushed the button labeled “YES” to report the appearance of a target and “NO” if the target was absent. The mapping between response type and response button was counterbalanced across participants. Displays remained on-screen until a response was made and the next trial began 500msec later. Participants were instructed to “report the presence/absence of the target as quickly but as accurately as possible”. The color and orientation searches were conducted in separate experiments, within which there were 16 repetitions for each target (present vs. absent) x set size (2 vs. 4 vs. 8 vs. 16) x target location (left visual field vs. right visual field) condition, resulting

in 256 trials per experiment. The ordering of experiment was counter-balanced across participants and the order of experimental trials randomized within participants. 15 practice trials preceded the experiment proper.

RESULTS

Mean correct reaction times (RTs) and error rates were calculated for each participant. In accordance with previous neglect search studies (Eglin et al., 1989; Esterman et al., 2000; Pavlovskaya et al., 2002) only target-present trials were analyzed (target-absent trials generated error rates of less than 5% in both patients and controls). Responses from the control and patient groups were entered into separate group analyses. The performance of each patient was also analyzed individually by treating each trial as a separate subject (as in Riddoch et al., 2004). RTs and error rates were analyzed in 2(target location: left visual field vs. right visual field) x 4(set size: two vs. four vs. eight vs. sixteen) repeated measures ANOVAs. To gauge whether search efficiency for color and orientation was equated in non-neglected space, responses were combined from both experiments and analyzed in the same way as above but with the addition of feature type (color vs. orientation) as a between-subjects factor. For this analysis, we report only those effects that involved the between-subjects factor. RT scores that were more than 2.5 standard deviations from the mean were excluded and all reported effects are Greenhouse-Geisser corrected. As is customary in search experiments, regression was also carried out on the RT x set size data.

To help inform on the hypotheses stated in the Introduction, we first analyzed the speed and accuracy of color and orientation search in the non-neglected field. We did this in two ways: (1) by comparing responses both within and between visual fields of our healthy controls, and (2) by comparing the detection of color and orientation in the non-neglected right visual field of our patients. To show that orientation and color targets were equally as easy to find outside the neglected left field, it was necessary to show no effects of feature type in the patients' ipsilesional fields nor, preferably, in either field of the controls. Following this combined

analysis (Analysis #1), we then report the separate analyses for the color (Analysis #2) and orientation (Analysis #3) experiments.

Analysis #1: Were color and orientation targets detected equally outside neglected space?

Group analysis

Controls

Error: No effects reached significance (all F ratios <1.2) indicating that orientation and color were detected as accurately both within and across visual fields.

RT: No effects reached significance (all F ratios <1.9).

Patients

Error: There was a two-way interaction between set size and feature type [$F(3,27)=3.4, p<0.05$], which was strongly moderated by the three-way interaction with visual field [$F(3,27)=2.5, p<0.05$]; set-size increased monotonically in left visual field (LVF) for orientation but not color. Planned pair-wise comparisons showed no differences between color and orientation in right visual field (RVF).

RT: No effects reached significance (all F ratios <6.0).

Individual patient analyses

Error: None of the effects that involved feature type reached significance in RVF in any of the patients (all F ratios <5.9).

RT: With the exception of Patient GA, none of the patients produced significant effects involving feature type in RVF (all F ratios <5.9).

G.A. was slower at detecting targets defined by orientation in both fields [$F(1,12)=136$, $p<0.01$]. We note, however, that detection of both orientation and color produced negative slopes in RVF (color = -5msec per item; orientation = -61msec per item) which is suggestive of a common search strategy. This flat orientation slope is not predictive of the steep slope seen in LVF (166msec per item), and suggests that something other than task difficulty per se (i.e. lateralized impairment) underlies the change.

With the debatable exception of G.A., these data indicate that the search for targets defined by color and orientation were broadly equated in non-neglected space.

Analysis #2: Color Search

Group analyses

Controls

RT: Responses to set size two were slower than to all other set sizes [$F(3, 30)=4.44$, $p < 0.02$].

No other effects reached significance (all F ratios < 2.0). Regression analysis showed slopes of less than 1msec per item in both visual fields. See Figure 3a.

Error: No effects reached significance (all F ratios < 2.3).

Patients

RT: No main effects reached significance (all F ratios < 2.4). Search rate was less than 1msec per item in the LVF and 2.5 msec per item in the RVF. The main effect of visual field produced a p -value of 0.2. See Figure 4a.

Error: No effects reached significance (all F ratios < 3.6)

Figures 3 and 4 about here

Individual patient analyses

Descriptive statistics for each patient are reported in Tables 2 (RT) and 3 (error).

K.G.

RT: Responses were slower in RVF compared to LVF [$F(1, 14) = 2.7, p < 0.01$]. No other effects reached significance (all F ratios < 2.0). Regression analysis showed slopes that were less than 1msec per item in both visual fields.

Error: There were no errors.

R.N.

RT: Responses were slower in LVF compared to RVF [$F(1, 13) = 16.2, p < 0.01$]. No other effects reached significance (all F ratios < 2.0). Search rate was 3msec per item in the LVF and 4 msec per item in the RVF.

Error: No effects reached significance (all F ratios < 1.0).

S.S.

RT: Responses were slower in LVF compared to RVF [$F(1,9) = 18.1, p < 0.01$]. No other effects reached significance (all F ratios < 2.0). Search rate was 5msec per item in the LVF and 4msec per item in the RVF.

Error: The effects of visual field [$F(1, 15) = 7.5, p < 0.02$], set size [$F(3, 45) = 4.2, p < 0.02$] and visual field by set size [$F(3, 45) = 4.2, p < 0.02$] were all significant; LVF responses were more

accurate at set size two compared to all other set sizes and responses were marginally less error prone at sixteen compared to eight ($p=0.06$). There were no errors in RVF.

G.A.

RT: LVF responses were generally slower than RVF responses [$F(1, 12)=72.1, p<0.01$]. No other effects reached significance (all F ratios <1.0). Search rate was -2.8 msec per item in the LVF and -4.7 msec per item in the RVF.

Error: No effects reached significance (all F ratios <2.1).

R.C.

RT: LVF responses were generally slower than RVF responses [$F(1, 14)=44.4, p<0.001$]. No other effects reached significance (all F ratios <2.4). Search rates were less than 1msec per item in both fields.

Error: No effects reached significance (all F ratios <1.0).

Analysis # 3: Orientation Search

Group analyses

Controls

RT and error: None of the effects reached significance (all F ratios <1.7). Search rates were less than 2msec per item in both visual fields. See Figure 3b.

Patients

RT: LVF responses were generally slower than RVF responses [$F(1,4)=7.7$, $p=0.05$]. No other effects reached significance (all F ratios <1.5). Search rates were -15msec per item in RVF and 38msec per item in LVF. See Figure 4b.

Error: The effect of visual field [$F(1,5)=6.0$, $p=0.05$], set size [$F(3,15)=8.2$, $p<0.01$] and visual field by set size [$F(3,15)=7.2$, $p<0.01$] were all significant; errors increased incrementally in LVF but not RVF.

Individual patient analyses

K.G.

RT: Responses were slower in LVF compared to RVF [$F(1, 8)=10.9$, $p<0.01$]. No other effects reached significance (all F ratios <1.0). Search rates were 2msec per item in the LVF and -1msec per item in the RVF.

Error: The effects of visual field [$F(1, 15)=10.4$, $p<0.01$], set size [$F(3, 45)=6.2$, $p<0.005$] and visual field by set size [$F(3, 45)=7.9$, $p<0.001$] were all significant; responses in LVF were more error prone than in RVF and became less accurate as set size increased from four to eight.

R.N.

RT: None of the effects reached significance (all F ratios <2.5). Search rates were 98msec per item in the LVF and -32msec per item in the RVF.

Error: The effects of visual field [$F(1, 15)=27.2$, $p<0.001$], set size [$F(3, 45)=8.2$, $p<0.001$] and visual field by set size [$F(3, 45)=13.4$, $p<0.001$] were all significant; responses were generally

more error prone in LVF than RVF and there were a greater number of errors at set size eight and sixteen compared to two and four in LVF but not RVF.

S.S.

RT: Responses were slower in LVF compared to RVF [$F(1, 9)=34.0, p<0.01$]. No other effects reached significance (all F ratios <1.4). Search rates were 44msec per item in the LVF and 6msec per item in the RVF.

Error: The effects of visual field [$F(1, 15)=9.0, p<0.01$], set size [$F(3, 45)=7.3, p<0.001$], and visual field by set size [$F(3, 45)=4.6, p<0.01$] were all significant; responses in LVF were more error prone than in RVF and became progressively worse from set size four upwards.

G.A

RT: Responses in LVF were generally slower than in RVF [$F(1, 14)=27.9, p<0.001$], and became progressively slower from set size two to eight [$F(3, 42)=8.4, p<0.001$]. Search rate was 166msec per item in the LVF and -61msec per item in the RVF.

Error: GA made no more than 1 error per condition so no further analysis was conducted.

R.C.

RT: The effects of visual field [$F(1, 14)=26.5, p<0.001$], set size [$F(3, 42)=5.3, p<0.01$] and visual field by set size [$F(3, 42)=9.3, p<0.001$] were all significant; responses in LVF were slower than in RVF and became progressively slower from two to eight. Search rate was 26msec per item in the LVF and -5msec per item in the RVF.

Error: R.C. made no more than 1 error per condition so no further analysis was conducted.

D.E.

RT: Responses were slower in LVF than RVF responses [$F(1, 9) = 54.2, p < 0.001$], and at set size sixteen relative to all other set sizes [$F(1, 9) = 6.2, p < 0.01$]. The interaction term was not significant ($F < 1.0$). Search rate was 30 msec per item in the LVF and less than 1 msec per item in the RVF.

Error: The effects of visual field [$F(1, 15) = 7.6, p < 0.05$], set size [$F(3, 45) = 3.5, p < 0.05$] and visual field by set size LVF [$F(3, 45) = 6.3, p < 0.01$] were all significant; responses in LVF were more error prone than in RVF and increased incrementally with set size.

Tables 2 and 3 about here

DISCUSSION

The aim of this study was to test if neglect affects the detection of salient color and orientation targets in a similar fashion. In the color experiment, search for a red bar amongst green distractors produced very shallow RT slopes (<3msec per item) and error rates that were equated across right and left visual fields in four of the five patients tested. In the orientation experiment, search for a white, vertical bar amongst horizontal distractors became slower and/or more error prone as set-size increased in left (38msec per item) but not right (-15msec per item) visual field in all patients. By contrast, our group of healthy age-matched controls produced approximately flat slopes (~1msec per item) and few errors for both forms of feature search. These data indicate that visual feature search is not uniformly preserved in hemi-spatial neglect; the detection of color can be spared when the detection of orientation is not.

Which of the three standpoints outlined at the end of the Introduction best account for this pattern? The first idea that feature detection should remain intact by virtue of spared

preattentive representations is clearly not supported by the data. The second idea that all forms of feature detection require at least a modicum of attention so should all to some degree be disrupted receives slightly more support: Patient S.S. showed an increased error rate for both color and orientation in left compared to right visual field. In addition, the RT intercept for color was elevated in four of the five patients' neglected fields which is consistent with a problem in attentional orienting/ipsilesional disengagement. The main point, however, is that except for S.S., search for color and orientation targets showed dramatically different RT and/or error slopes in the left visual field. Although detection always took longer in the neglected field, once started it proceeded at both the normal speed and level of accuracy for color but not orientation. One might quibble about whether attentional demands for color and orientation were perfectly equated, but the similarities in search slope in both the non-neglected field and in the controls were not predictive of the extreme difference seen in the neglected field. The result is consistent with a selective loss of orientation discrimination and suggests that neglect can affect specific types of perceptual encoding, over and above the amount of attention needed to perform the task.

Our finding is in keeping with a growing consensus that neglect affects not only attentional but also perceptual processing (see Deouell et al., 2000; Driver and Vuilleumier, 2001; Farah et al., 1991). Studies have shown reduced contrast sensitivity to low-luminance stimuli presented at both threshold (Angelelli et al., 1998) and suprathreshold levels (Pitzalis et al., 2005) in the neglected field, while measures of steady-state evoked potentials show delayed latencies during judgments of luminance-contrast defined sine-wave gratings viewed at high temporal frequencies (Angelelli et al., 1996; Spinelli et al., 1994). Interestingly, discriminations based on equiluminant chromatic differences appear to be intact in many of these patients (Spinelli et al., 1996; Pitzalis et al., 2005; and also see Dorrichi et al., 1996). In one study, patients had to make explicit (What

are they?) or implicit (Which do you prefer?) judgments about pairs of stimuli that could appear in the left or right field (Dorocchi et al., 1997). When stimuli were segregated from their backgrounds by a 10% variation in luminance, patients performed very poorly on both kinds of judgment in contralesional (but not ipsilesional) space. Consistent with spared color processing, no such deficit was apparent when stimuli were presented on a lighter, higher contrast color background.

Further evidence for a dissociation between color and orientation discrimination can be found in anoxic patient M.H. (Riddoch et al., 2004). The patient behaved normally when detecting a red line amongst blue lines but was unusually slow at detecting a horizontal line amongst vertical lines. Of particular relevance, the normal control sample produced RT slopes that were marginally steeper for color compared to orientation. This implied that the orientation deficit observed in the patient could not be easily explained by increased attentional demand, and rather pointed to a selective deficit at the level of feature encoding.

At one level, the selective loss of spatial apprehension in our patients fits with the idea that neglect most affects those processes driven by magnocellular as opposed to parvocellular neurons. By virtue of their large receptive fields, magnocellular neurons have been associated with a variety of spatial functions, including attentional deployment (Posner and Dehaene, 1994) voluntary eye movement (Andersen, 1989) and other visually directed action (Goodale and Milner, 1992). In monkeys, neurons have been found in the lateral bank of caudal intraparietal sulcus (IPS) that are sensitive to the orientation of luminous bars (Sakata et al., 1997). These neurons are largely unaffected by changes in stimulus length and thickness and have been associated with coding the orientation of the longitudinal axis of 3D objects. In line with this latter finding, all except one of our patients suffered damage within the vicinity of posterior

parietal lobe (although only two showed direct damage to IPS). From a more general perspective, however, the profile of lesions does not strongly support a magnocellular account. This is because all patients' lesions extended to those inferior temporal regions that are densely populated with parvocellular cells. This finding is in keeping with the checkered history of anatomical models in predicting the nature of impairment in neglect. As pointed out by McGlinchey et al. (1996), the pattern of clinical performance cannot be reliably predicted from a single lesion site, and nor can lesion site be predicted on the basis of performance. In the present case, patients with more circumscribed lesions than ours will be needed before the contribution of the magnocellular route to neglect can be fully determined.

Given that lesion distribution cannot easily account for the search differences we observed, consideration should be given to the different computational demands that underlie color and orientation detection. Recent studies have shown that the detection of color 'pop-out' is more sensitive to both bottom-up and top-down cues: the detection of color pop-out, but not orientation pop-out, is speeded by priming the subject to attend to the relevant feature dimension (Müller et al., 2003) and repetition priming for color pop-out is much stronger than that for orientation (Maljkovic and Nakayama, 1994). These findings underscore the earlier conclusion by Treisman and Gormican (1988) that, "parallel processing is more natural for color than for properties of lines or shapes" (p. 30), and may provide further reason why the detection of color pop-out seems more resistant than orientation to the effects of stroke.

How do our findings fit with those of previous neglect search studies? As reviewed in the Introduction, the majority of studies also report evidence of feature impairment. However, given that these have all involved search for only one type of feature (e.g. color *or* orientation), it is difficult to establish the specificity of patients' deficits. For example, patients who show

impaired color detection (as in Eglin et al., 1989) may in fact be even poorer at orientation detection, while an apparent dissociation between color and orientation (as seen across the Riddoch and Humphreys, 1987, and Pavlovskaya et al., 2002, studies) may disappear when task difficulty is equated or the same patients are tested. These two factors may also explain the discrepancy between the results of the Esterman et al. (2000) and Behrmann et al. (2004) studies, which both had patients search for a Q amongst Os. We note, however, that performance may have appeared more intact in the Esterman study because changes in set size were accompanied by changes in the overall configuration of displays. This may have provided a clue as to the full spatial extent of stimuli, which helped guide search to regions that may otherwise have been neglected. Regardless, the important point is that many of the inconsistencies seen across studies may be avoided if patients are tested on more than one kind of feature search and the attentional demands carefully controlled.

A final consideration concerns the clinical implications of our findings. In their present guise, the diagnostic tests of line bisection, cancellation and lateralized picture discrimination do not allow one to confirm the presence of perceptual impairment. For example, accurate performance on line bisection could belie a deficit in the coding of either orientation or color since neither property is important for midpoint estimation. With respect to cancellation and picture discrimination, poor performance could on one hand result from a deficit in attentional orienting. On the other, it could also result from a more basic failure to correctly apprehend either the colors or orientations that help differentiate targets from distractors. These interpretive difficulties can be easily resolved by manipulating the visual features that make up the stimuli in these tasks. In terms of clinical rehabilitation, we want to draw attention to the conventional method that is used to assuage neglect, in which patients are told to constantly remind

themselves to 'attend left'. If patients are unable to register the presence of certain basic features then some stimuli may continue to be neglected if this attentional shift is covert as opposed to overt. Only by overtly shifting attention (i.e. looking left) and thus directing left-sided stimuli into the undamaged hemisphere might it be possible to bypass the deficit. We note that in such cases the use of a specific color or other salient visual feature to highlight the location of important household items such as food-trays and bathroom materials may prove ineffective. In essence, such patients will need to be treated as if they are hemianopic within a given feature dimension.

In conclusion, we have found evidence of impaired orientation search in all of our subjects, and concurrent evidence of impaired color search in only one. Given that our control conditions established these features to be broadly as difficult to detect, we are reluctant to attribute these effects to simple differences in attentional demand. We suggest, therefore, that neglect compromises specific domains of perceptual encoding, over and above its documented effect on attention. The challenge is now to establish if these perceptual deficits play a causal role in neglect, or whether they are merely epiphenomenal. In potential support of a causal role, it has yet to be shown that neglect occurs in the complete absence of a feature coding deficit, or that a lateralized feature coding deficit can occur in the absence of neglect. Systematic studies are needed before this possibility can be dismissed.

FOOTNOTES

¹ We also report the abilities of a sixth patient, D.E., who through ill-health declined from the study after completing only the orientation task.

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FIGURE LEGENDS

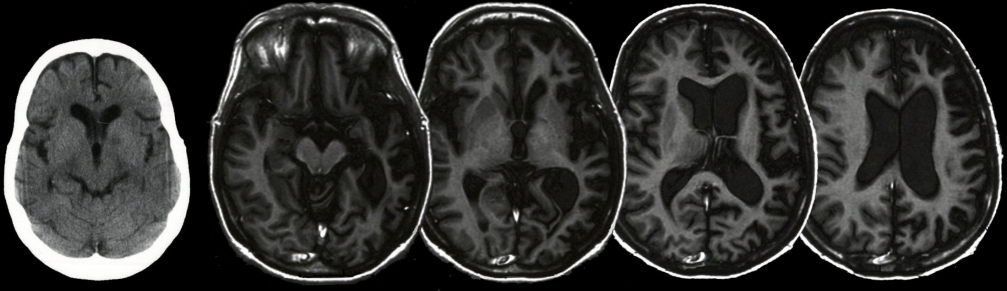
Figure 1. Patients' lesion sites. The left and right radiological coordinates are reversed so that the right-side of each image corresponds with the right-side of the brain. KG suffered an infarction to the right internal capsule (shown in CT) and also has general cortical atrophy of the right hemisphere (shown in MRI); RN suffered from a ruptured aneurysm that affected white matter deep to the middle and superior temporal gyri and which extended dorsally to motor, somatosensory and supramarginal parietal areas; SS suffered from a sub-cortical bleed that extended from the level of the temporal horns to the top of the body of the ventricles. There was also evidence of a low density region in posterior parietal lobe; GA suffered from a hemorrhagic infarct that affected the striatum and much of the frontal, temporal and parietal lobes; RC suffered an embolic infarct and showed extensive damage to the frontal, temporal and parietal lobes and underlying white matter; DE suffered an infarct to a small region within the fusiform/parahippocampal area.

Figure 2. Example of a stimulus display used in the orientation task. In the color task, all bars were horizontal, and the target and distractors were colored red and green respectively.

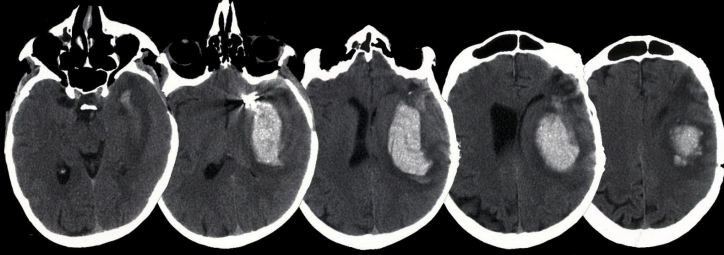
Figure 3. Group means (with standard error bars) and mean percent error of control group in the (a) color and (b) orientation tasks.

Figure 4. Group means (with standard error bars) and mean percent error of the patient group in the (a) color and (b) orientation tasks.

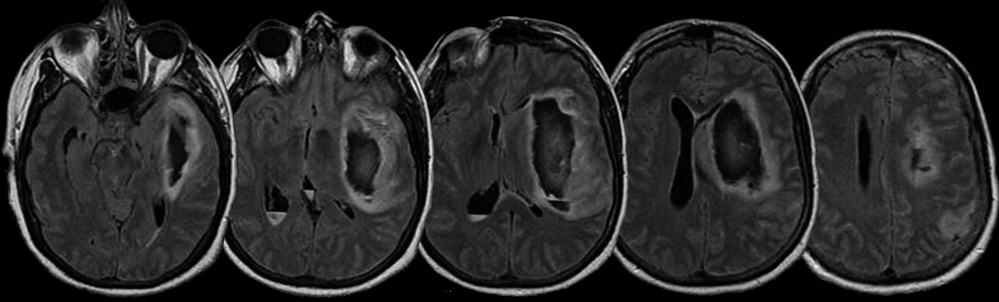
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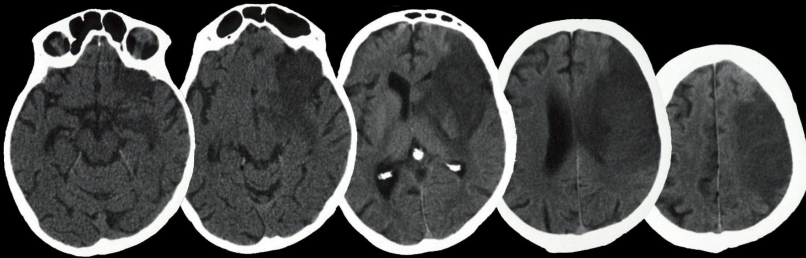
RN



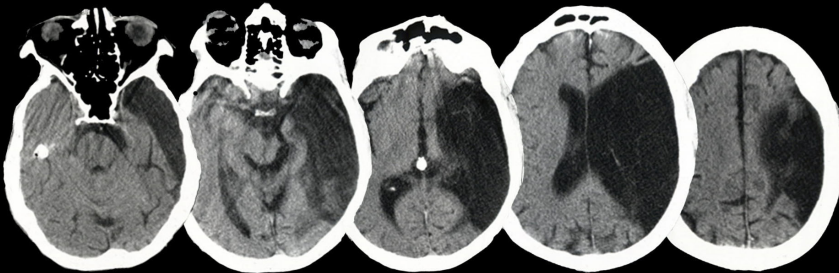
SS



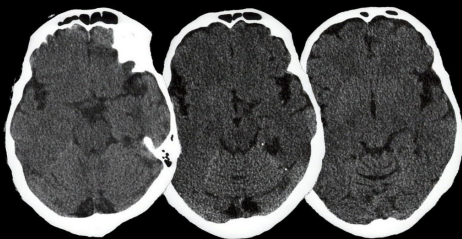
GA

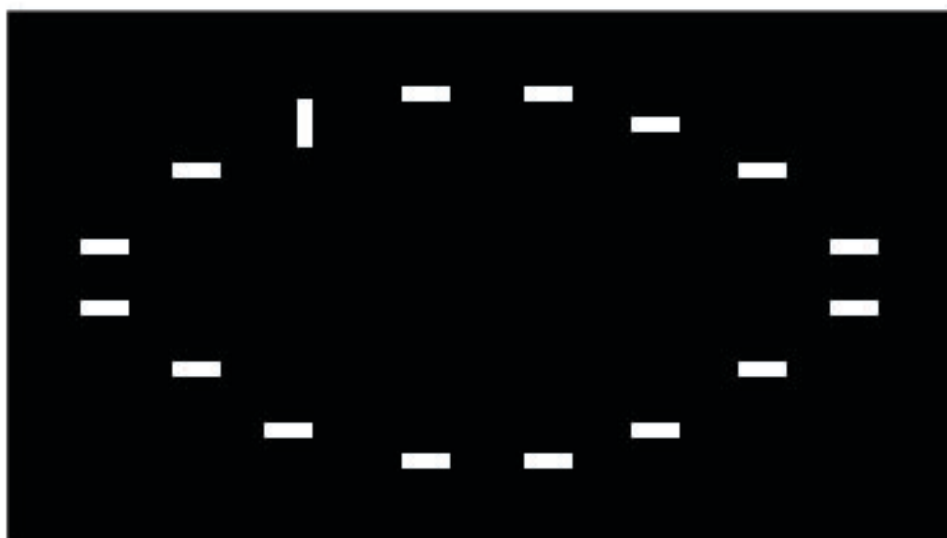


RC



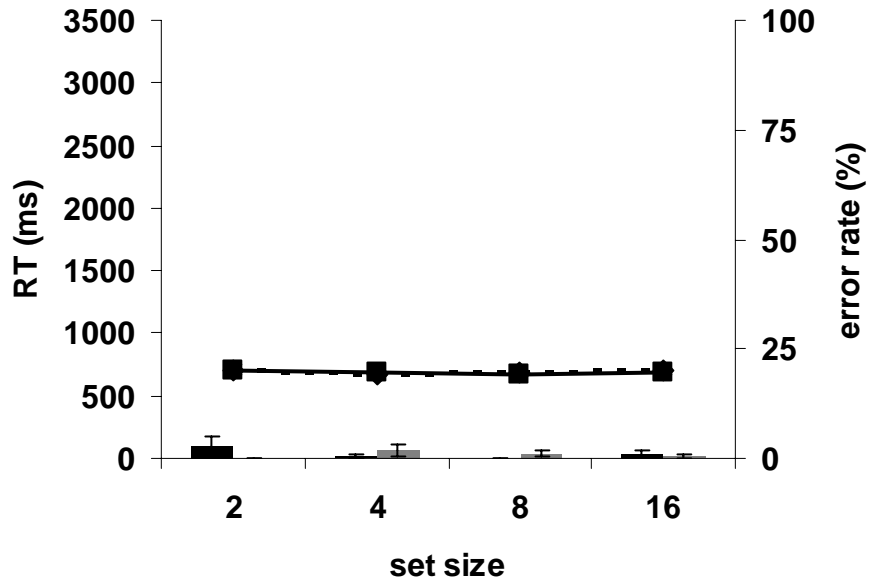
DE





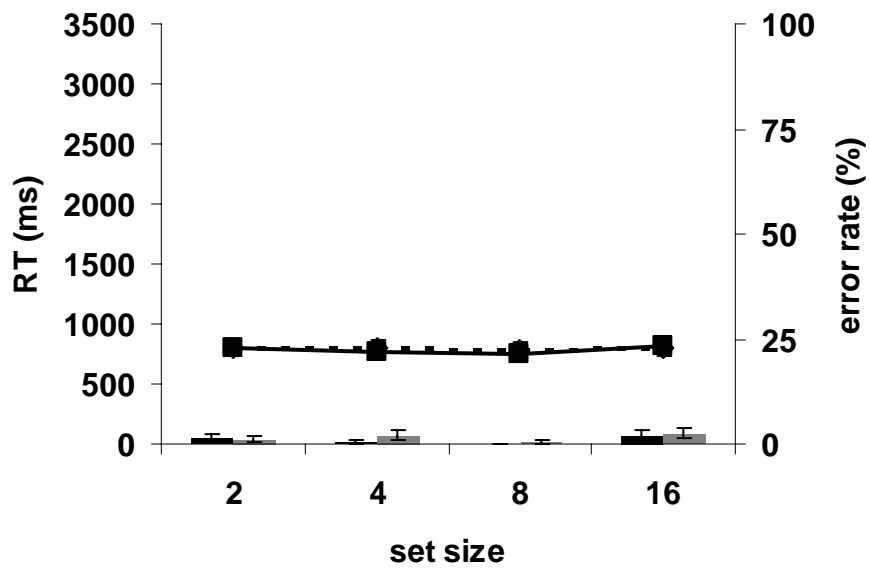
(a)

CONTROLS: COLOR



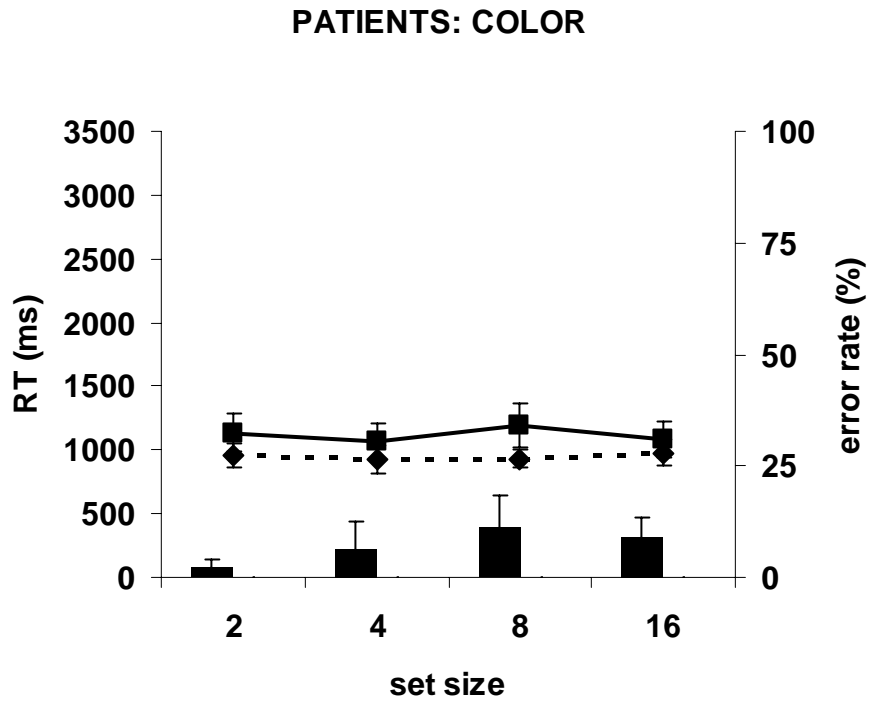
(b)

CONTROLS: ORIENTATION



■ LVF - errors ■ RVF - errors
—■— LVF - RT -◆- RVF - RT

(a)



(b)

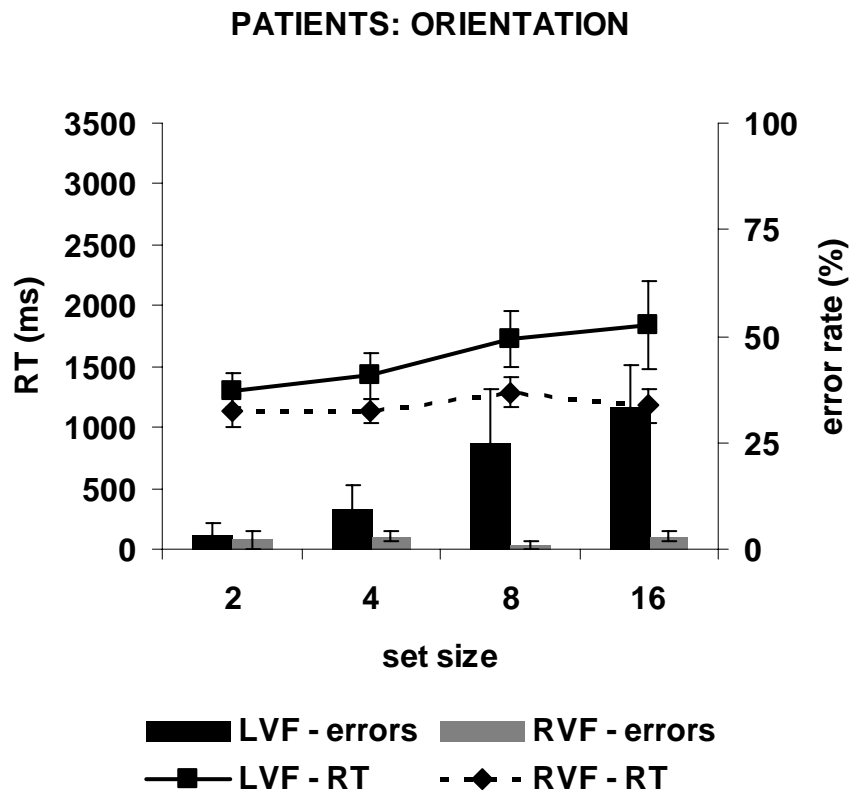


Table 1. Demographic and clinical characteristics of participants. F=female; M=male; quad=quadrantopia; pic discrim=picture discrimination.

	Gender	Age (yrs)	Education (yrs)	Years post stroke	Visual Fields	Clinical manifestations
<i>Controls</i>						
Exp 1	7 F, 4 M	60	16	-	-	-
Exp 2	10 F, 2 M	57	16	-	-	-
<i>Patients</i>						
K.G.	F	57	16	5	Full	pic discrim: 35% left- vs. 15% right-sided targets misidentified scene copy: 80% left- vs. 0% right-sided items omitted symbol cancellation: 50% left- vs. 0% right-sided targets missed
R.N.	M	55	16	0.6	Full	bisection: 0.7cm (3%) mean left-sided deviation extinction: 71% left- vs. 0% right-sided targets missed line crossing: 23% left- vs. 0% right-sided lines missed pic discrim: 33% left- vs. 0% right-sided targets misidentified
S.S.	F	59	16	2	Full	extinction: 58% left- vs. 0% right-sided targets missed line crossing: 36% left- vs. 7% right-sided lines missed pic discrim: 42% left- vs. 0% right-sided targets misidentified
G.A.	M	57	14	7	Full	extinction: 7% left- vs. 0% right-sided targets missed pic discrim: 48% left- vs. 4% right-sided targets misidentified scene copy: 40% left- vs. 0% right-sided items omitted
R.C.	M	60	17	20	lower left quad	bisection: 1.6cm (8%) mean left-sided deviation extinction: 37% left- vs. 16% right-sided targets misidentified
D.E.	M	73	12	3	upper left quad?	extinction: 81% left- vs. 0% right-sided targets missed pic discrim: 48% left- vs. 10% right-sided targets misidentified scene copy: gross misalignment of left-sided items

Table 2. Mean correct reaction times in milliseconds (with standard deviation) for each patient as a function of experimental condition.

	Set size							
	2		4		8		16	
			Target location					
	lvf	rvf	lvf	rvf	lvf	rvf	lvf	rvf
<i>K.G.</i>								
color	664(125)	768(168)	705(92)	698(122)	700(119)	817(206)	681(108)	719(122)
orientation	940(261)	743(83)	931(257)	795(175)	856(215)	799(178)	906(302)	710(83)
<i>R.N.</i>								
color	1308(228)	1108(376)	1173(264)	1187(387)	1296(396)	962(141)	1308(339)	1143(384)
orientation	1253(439)	1310(718)	1550(603)	1195(219)	1908(709)	2215(301)	2653(1825)	1226(507)
<i>S.S.</i>								
color	976(205)	722(92)	809(196)	695(86)	935(334)	740(140)	965(238)	787(154)
orientation	1084(244)	780(122)	1122(413)	771(103)	1153(481)	809(168)	1341(578)	917(181)
<i>G.A.</i>								
color	1131(269)	922(191)	1041(309)	877(105)	1196(362)	855(60)	1078(230)	878(149)
orientation	1291(103)	1369(238)	1477(228)	1328(288)	2013(726)	1231(277)	1719(325)	1190(167)
<i>R.C.</i>								
color	1490(321)	1212(207)	1478(227)	1220(114)	1707(454)	1123(127)	1542(335)	1161(172)
orientation	1502 (170)	1305 (291)	1588 (314)	1309 (182)	2251 (725)	1255 (201)	1891 (535)	1220(204)
<i>D.E.</i>								
orientation	1768(470)	1293(257)	1864(508)	1432(275)	2202(560)	1409(389)	2532(977)	1807(738)

Table 3. Percent errors for each patient as a function of experimental condition.

	<u>Set size</u>							
	2		4		8		16	
	<u>Target location</u>							
	lvf	rvf	lvf	rvf	lvf	rvf	lvf	rvf
<i>K.G.</i>								
color	0	0	0	0	0	0	0	0
orientation	0	0	6	6	38	0	44	6
<i>R.N.</i>								
color	0	0	0	0	0	0	13	0
orientation	25	13	31	6	81	6	69	6
<i>S.S.</i>								
color	6	0	31	0	38	0	25	0
orientation	0	0	0	0	6	0	38	6
<i>G.A.</i>								
color	6	0	0	0	13	0	13	0
orientation	0	0	0	0	6	0	6	0
<i>R.C.</i>								
color	0	0	0	0	6	0	0	0
orientation	0	0	0	0	0	0	6	0
<i>D.E.</i>								
orientation	0	0	6	6	19	0	38	0